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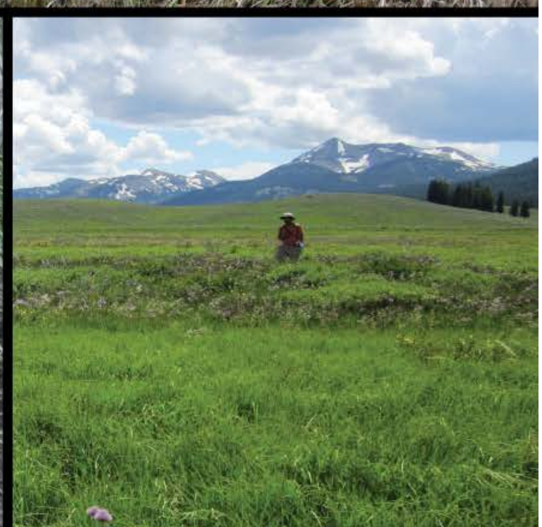
National Wetland Condition Assessment

2011 Draft Technical Report







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EPA-843-R-15-006

NATIONAL WETLAND CONDITION ASSESSMENT

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Notice

Methods described in the *National Wetland Condition Assessment: 2011 Technical Report* are to be used specifically in work relating to the National Wetland Condition Assessment (NWCA). Mention of trade names or commercial products in the document does not constitute endorsement or recommendation for use.

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Companion documents for the NWCA are:

> *National Wetland Condition Assessment: Quality Assurance Project Plan* (EPA-843-R-10-003)
> *National Wetland Condition Assessment: Site Evaluation Guidelines* (EPA-843-R-10-004)
> *National Wetland Condition Assessment: Field Operations Manual* (EPA-843-R-10-001)
> *National Wetland Condition Assessment: Laboratory Operations Manual* (EPA-843-R-10-002)
> *National Wetland Condition Assessment 2011: A Collaborative Survey of the Nation's Wetlands* (EPA-843-R-15-005) (In Review)

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Acknowledgements

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Chapters 1 – 9 of this Technical Report support the core indicators of ecological condition and stress for the NWCA. Authors for these nine chapters included Mary Kentula and Teresa Magee from EPA Office of Research and Development, Amanda Nahlik from Kenyon College; Alan Herlihy from Oregon State University and USEPA Office of Water; and Gregg Lomnicky from Dynamac. Chapters 10 – 12 describe research indicators for the NWCA, and contributors were Keith Loftin from US Geological Survey, Annett Trebitz and Janet Nestlerode from USEPA Office of Research and Development, Siobhan Fennessy from Kenyon College, and Josh Collins from San Francisco Estuary Institute.

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Acronym List

AA	Assessment Area
AR	Attributable Risk
BPJ	Best Professional Judgement
CCs	Coefficients of Conservatism
CDF	Cumulative Distribution Function
C-value	Coefficients of Conservatism
ECO_9	Nine Aggregated Ecoregions used by the USEPA NARS program
FQAI	Floristic Quality Assessment Index
GIS	Geographic Information System
GRTS	Generalized Random Tessellation Stratified
HGM	Hydrogeomorphic Class
HMI	Heavy Metal Index
ICP-MS	Inductively Coupled Plasma Mass Spectrometer
IM	Information Management
IQR	Interquartile Ranges
MDL	Minimum Detection Limit
Mean C	Mean Coefficients of Conservatism
MMI	Multimetric Index
NARS	USEPA National Aquatic Resource Surveys
NFQD	National Floristic Quality Database
NPS	US National Park Service
NPSI	Nonnative Plant Stressor Indicator
NRCS	Natural Resources Conservation Service
NWCA	USEPA National Wetland Condition Assessment
NWPL	National Wetland Plant List
ORD	USEPA Office of Research and Development
OW	USEPA Office of Water
PQL	Practical Quantitation Limit
Pr	Probability
QA	Quality Assurance
REMAP	USEPA Regional Environmental Monitoring and Assessment Program
RR	Relative Risk
S&T	USFWS Status and Trends
S:N	Signal:Noise (i.e., signal to noise ratio)
UID	Unique Identification
US	United States
USACE	US Army Corps of Engineers
USDA	US Department of Agriculture
USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service
VMMI	Vegetation Multimetric Index
WD	USEPA Office of Water, Wetland Division
WED	USEPA Office of Research and Development, National Health and Environmental Effects Laboratory, Western Ecology Division
WIS	Wetland Indicator Status

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Important NWCA Terms

USFWS S&T Wetland Categories – wetland types, often expressed as codes, specifically surveyed by US Fish and Wildlife Service to quantify status and decadal trends in national wetland area

NWCA Wetland Types – seven wetland types included in the NWCA Survey, which represent a subset of USFWS S&T Categories[1]

Target population – all wetland area included in the NWCA Wetland Types and used in the survey design; defined as all tidal and nontidal wetted areas with rooted vegetation and, when present, shallow open water less than 1 meter in depth, and not currently in crop production, across the conterminous US

Sample frame – a list of all members of the target population from which the sample is drawn, which, in the case of the NWCA, is all the NWCA Wetland Types in the USFWS Status and Trends mapped plots

Probability sites – sites defined by the NWCA sample draw (i.e., NWCA design sites) and some state intensifications using the same design as NWCA

Not-probability sites – sites not defined by the NWCA sample draw but sampled, including handpicked sites and some state intensifications

Inference population – final wetland area represented by sampled probability sites; ultimately used by the NWCA for reporting condition and stressor extent

NWCA Aggregated Wetland Types – four wetland types based on combined NWCA Wetland Types

Nine Aggregated Ecoregions – nine ecoregions in the conterminous US that are based on combinations of USEPA Level III Ecoregions used in previous NARS[2,3]

NWCA Aggregated Ecoregions – four ecoregions in the conterminous US that are based on combinations of Nine Aggregated Ecoregions

NWCA Reporting Groups – ten groups that represent combined NWCA Aggregated Ecoregions and NWCA Aggregated Wetland Types

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[1] *NOTE: There is a discrepancy with how these seven NWCA Wetland Types are named on the 2011 NWCA field forms; NWCA Wetland Types are designated as 'Status & Trends Categories' on Form PV-1, 'FWS Status and Trends Class' on Form AA-2, and 'Predominant S & T Class' on Form V-3.*

[2] Omernik JM (1987) Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77: 118-125

[3] USEPA (2011) Level III Ecoregions of the Continental United States (revision of Omernik, 1987). US Environmental Protection Agency, National Health and Environmental Effects Laboratory-Western Ecology Division, Corvallis, OR

Reference – sites that represent least disturbed ecological condition[4] and the associated functional capacity typical of a given wetland type in a particular landscape setting (e.g., ecoregion, watershed)

Disturbance Class – classes reflecting the gradient of anthropogenic disturbance across all sampled wetland sites, and used for Multimetric Index (MMI) development and to set thresholds for indicators of stress and condition

- ***Least Disturbed*** – a Disturbance Class describing sites that represent the best available physical, chemical, and habitat conditions in the current state of the landscape[4]; used as Reference for the NWCA Survey

- ***Most Disturbed*** – a Disturbance Class describing sites defined as most disturbed relative to Least Disturbed; typically representing 20-30% of sites in an NWCA Reporting Group

- ***Intermediately Disturbed*** – a Disturbance Class used to describe sites that fall between Least Disturbed and Most Disturbed

- ***Minimally Disturbed*** – a Disturbance Class used to describe sites with zero observable human disturbance, with the exception of up to 5% alien plant species cover

Index period – the temporal range when sites were sampled for the 2011 NWCA; the peak growing season (April through September, depending on state) when most vegetation is in flower or fruit

Assessment Area (AA) – the 0.5 ha area that represents the location defined by the coordinates generated by the NWCA sample draw, and in which most of the data collection for the NWCA occurs

Buffer – the area (representing a prescribed measurement area) surrounding the Assessment Area

Metric – an individual measurement or combinations of data types to describe a particular property (e.g., soil phosphorus concentration, species richness, species cover by growth form, etc.) for a site

Index – a combination of metrics used to generate a single score to describe a particular property (condition or stress in the case of the NWCA) for a site

Native Status – state level designations of plant taxa nativity for the NWCA, designations include:
- ***Native*** – plant taxa native to a specific state
- ***Introduced*** – plant taxa introduced from outside the conterminous US
- ***Adventive*** – plant taxa native to some areas or states of the conterminous US, but introduced in the location of occurrence
- ***Alien*** – combination of introduced and adventive taxa
- ***Cryptogenic*** – plant taxa with both native and introduced genotypes, varieties, or subspecies
- ***Undetermined*** – plants identified to growth form or family, or genera with native and alien species
- ***Nonnative*** – combination of alien and cryptogenic taxa

[4] Stoddard JL, Larsen DP, Hawkins CP, Johnson PK, Norris RH (2006) Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16: 1267-1276

Taxon-location pair – A particular plant taxon occurring at a particular location:

- ***X-region pairs*** – where ***X*** can be any particular ***taxon***, ***species***, or ***name*** (e.g., one of several potential taxonomic names) that occurs or was observed in a given region
- ***X-state pairs*** – where ***X*** can be any particular ***taxon***, ***species***, or ***name*** (e.g., one of several potential taxonomic names) that occurs or was observed in a given state
- ***X-site pairs*** – where ***X*** can be any particular ***taxon***, ***species***, or ***name*** (e.g., one of several potential taxonomic names) that occurs or was observed in a given site
- ***X-plot pairs*** – where ***X*** can be any particular ***taxon***, ***species***, or ***name*** (e.g., one of several potential taxonomic names) that occurs or was observed in a given plot

Population estimates – estimates of characteristics of the target or inference population of wetlands in the conterminous US (or smaller reporting groups), usually described in acres or percent total area

Condition Class – describes the ecological condition of wetlands based on a biological indicator, a Vegetation Multimetric Index (VMMI); classes include 'Good', 'Fair', or 'Poor'

Condition Extent – estimates of the wetland area in good, fair, and poor condition classes

Stressor-Level Class – describes the ecological stress to wetlands associated with physical, chemical, and biological indicators of stress as 'Low', 'Moderate', or 'High' (and 'Very High' for Nonnative Plant Stressor Indicator, only)

Stressor Extent – an estimate (by percent of the resource or relative ranking of occurrence, or stressor-level class) of how spatially common a stressor is based on the population design

Relative Risk (RR) – the probability (i.e., risk or likelihood) of having poor condition when the magnitude of a stressor is high relative to when the magnitude of a stressor is low

Attributable Risk – an estimate of the proportion of the population in poor condition that might be reduced if the effects of a particular stressor were eliminated[5]

[5] Van Sickle J, Paulsen SG (2008) Assessing the attributable risks, relative risks, and regional extents of aquatic stressors. Journal of the North American Benthological Society 27: 920-931

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Foreword

This document, the *National Wetland Condition Assessment: 2011 Technical Report*, accompanies the *National Wetland Condition Assessment 2011: A Collaborative Survey of the Nation's Wetlands*. The National Wetland Condition Assessment (NWCA) is a collaboration among the USEPA, and State, Tribal, and other Federal partners. It is part of the National Aquatic Resource Survey (NARS) program, a broad effort to conduct national scale assessments of aquatic resources. The NWCA provides the first survey at national and regional scales of the ecological condition of wetlands and indicators of stress likely affecting condition. This was accomplished by analyzing data collected across the conterminous US.

National Wetland Condition Assessment 2011: A Collaborative Survey of the Nation's Wetlands (referred to as the "Public Report") is not a technical document, but rather a report geared toward Congress and a broad, public audience, that describes the background and main findings of the 2011 NWCA. The *National Wetland Condition Assessment: 2011 Technical Report* is a supplemental document that serves as the technical reference to support the findings presented in the Public Report. The Technical Report is organized into chapters and appendices that describe the development of the survey design and the scientific methods used to collect, evaluate, and analyze data collected for the 2011 NWCA. **Chapters 1 through 9** provide the key technical information supporting the Public Report.

The technical document includes information on the target population, sample frame, and site selection underlying the 2011 NWCA survey design. The report also provides a synthesis of data preparation and management processes, including field and laboratory data entry and review, as well as several quality assurance checks employed for the 2011 NWCA. The NWCA evaluates the ecological condition of and potential stress to wetlands along a gradient of disturbance, based on the comparison to sites designated as least-disturbed or reference. The Technical Report provides a thorough overview of the development of this approach.

A variety of biological, chemical, and physical data were collected and developed into several indicators of ecological condition or stress to wetlands that inform the population estimate results of the 2011 NWCA. For each of these indicators the Technical Report provides background and underlying rationale, evaluation of candidates, and development of the final indicators chosen for the NWCA, including defining threshold categories for condition and disturbance in order to evaluate and compare data.

In addition to the key technical information described in the previous paragraphs, the Technical Report provides information about data that were collected during the 2011 NWCA but which are not all included in the population estimates presented in the Public Report. These include data collected and analyzed for microcystins (**Chapter 10**), water chemistry (**Chapter 11**) and the USA Rapid Assessment Method (USA-RAM; **Chapter 12**). The structure of these final three chapters is analogous to a white paper. Although water chemistry and USA-RAM were not included in the Public Report, estimates for extent of microcystins in wetlands were reported.

The information described in the *National Wetland Condition Assessment: 2011 Technical Report* was developed through the efforts and cooperation of NWCA scientists from EPA, technical experts and participating cooperators from academia and state and tribal wetland programs. While this Technical Report serves as a comprehensive summary of the NWCA procedures, including information regarding procedures, design, sampling, and analysis of data, it is not intended to present an in-depth report of data analysis results.

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Conceptual Background

This section briefly describes key concepts related to the goals of the NWCA, the survey design, and reporting of results, each of which is important to the analysis and interpretation of the 2011 NWCA data. These concepts tie together the components of the NWCA – from survey design through reporting the results. They will also be incorporated into future assessments to assure the consistency necessary for reporting on status and trends in wetland condition and in the patterns in indicators of stress.

NWCA Goals

The National Wetland Condition Assessment (NWCA) is one of the US Environmental Protection Agency's National Aquatic Resource Surveys (NARS). The purpose of NARS is to generate statistically-valid and environmentally relevant reports on the condition of the nation's aquatic resources every five years. The goals of the NWCA are to:

- Produce a national report describing the ecological condition of the nation's wetlands and anthropogenic stressors commonly associated with poor condition;

- Collaborate with states and tribes in developing complementary monitoring tools, analytical approaches, and data management technology to aid wetland protection and restoration programs; and

- Advance the science of wetland monitoring and assessment to support wetland management needs.

Relationship between the NWCA and USFWS Status and Trends Program

The NWCA was designed to complement the US Fish and Wildlife Service's National Wetland Status and Trends Program (S&T). The S&T reports on wetland quantity, while the NWCA reports on the quality of the nation's wetlands (see **Chapter 1**).

Estimates of wetland area for the S&T and NWCA were based on samples drawn from the same digital map created by S&T from 2005 aerial photography (see **Chapter 1**). However, the wetlands sampled as part of NWCA, i.e., the "target population," are a subset of the wetland categories sampled by S&T. The NWCA samples tidal and nontidal wetlands of the conterminous US, including farmed wetlands not currently in crop production. The wetlands must have rooted vegetation and, when present, open water less than one meter deep. Consequently, the S&T Program's estimate of the wetland area in the conterminous US in 2009 was 110.1 million acres (Dahl 2011), while the 2011 NWCA estimated the area of the target population as 94.9 million acres. Thus, the 2011 NWCA target population was approximately 84% of the wetland area reported by S&T for 2009. For more information on the relationship between what was sampled in the 2011 NWCA and by S&T see **Chapter 1**, especially **Table 1-1** which relates NWCA Wetland Types to the wetland categories found on the S&T digital maps.

The seven NWCA wetland types used in the 2011 survey design were combined into four for analysis and reporting. Similarly, the nine ecoregions used in the 2011 survey design were combined into four. Aggregations of the wetland types and ecoregions used in the 2011 NWCA survey design were necessary to ensure adequate sample sizes for analysis and provided unique, descriptive names for NWCA reporting (see **Section 4.4** for details).

Relationship between Field Sampling and Reporting

NWCA data and samples are collected in an Assessment Area (AA) and its associated 100-m buffer. The AA represents the location defined by the coordinates (hereafter, called the point) generated by the sample draw from the survey design (see **Chapter 1**). The NWCA field sampling protocols are designed to support the assessment of the ecological condition of the wetland area at the point (USEPA 2011). Collecting data and samples within a consistent wetland area (i.e., the AA) – regardless of the size of the individual wetland in which the point resides – is an important distinction from sampling individual wetlands. Sampling points that represent a percentage of the area of the entire target population assumes that condition can change spatially, especially in a large wetland, and can result in a wetland having more than one point. It also allows for reporting the results as wetland area and as a percentage of the entire target population.

The AA is established using an ecological (not jurisdictional) definition of a wetland. It must contain the point, can range from 0.1 to 0.5ha in size, and can encompass one or more of the wetland types used in the design (see **Table 1-1**). The area of the AA was chosen to be large enough to accurately characterize the wetland area at the point using rapid or comprehensive assessment methods (e.g., see Wardrop et al. 2007a, b) but is small enough for a team of four people to typically complete sampling in one day (e.g., see Kentula and Cline 2004, Fennessy et al. 2008).

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Chapter 1: Survey Design

NWCA was designed to assess the ecological condition of broad groups or populations of wetlands, rather than as individual wetlands or wetlands across individual states. The NWCA design allows characterization of wetlands at national and regional scales using indicators of ecological condition and stress. It is not intended to represent the condition of individual wetlands.

1.1 Description of the NWCA Wetland Type Population

The ***target population*** for the NWCA included all wetlands of the conterminous United States (US) not currently in crop production, including tidal and nontidal wetted areas with rooted vegetation and, when present, shallow open water less than 1 meter in depth. A wetland's jurisdictional status under state or federal regulatory programs did not factor into this definition. Wetland attributes are assumed to vary continuously across a wetland.

1.2 Survey Design and Site Selection

The selection of the sites was completed in two steps. Since a consistent national digital map of all wetlands in the conterminous US was not available, and the US Fish & Wildlife Service (USFWS) conducts the National Wetland Status and Trends (S&T) survey every five years, the approximately 5,000 4-square mile plots from S&T were used to identify wetlands in the first step. The S&T survey is an area frame design stratified by state and physiographic region (Dahl and Bergeson 2009; Dahl 2011). This step results in the aerial imagery interpretation of land cover types focused on S&T Wetland Categories within each 2-mile by 2-mile plot selected (S&T sample size is 5,048 plots).

In the next step, a Generalized Random Tessellation Stratified (GRTS) survey design (Stevens and Olsen 1999; Stevens and Olsen 2004) for an area resource was applied to the S&T wetland polygons. This step was stratified by state with unequal probability of selection by seven ***NWCA Wetland Types*** based on a subset of the S&T Wetland Categories (**Table 1-1**).

Table 1-1. Definition of NWCA Wetland Types.

USFWS S&T Wetland Category Codes	Description of wetlands included in each NWCA Wetland Type
E2EM	Estuarine intertidal emergent
E2SS	Estuarine intertidal forested and shrub
PEM	Emergent wetlands in palustrine, shallow riverine, or shallow lacustrine littoral settings
PSS	Shrub-dominated wetlands in palustrine, shallow riverine, or shallow lacustrine littoral settings
PFO	Forested wetlands in palustrine, shallow riverine, or shallow lacustrine littoral settings
Pf	Farmed wetlands in palustrine, shallow riverine, or shallow lacustrine littoral settings; subset that was previously farmed, but not currently in crop production
PUBPAB*	Open-water ponds and aquatic bed wetlands

*PUBPAB is comprised of S&T Wetland Categories: PAB (Palustrine Aquatic Bed), PUBn (Palustrine Unconsolidated Bottom, natural characteristics), PUBa (aquaculture), PUBf (agriculture use), PUBi (industrial), and PUBu (PBU urban).

Note that the S&T Category Codes for the NWCA Wetland Types often encompass more kinds of wetlands than the code might suggest. For example, E2SS includes both estuarine intertidal shrub and forested wetlands. Palustrine codes (e.g., PEM and others) reflect palustrine wetlands, and also riverine and lacustrine wetlands with < 1 m water depth. Palustrine farmed and Palustrine Unconsolidated Bottom wetlands with non-natural modifiers were retained in the NWCA frame to allow evaluation of whether they met NWCA Wetland Type criteria; those that did not were identified as non-target during site evaluation.

Two major S&T wetland categories, Marine Intertidal (M1, near shore coastal waters) and Estuarine Intertidal Unconsolidated Shore (E1UB, beaches, bars, and mudflats), were not included in the NWCA because they fall outside the NWCA Wetland Type population; i.e., they typically occur in deeper water (> 1m deep) or are unlikely to contain rooted wetland vegetation. Other S&T Categories not meeting the NWCA criteria or that were not wetlands were also excluded: Estuarine Intertidal Aquatic Bed (E2AB) or Unconsolidated Shore (E2US), Marine Subtidal (M2), deep-water Lacustrine (LAC, lakes and reservoirs) and Riverine (RIV, river systems), Palustrine Unconsolidated Shore (PUS), Upland Agriculture (UA), Upland Urban (UB), Upland Forest Plantations (UFP), Upland Rural Development (URD), and Other Uplands (UO).

The expected sample size was 900 sites for the conterminous 48 states. Allocation of sites by state and wetland type categories was completed by solving a quadratic programming problem that minimized the sum of the squared deviations of the expected sample size minus proportional allocation of sites by wetland type based on state area within each wetland type subject to constraints that:

- The expected sample sizes across conterminous US by wetland type were:
    - *E2EM = 128*
    - *E2SS = 127*
    - *PEM = 129*
    - *PSS = 129*
    - *PFO = 129*
    - *Pf = 129*
    - *PUBPAB = 129*
- The minimum number of sites for a state was 8;
- The maximum number of sites within a state for E2EM or E2SS was 13 (coastal states);
- The maximum number of sites within a state for PEM, PSS, PFO, Pf, or PUBPAB was 10; and,
- The minimum number of sites was greater than or equal to zero for each wetland type and state combination.

This approach ensured that the sample size for the seven NWCA Wetland Types was sufficient for national reporting, each state received a minimum number of sites (which also improved the national spatial balance of the sites) and otherwise proportionally allocated the sites by area within a wetland type. Site selection was completed using the R package 'spsurvey' (Kincaid and Olsen 2013).

1.2.1 *Site Visits*

The total number of site visits planned was 996 allocated to 900 unique sites with 96 sites to be revisited (two per state). To ensure a sufficient number of sites were available for sampling, an additional 900 sites were selected as an oversample to provide replacements for any sites that were either not part of the target population or could not be sampled (i.e., permission to sample was not provided by the landowner, or access was not possible due to safety or other access issues). A total of 1800 sites were selected for potential sampling. To ensure that the final set of sites evaluated satisfied the requirements for a probability survey design, the sites were ordered in reverse hierarchical order (Stevens and Olsen 2004). Sites were sampled based on this order, and all sites from the first one in the list through the last site sampled in the list were evaluated and, hence, included in the study.

1.2.2 *State-Requested Modifications to the Survey Design*

Three states elected to modify the survey design for their state because of the availability of additional wetland mapping information. The state modifications replaced the above survey design for their state.

1.2.2.1 *Wisconsin*

Wisconsin chose to intensively study the Southeastern Plains Till region in addition to the sites sampled for the national estimates as part of the NWCA. This was accomplished by the USFWS S&T team selecting additional 4-square mile plots within the study region. For the NWCA survey, the Wisconsin state stratum was replaced by a new design that included two strata – the Southeastern Plains Till region and the rest of the state. The sites selected under the national NWCA design were used for the rest of Wisconsin state region, and a new GRTS unequal-probability survey design of 50 sites were selected for the Southeastern Plains Till region. Unequal-probability selection categories were the five wetland types PEM, PSS, PFO, Pf, and PUBPAB.

1.2.2.2 *Ohio*

Ohio decided to base their survey design on a current digital map of wetlands in Ohio. A sample of size 50 was selected using a GRTS unequal-probability survey design. The unequal-probability categories were the five wetland types PEM, PSS, PFO, Pf, and PUBPAB.

1.2.2.3 *Minnesota*

In 2006, Minnesota developed a Comprehensive Wetland Assessment, Monitoring, and Mapping Strategy (CWAMMS). One of the primary outcomes of the CWAMMS was the development of statewide random surveys under the Wetland Status and Trends Monitoring Program (WSTMP), to begin assessing the status and trends of wetland quantity and quality in Minnesota (Kloiber 2010). The wetland quantity survey, implemented by the Minnesota Department of Natural Resources, was modeled after the USFWS S&T program (Dahl 2006, 2011). The WSTMP survey design was the basis for the Minnesota NWCA design.

The WSTMP design contains 1-square mile grid cells for Minnesota (and requires that at least 25% of grid cell be within state of Minnesota) where the grid matches the USFWS S&T 4-square mile grid boundaries. Each 4-square mile grid cell was subdivided into four 1-square mile grid cells. An equal-probability GRTS survey design was used to select 4,740 1-square mile plots assigned to panels 1 through 3 of the WSTMP design. All wetland habitats within these plots were delineated using aerial imagery obtained in years 2006, 2007, and 2008 (panels 1, 2, and 3, respectively). Where portions of some 1-square mile plots fell outside of state boundaries, only the portion occurring within the state was photo-interpreted and mapped. Therefore, the total area of the sample frame extent was less than 4,740 square-miles. NWCA Wetland Types were PEM, PSS, PFO, Pf, and PUBPAB. The next step was to select 150 sample sites using a GRTS equal-probability survey design from the delineated wetland polygons. The 22 Minnesota sites required for the NWCA were the first 22 sites that were sampled when ordered by their site identification. An additional 150 sites were selected for use if any of the initial 150 sites could not be sampled, using the same process described in **Section 1.2.1**.

1.3 Sample Frame Summary

The NWCA sample frame (with the exception of Minnesota and Ohio, see **Sections 1.2.2.2** and **1.2.2.3**) was the USFWS 2005 National Wetland Status and Trends survey, obtained through collaboration with the USFWS. This sample frame consisted of all S&T polygons mapped based on 2005 remote sensing information for a 5,048 2-mile by 2-mile plots across the 48 states. Additional attributes added to the sample frame are state, EPA Region, USEPA Level III Ecoregions (Omernik 1987; USEPA 2011a) and Three Major Regions and Nine Aggregated Ecoregions (those used in the Wadeable Stream Assessment; USEPA 2006). Seven NWCA Wetland Types were used: E2EM, E2SS, PEM, PSS, PFO, Pf, and PUBPAB (See **Table 1-1** for definitions). The wetland area from the USFWS S&T 2005 plot imagery is provided in **Table 1-2**.

Table 1-2. Sample frame wetland area from the US Fish and Wildlife 2005 National Wetland Status & Trends plots. Wetland area (in acres) is reported by state and S&T Wetland Categories that represent the NWCA Wetland Types. See Table 1-1 for definitions of the acronyms and descriptions of included wetland types.

State	E2EM	E2SS	PEM	PSS	PFO	Pf	PUBPAB	Total
AL	1,007	184	807	4,106	31,039	3.78	684	37,829
AR	0	0	2,595	6,675	34,952	108,895	2,209	155,327
AZ	0	0	107	31	2.67	0	12	153
CA	4,049	0	6,552	1,991	1,580	14,593	1,395	30,159
CO	0	0	242	113	18	18	68	460
CT	1,544	0.67	231	325	543	0	224	2,869
DE	4,677	132	52	63	1,054	7.68	92	6,078
FL	22,402	45,553	84,540	60,208	190,067	310	10,184	413,263
GA	41,117	1,188	4,955	11,721	78,058	19	3,239	140,298
IA	0	0	1,342	65	1,321	19	189	2,937
ID	0	0	2,155	1,395	366	3.61	106	4,026
IL	0	0	953	274	2,283	73	739	4,321
IN	0	0	1,788	591	2,776	465	581	6,200
KS	0	0	172	22	92	4.65	298	589
KY	0	0	213	253	1,745	4.4	505	2,720
LA	171,338	1,262	67,053	31,670	181,941	93,522	8,523	555,308
MA	1,313	17	359	683	1,512	0	72	3,957
MD	7,571	238	539	396	3,154	23	430	12,350
ME	297	0	2,483	8,797	18,031	0	709	30,317
MI	0	0	4,759	8,279	25,420	103	1,057	39,618
MN	0	0	21,344	23,122	25,078	2,473	1,746	73,764
MO	0	0	377	280	2,096	67	907	3,728
MS	1,738	77	2,117	1,681	36,552	24	7,007	49,197
MT	0	0	1,106	1,068	115	4.37	125	2,418
NC	14,279	1,258	2,573	20,534	55,435	173	1,185	95,437
ND	0	0	21,132	128	80	205	1,305	22,849
NE	0	0	6,935	416	259	148	479	8,237
NH	63	0	513	1,211	941	0	152	2,879
NJ	19,234	34	1,635	835	4,103	0	365	26,206
NM	0	0	233	91	6.38	0	25	355
NV	0	0	1,056	220	18	0	28	1,321
NY	3,234	0	2,075	2,445	4,463	118	1,365	13,701
OH	0	0	189	236	1,341	113	433	2,311
OK	0	0	557	674	3,463	27	728	5,448

State	E2EM	E2SS	PEM	PSS	PFO	Pf	PUBPAB	Total
OR	69	0	1,808	272	143	0.37	79	2,371
PA	0	0	305	568	1,729	0.25	375	2,977
RI	243	0	60	252	561	0	46	1,162
SC	22,418	217	5,060	6,521	56,211	0.57	1,808	92,235
SD	0	0	12,567	116	251	290	741	13,964
TN	0	0	243	176	5,820	489	596	7,325
TX	34,122	56	17,357	5,341	9,467	26,912	2,689	95,944
UT	0	0	836	149	15	0	4.45	1,005
VA	9,010	603	800	648	4,523	6.35	417	16,007
VT	0	0	1,301	843	1,522	0	211	3,878
WA	1,032	1.38	2,784	1,636	2,835	84	546	8,918
WI	0	0	5,999	12,961	17,436	83	732	37,211
WV	0	0	37	8.13	31	17	27	120
WY	0	0	2,234	779	44	0	87	3,145
Sum	360,758	50,819	295,132	220,869	810,492	249,298	55,526	2,042,894

The sample frame areas (acres) for Ohio were:

- 110,403.7 for PEM,
- 17,658.2 for Pf,
- 309,671.2 for PFO,
- 87,158.8 for PSS,
- 63,602.5 for PUBPAB, and
- 588,494.5 total acres in the GIS layer for the state.

The sample frame areas (acres) from Minnesota phase 1 plots were:

- 244,236.6 for PFO,
- 128,787.8 for PSS,
- 175,446.9 for PEM,
- 30,283.3 for PABPUB,
- 7,698.2 for Pf, and
- 586,453.1 total in the plots.

1.4 Site Selection Summary

Table 1-3 shows the number of sites planned to be sampled for the NWCA by state and NWCA Wetland Types (subset of S&T wetland categories). The maximum number of sites for a state was 69 (Louisiana) and the minimum number of sites for a state was 8 (Vermont). Additional sites were sampled in some states with the objective of enabling a state-level assessment.

Table 1-3. Number of sites planned to be sampled. Number of sites is reported by state and S&T Wetland Categories that represent the NWCA Wetland Types. See **Table 1-1** for definitions of the acronyms and descriptions of included wetland types.

State	E2EM	E2SS	PEM	PSS	PFO	Pf	PUBPAB	Total
AL	4	5	2	3	4	0	3	**21**
AR	0	0	4	4	1	10	3	**22**
AZ	0	0	4	1	0	0	4	**9**
CA	5	0	3	1	0	11	3	**23**
CO	0	0	6	1	1	3	1	**12**
CT	4	0	2	1	3	0	1	**11**
DE	2	8	1	1	2	2	2	**18**
FL	13	10	11	8	10	3	12	**67**
GA	15	12	3	8	6	3	2	**49**
IA	0	0	3	0	4	1	4	**12**
ID	0	0	1	4	2	2	4	**13**
IL	0	0	3	2	1	3	3	**12**
IN	0	0	2	1	2	3	3	**11**
KS	0	0	3	1	0	0	6	**10**
KY	0	0	5	0	3	3	1	**12**
LA	14	13	8	7	11	11	5	**69**
MA	1	4	2	1	2	0	2	**12**
MD	5	12	2	2	2	2	2	**27**
ME	2	0	1	4	5	0	2	**14**
MI	0	0	1	5	5	4	0	**15**
MN	0	0	1	12	4	3	2	**22**
MO	0	0	2	1	2	4	2	**11**
MS	4	8	1	1	7	4	3	**28**
MT	0	0	2	5	1	2	1	**11**
NC	6	12	1	12	11	4	1	**47**
ND	0	0	1	2	1	4	3	**11**
NE	0	0	5	1	2	2	2	**12**
NH	4	0	1	3	2	0	1	**11**
NJ	11	2	3	2	0	0	2	**20**
NM	0	0	3	0	2	0	4	**9**
NV	0	0	3	3	2	0	1	**9**
NY	4	0	4	0	2	3	2	**15**
OH	0	0		1	1	3	4	**11**
OK	0	0	0	4	3	3	2	**12**
OR	3	0	3	2	1	1	2	**12**
PA	0	0	4	2	2	0	2	**10**
RI	2	0	1	2	2	0	3	**10**
SC	8	12	1	2	11	2	4	**40**
SD	0	0	3	2	0	3	3	**11**
TN	0	0	3	1	2	3	3	**12**
TX	15	9	4	0	1	10	3	**42**
UT	0	0	3	3	1	0	2	**9**
VA	5	14	2	1	2	2	1	**27**
VT	0	0	2	3	1	0	2	**8**
WA	3	1	3	1	3	3	1	**15**
WI	0	0	3	6	3	3	2	**17**
WV	0	0	2	1	2	1	4	**10**
WY	0	0	5	0	1	0	3	**9**
Total	**130**	**122**	**135**	**128**	**136**	**121**	**128**	**900**

The number of sites selected for Ohio was 10, 11, 10, 12, and 6 for PEM, Pf, PFO, PSS, and PUBPAB, respectively. Only the first 11 sites were included in the NWCA.

The number of sites selected for Minnesota was 41, 30, 63, 7 and 9 for PFO, PSS, PEM, PABPUB, and Pf, respectively. Only the first 11 sites were included in the NWCA.

1.5 Survey Analysis

Any statistical analysis of data must incorporate information about the monitoring survey design. In particular, when estimates of characteristics for the entire target population are computed, called ***population estimates*** (discussed in **Chapter 9, Section 9.2**), the statistical analysis must account for any stratification or unequal probability selection in the design. The statistical estimates for the NWCA population estimates were completed using the R package 'spsurvey' (Kincaid and Olsen 2013) which implements the methods described by Diaz-Ramos et al. (1996).

1.6 Estimated Wetland Extent of the NWCA Wetland Type Population and Implications for Reporting

Sites from the NWCA survey design were screened using aerial photo interpretations and GIS analyses to eliminate locations not suitable for NWCA sampling (e.g., non NWCA wetland types, wetlands converted to non-wetland land cover due to development). Sites could also be eliminated during field reconnaissance if they were a non-target type or could not be assessed due to accessibility issues. Dropped sites were systematically replaced from a pool of replacement sites from the random design.

The treatment of sites eliminated from sampling affects how the final population results are estimated and reported. Taking into account the sites identified as non NWCA wetland types (e.g., wetlands in active crop production, deeper water ponds, mudflats), it was estimated there were 94.9 million acres of wetlands in the NWCA wetland type population across the conterminous US. The area represented by sites that were part of the target population, but not sampled because of accessibility issues, is excluded from the assessment of condition and stress. Sites which had access issues cannot be assumed to be randomly distributed. For example, there may be a bias in land-ownership for sites where access was denied, or sites which were inaccessible may often occur in areas with limited disturbance. As a result, the final acreage represented by the probability sites sampled and reported by the NWCA, i.e., the inference population, was 62.2 million acres or approximately 65% of the target population of NWCA Wetland Types. Throughout this report, wetland area as percentages are relative to the 62.2 million acres.

Figure 1-1 provides the distribution of the NWCA probability sites that were part of the NWCA wetland type population and the estimated acres and percent of wetland area the sites represent. The inference population is represented by 967 probability sites. The non-assessed component of the population is represented by sites 1) where access was denied (n = 429), 2) inaccessible due to safety considerations or remote location (n = 126 sites), and 3) with various other (n = 122) constraints (e.g., too close to another NWCA sampling point, sampling area crossing HGM boundaries, assessment area too small).

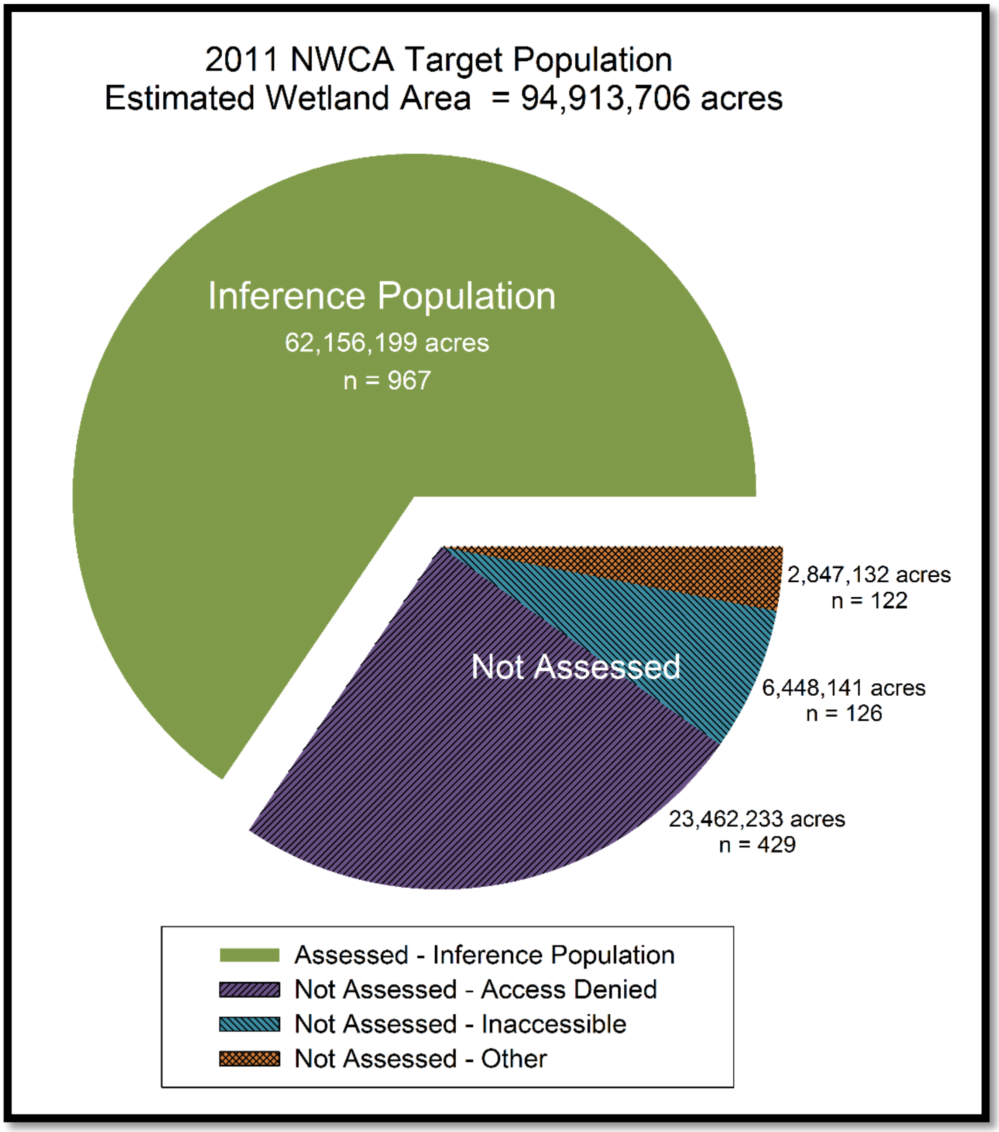

Figure 1-1. Estimated wetland area included in the NWCA Wetland Type Population, the proportion of the population that was assessed (for which inference of results can be made), and the proportion not assessed.

Table 1-4 illustrates the distribution of estimated extents of the1) total population of NWCA wetland types, 2) the inference population (based on sampled probability sites), and 3) non-assessed area (based on probability sites that could not be assessed) for the nation (conterminous US) and within four major geographic regions. Some differences were evident among the NWCA regions in the percent of the total estimated area of NWCA wetland types for which results can be inferred. The percent of the total estimated NWCA wetland area in particular region that was represented by the inference area was greatest in the Eastern Mountains & Upper Midwest region (80%), but least in the West (40%), and intermediate in the Coastal Plains (63%) and the Interior Plains (62%). These differences were related to varying levels of land-owner denial of access and physical accessibility across the regions.

Table 1-4. Total estimated areal extents for the NWCA Wetland Type population, the inference population extents (based on sampled probability sites (n)), and non-assessed area extents (based on probability sites (n) that could not be assessed) for the nation and within subpopulations represented by four major geographic regions. Results are reported as millions of acres or % of total estimated NWCA wetland area for the nation or by region.

NWCA Region[1]	Estimated Total NWCA Wetland Area millions acres	Inference Area millions acres (% area)	Access Denied millions acres (% area)	Inaccessible millions acres (% area)	Other Non-Assessed millions acres (% area)
Nation	94.9	62.2 (65%) n = 967	23.5 (25%) n = 429	6.4 (7%) n = 126	2.8 (3%) n = 122
Coastal Plain	48.7	30.9 (63%) n=513	12.7 (26%) n = 165	4.2 (9%) n = 86	0.9 (2%) n = 105
Eastern Mtns & Upper MidW	24.7	19.9 (80%) n =152	3.5 (14%) n = 42	0.9 (4%) n = 6	0.4 (2%) n = 17
Interior Plains	12.3	7.7 (62%) n=156	3.6 (29%) n = 119	1.7 (1%) n = 6	8.4 (7%) n = 55
West	9.2	3.6 (40%) n =146	3.7 (40%) n = 103	1.2 (13%) n = 28	0.7 (7%) n = 31

[1]See **Chapter 4, Section 4.4** and **Figure 4-11** for definition of NWCA regions.

1.7 Literature Cited

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Chapter 2: Overview of Analysis

The analysis for the 2011 National Wetland Condition Assessment (NWCA) involved a number of interrelated tasks composed of multiple steps. This brief overview of the entire process provides a context for the details of each of the major tasks described in **Chapters 3 through 9**.

Figure 2-1 illustrates the analysis process, represented as the 2011 National Wetland Condition Assessment Analysis Pathway, beginning with data acquisition (left side of chart) and concluding with the population estimates for the wetland resource of ecological condition, stressor extent, and relative and attributable risk for the NWCA target population in the conterminous US (right side of chart). The components of each of the major tasks are indicated in the chart by color:

> ***Orange*** = data acquisition, preparation, and quality assurance (**Chapter 3**);
> ***Black & Yellow*** = selection of reference sites and definition of disturbance gradient (**Chapter 4**);
> ***Green*** = ecological condition analysis using the vegetation indicator (**Chapters 5, 6, and 7**); and
> ***Blue*** = development of indicators of stress (**Chapter 8**); and,
> ***Teal*** = calculation of population estimates of ecological condition, stressor extent, and relative and attributable risk (**Chapter 9**).

The four key elements of the analysis outlined in the Analysis Pathway flowchart (**Figure 2-1**) are:

1) Data acquisition and quality assurance continues throughout all of the analyses, beginning with a major effort resulting in the production of the data tables used by the analysts;

2) Data collected at probability (from the assessment design) and not-probability (from other sources, e.g., handpicked) sites are used in reference site selection and index development for condition and stressors. Only data from probability sites are used to generate the population estimates for assessment results;

3) Reference Site Selection (yellow box) involves the definition of a disturbance gradient, which requires setting disturbance thresholds; and

4) Reference sites are used in the development of the Vegetation Multimetric Index (VMMI) and to set condition class thresholds for the VMMI (i.e., Good, Fair, Poor classes) and stressor-level class thresholds for some indicators of stress (i.e., Low, Moderate, High stressor-level classes).

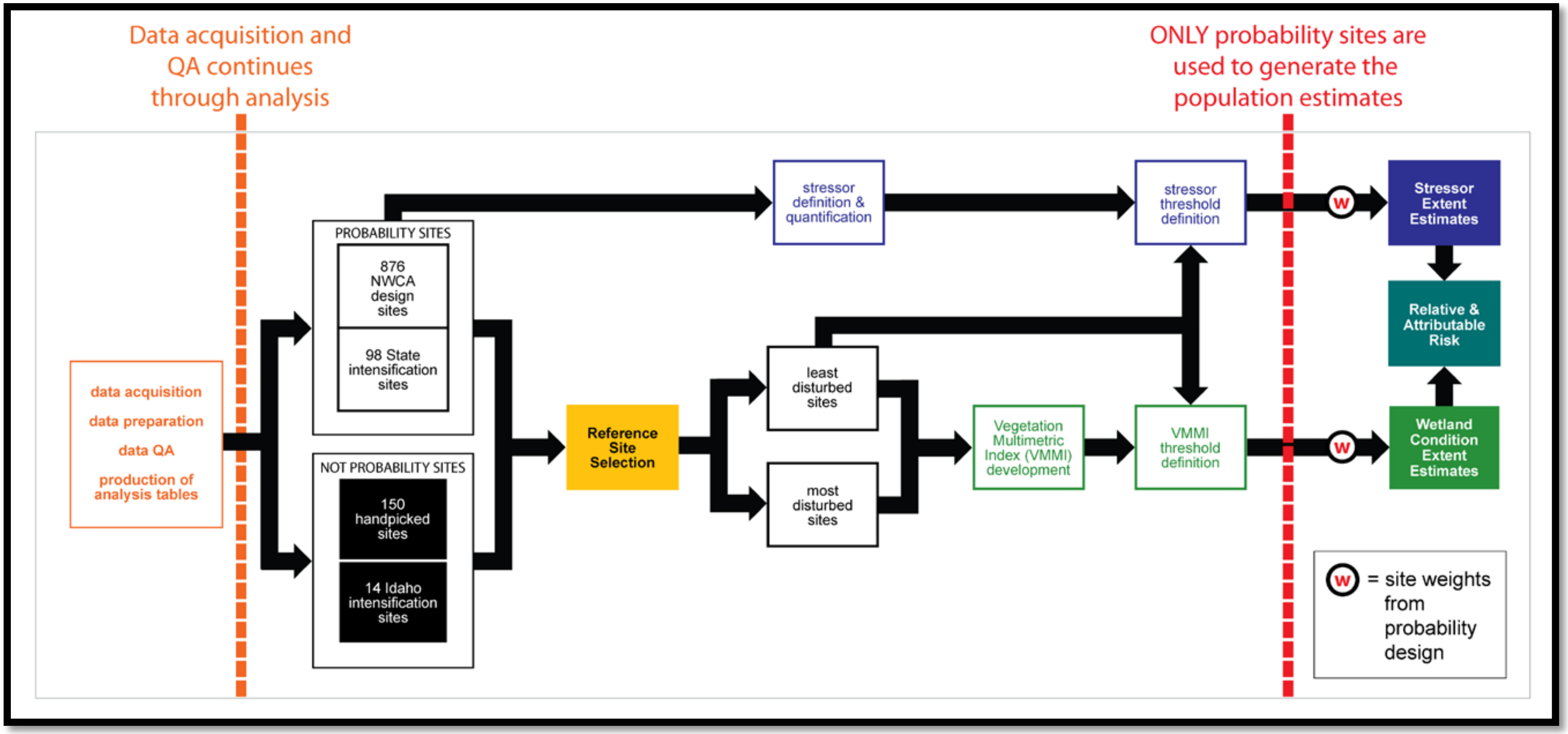


Figure 2-1. The 2011 National Wetland Condition Assessment Analysis Pathway, which illustrates the major components of the analysis and this report.

Chapter 3: Data Preparation and Management

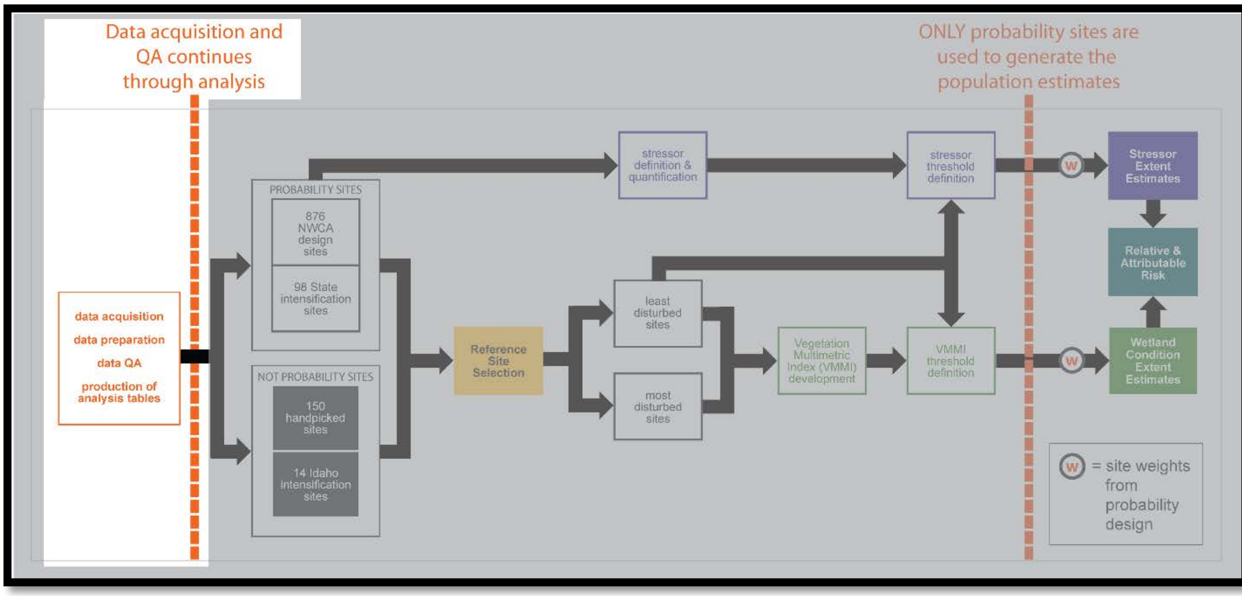


Figure 3-1. The major components of the 2011 National Wetland Condition Assessment Analysis Pathway discussed in this chapter (i.e., data preparation and management). A full-page, unhighlighted version of this figure may be found on **page 14** of this report.

3.1 Introduction

This chapter:

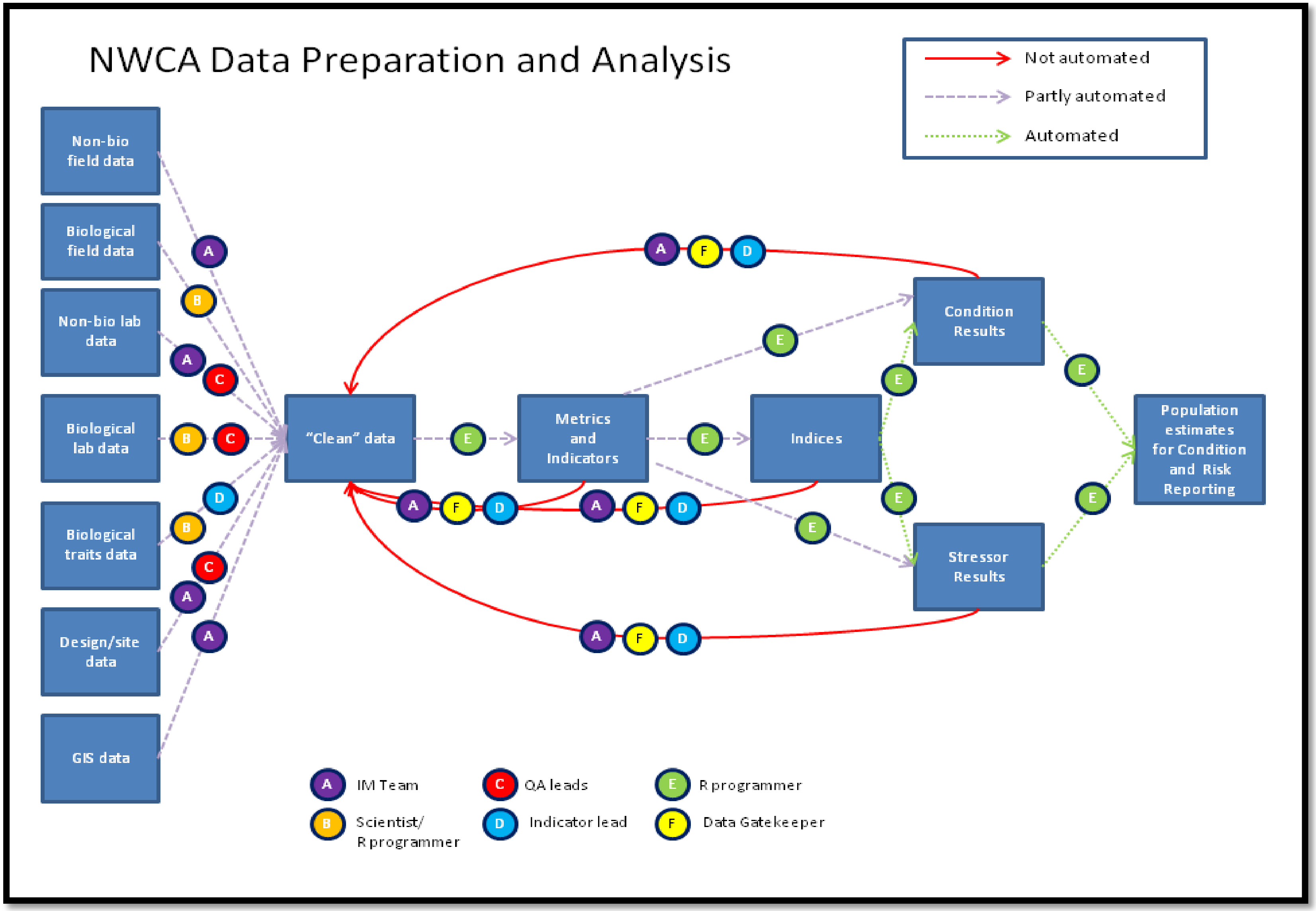
- Documents data entry, preparation, and management, and
- Presents procedures used to conduct standard quality assurance checks.

Figure 3-1 presents the Analysis Pathway leading to the results reported for the 2011 National Wetland Condition Assessment (NWCA). The highlighted area indicates the part of the pathway presented in this chapter.

The tasks to produce the datasets used in the analysis are described in this chapter. The data checking steps described, here, were designed to catch many errors. Other errors were found and corrected during analysis using processes documented in the chapters presenting each phase of the analysis (i.e., **Chapters 4 through 9**).

The master database for the 2011 NWCA includes:

1) Raw data collected by Field Crews and from laboratory processing of samples collected in the field (USEPA 2011a; b), represented by boxes for field and lab data (top four boxes, left side of **Figure 3-2**).
2) Data documenting and characterizing the NWCA sites from the survey design and other ancillary information represented by the three boxes on the bottom left of **Figure 3-2**.
3) Field and lab raw data, site information, and ancillary data combined for use in specific analyses.
4) Metrics calculated from raw data from the field forms and the laboratory results.



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445 **Figure 3-2**. Flowchart of the data preparation and analysis used in the NWCA and other National Aquatic Resource Surveys (NARS).

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3.2 Key Personnel

USEPA Office of Water (OW), Wetlands Division (WD) provided overall leadership for the 2011 NWCA. Gregg Serenbetz led the team in Wetlands Division and coordinated and fostered cooperation with the Analysis Team. Personnel from the Office of Research and Development, National Health and Environmental Effects Laboratory, Western Ecology Division (WED) were responsible for data entry, quality assurance, and preparation of datasets for analysis with input from the Indicator Leads as illustrated in **Figure 3-2**.

Mary E. Kentula was the primary contact at WED for the 2011 NWCA. She provided oversight and coordination of the various components at WED and their interactions with Wetlands Division. She served as one of the Data Gatekeepers and Quality Assurance (QA) leads.

Karen Blocksom has extensive experience with the data management and analysis with other National Aquatic Resource Surveys (NARS). She deals with all aspects of the management of the data for an assessment, e.g., finding, correcting and documenting errors, designing formats for the specific datasets needed for the various analyses, programming required for data management and analyses. She served as one of the Data Gatekeepers and QA leads and was the primary R programmer.

Information Management Team (IM Team) performs data entry and checks, makes and documents corrections to the database, and creates various data sets for analysis for the NARS assessments. The IM Team for the 2011 NWCA is a group of people on contract to USEPA who are located at WED, and led by Marlys Cappaert of SRA International, Inc.

The NWCA Analysis Team was composed of the Indicator Leads, the scientists working with them on the analysis, and the scientists conducting work that supported multiple analyses. **Table 3-1** lists the members of the Analysis Team and their roles.

Table 3-1. The 2011 Analysis Team and roles. All people listed are USEPA except as noted.

Reporting Topics	Leads	Associates
Extent and Description of the Resource	Gregg Serenbetz	Anthony R. Olsen, Thomas M. Kinkaid
Wetland Condition - Vegetation	Teresa K. Magee	Karen Blocksom, M. Siobhan Fennessy*
Stressor Extent and Risk	Mary E. Kentula	Alan T. Herlihy, Gregg A. Lomnicky[#], Teresa K. Magee, Amanda M. Nahlik*
Research Indicators and Topics	**Leads**	**Associates**
Algae	Chris Faulkner	Battelle Memorial Institute
Algal Toxins	Keith A. Loftin[%]	
Ecosystem Services	Amanda M. Nahlik*	Mary E. Kentula
Sediment Enzymes	Brian H. Hill	
Water Chemistry	Anett S. Trebitz	Janet A. Nestlerode
USA-RAM	Gregg Serenbetz	M. Siobhan Fennessy* and Josh Collins[@]

Table 3-1 continued

Work Supporting Multiple Analyses	Leads	Associates
Data QA and Management	Karen Blocksom, Mary Kentula	IM Team^
Development of Disturbance Gradient	Mary E. Kentula	Karen Blocksom, Alan T. Herlihy, Gregg A. Lomnicky, Teresa K. Magee, Amanda M. Nahlik*, Marc Weber
Landscape data	Gregg Serenbetz	Marc Weber, Horizon Systems
Population estimates	Gregg Serenbetz	Steven G. Paulsen, Thomas M. Kincaid

*Kenyon College; #Dynamac Corporation; %US Geological Survey; @San Francisco Estuary Institute; ^SRA International, Inc.

3.3 Data Entry and Review

3.3.1 *Field Data*

Field forms for the 2011 NWCA were created in TeleForm™ software. This form development software uses optical character recognition/intelligent character recognition technology along with operator verification to capture data from paper field forms.

The Field Crews mailed packets of completed field forms directly to the data management center at WED. Form packets were logged and checked for quality and completeness. Field Crews were immediately contacted if the form packets were incomplete or if there were questions regarding data written on the forms. Then each page was scanned and evaluated by the scanning software. Because the forms were designed in TeleForm™, the evaluation process was coded to flag restricted input. For example, a field may have an allowable numerical range, or a specified list of expected values. Any data entries not meeting the criteria were marked by the software as potential errors. The operator reviewed the marked entries by comparing the entered value to that on the paper form and making corrections to mis-scanned data. This was followed by a visual check whereby the operator reviewed the entered data in tabular form. Finally, on a daily basis, the data were reviewed for logical errors, for example:

- Did Sample ID numbers meet sequential expectations?
- If there were flags on a data form, was an associated comment recorded by the Field Crew?
- Were there form images for each sheet?
- Do the samples in the samples table match the samples in the tracking tables?

Once the phase of verification described above was complete, the data were further scrutinized via programmatic validation checks described in **Section 3.4**.

3.3.2 *Laboratory Data*

Laboratory results were submitted to USEPA Wetland Division staff, who checked the data for completeness and obvious errors. Then the data files were transferred to the IM Team for incorporation into the master NWCA database.

The water chemistry data produced by Dynamac Corporation located at WED was handled by a different process. Dynamac checks their results based on the approved Quality Assurance Project Plan and the data files are transferred from Dynamac to the IM Team through the Work Assignment Contract Officer Representative.

3.4 Quality Assurance Checks

There were three types of Quality Assurance (QA) checks completed before datasets were assembled for analysis:

1) Verification of the fate of every sample point from the 2011 NWCA design;
2) Confirmation of longitudes and latitudes associated with the sites sampled; and
3) Legal value and range checks.

3.4.1 *Verification of Points from the 2011 NWCA Design*

Estimates of the wetland area falling into a particular condition class are based on the weight from the survey design used to select the points to be sampled. For examples of how this has been done for other surveys see Stevens and Jensen (2007) and Olsen and Peck (2008). **Chapter 1** provides specific details of the NWCA survey design, and **Chapter 9** discusses how estimates for the 2011 NWCA wetland area were made.

In the NWCA survey design, the weight indicates the wetland area in the NWCA target population represented by a point from the sample draw. After the assessment is conducted, the weights were adjusted to account for additional sites (i.e., the oversample points) evaluated when primary sites could not be sampled (e.g., due to denial of access, being non-target).

All points in the design were reviewed to confirm which were sampled, and if not, why not. Three sources were used:

1) Information compiled during the desktop evaluation of sites (see Section 2.0 in the *NWCA Site Evaluation Guidelines* (USEPA 2011c)), and documented by state and contractor field crews in spreadsheet submissions to EPA during and after the 2011 field season,
2) Information recorded on Form PV-1 during a field evaluation performed prior to sampling (see Section 3.0 in the *NWCA Site Evaluation Guidelines* (USEPA 2011c)), and
3) Information recorded on Form PV-1 at the time of sampling (see Chapter 3 in the *NWCA Field Operations Manual* (USEPA 2011a)).

Results from this evaluation were added to the database containing site information data from the NWCA survey design and for the not-probability sites.

3.4.2 *Confirmation of Coordinates Associated with the Sites Sampled*

Longitudes and latitudes are taken at various key locations associated with field sampling (e.g., the location of the point from the design). These coordinates are especially important if a point needs to be relocated or shifted to accommodate sampling protocols (see Chapter 3 in the *NWCA Field Operations Manual* (USEPA 2011a)). The coordinates are used to:

- Verify the relationship between the point coordinates from the design and those of the sampled Assessment AA (AA) that represents the point (see Chapter 3 in the *NWCA Field Operations Manual* (USEPA 2011a));
- Tie the field data to landscape data from GIS layers; and
- Relocate the site and key locations of the field sampling protocol (e.g., the AA center, vegetation plots) for resampling in future surveys.

Point coordinates from the design and the field were compared. The locations of points from the field that were more than 60m from the corresponding design coordinates, i.e., that exceeded protocol guideline (see Section 4.2 in the *NWCA Site Evaluation Guidelines* (USEPA 2011c)), were flagged. There were 25 sites that required further evaluation. All were determined to meet design standards because in some cases permission to move the point beyond 60m was obtained, recording errors made by the Field Crew were identified and corrected, or the distance exceeding 60m from the sample point was determined to be negligible.

3.4.3 *Legal Value and Range Checks*

The first step in this series of checks was to assure all sites with data from a second field sampling (i.e., Visit 2 or Quality Assurance Visit) had a corresponding initial sampling (i.e., Visit 1). Next, for all data types, computer code was written to generate a list of missing data, and checks were performed to identify why they were missing (e.g., part of the sampling was not completed by the Field Crew, data sheet(s) not scanned, etc.). Additional computer code was written to generate a list of data not meeting a series of legal value and range tests. These tests were to confirm that:

- Data type was correct,
- Data fell within the valid range or legal value, and
- Units reported (especially for laboratory results) matched those expected.

Results of the checks were converted to Excel spreadsheets. Each potential error was evaluated by the Data Gatekeeper or the Indicator Lead using the original forms submitted by the Field Crew. A description of the error and recommended resolution were recorded in the spreadsheet for each type of data and incorporated into the master NWCA database. The Indicator Lead who would be the primary user of the data was consulted in cases where the resolution of the issue could affect the results of the analysis.

3.5 Literature Cited

Olsen AR, Peck DV (2008) Survey design and extent estimates for the Wadeable Streams Assessment. Journal of the North American Bethological Society 27: 822-836

Stevens DL, Jr., Jensen SF (2007) Sample design, implementation, and analysis for wetland assessment. Wetlands 27: 515-523

USEPA (2011a) National Wetland Condition Assessment: Field Operations Manual. US Environmental Protection Agency, Washington, DC

USEPA (2011b) National Wetland Condition Assessment: Laboratory Operations Manual. U. S Environmental Protection Agency, Washington, DC

USEPA (2011c) National Wetland Condition Assessment: Site Evaluation Guidelines. US Environmental Protection Agency, Washington, DC

Chapter 4: Selection of Reference Sites and Definition of Disturbance Gradient

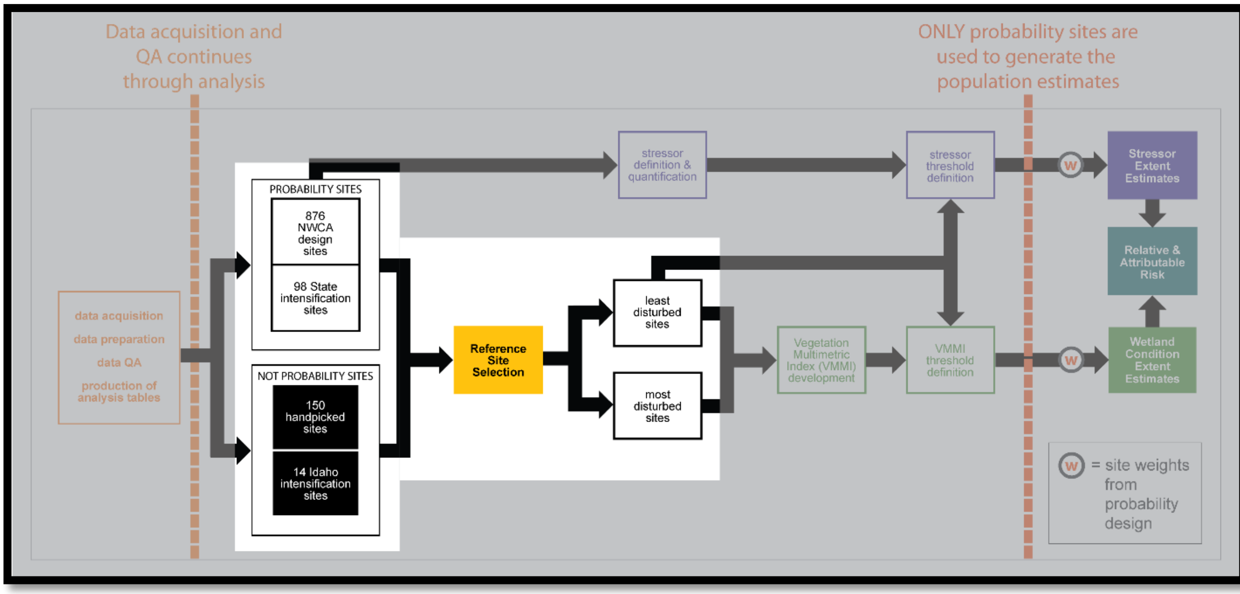

Figure 4-1. The major components of the 2011 National Wetland Condition Assessment Analysis Pathway discussed in this chapter (i.e., the selection of reference sites and development of the disturbance gradient). A full-page, unhighlighted version of this figure may be found on **page 14** of this report.

4.1 Background Information

The USEPA National Aquatic Resource Survey (NARS) assessments, including the National Wetland Condition Assessment (NWCA), evaluate the ecological condition of, and potential stress to, aquatic resources based on biotic, chemical, and physical characteristics along a gradient of disturbance. In NARS, development of a quantitative definition of disturbance begins with the identification of the end of the gradient in reference condition. Because pristine conditions are uncommon or absent in most places, the 2011 NWCA followed the practice of previous NARS assessments and defined ***reference condition*** as least-disturbed (USEPA 2006, 2008, 2009).

Least-disturbed is defined as those sites with the best available physical, chemical, and biological condition given the current status of the landscape in which the site is located (Stoddard et al. 2006). Least disturbed status for the NWCA was defined using a set of explicit quantitative criteria for specific disturbance indicators, to which all reference sites must adhere. It is expected that these least disturbed reference sites will typically represent good ecological condition (see **Chapter 7**) and low stress (see **Section 8.6**) (Karr 1991; Dale and Beyeler 2001; Stoddard et al. 2006; Stoddard et al. 2008).

This chapter documents the process for:

- Developing a quantitative definition of site-level disturbance based on the NWCA definition of reference condition,
- Defining a disturbance gradient, and
- Assigning sites sampled in 2011 to categories of disturbance.

How this process fits into the overall analysis process is highlighted in **Figure 4-1**.

The planning for the 2011 NWCA assumed:

- Reference sites represent least disturbed ecological condition and the associated functional capacity and delivery of services typical of a given wetland type in a particular landscape setting (e.g., ecoregion, watershed);
- The survey design provides a representative sample of the target population; and,
- Wetlands in least disturbed condition provide a benchmark against which to compare assessment results through the establishment of a disturbance gradient defined using data collected on-site during the 2011 assessment.

Least disturbed wetland sites sampled in 2011 were selected from three sources:

1) Handpicked sites selected pre-sampling,
2) Probability sites from the 2011 NWCA probability design, and
3) State intensifications that used NWCA protocols to sample sites representing the NWCA Wetland Types.

A two-step selection processes was used. An initial pool of potential reference sites were picked prior to the 2011 field sampling (see **Section 4.2**); the final set of least disturbed sites were chosen after sampling based on data collected in the field (see **Section 4.3**).

4.2 Pre-Sampling Selection of Handpicked Sites

A group of sites were evaluated prior to the field sampling in 2011 to identify 150 handpicked sites likely to be in least disturbed or reference condition. The candidate handpicked sites came from three sources:

1) Best Professional Judgment (BPJ) sites recommended by the following entities with responsibilities for wetlands (**Figure 4-2**):
    - States
    - Tribes
    - National Estuarine Research Reserve System
    - National Park Service
    - US Fish and Wildlife National Refuge System
    - US Forest Service
    - Other USEPA NARS reference sites with associated wetlands;

2) Collaborations with partner organizations conducting wetland assessments (**Figure 4-2**); and,

3) In-the-field replacements for screened and un-screened sites determined not sampleable, e.g., access issues (see **Section 4.2.5**).

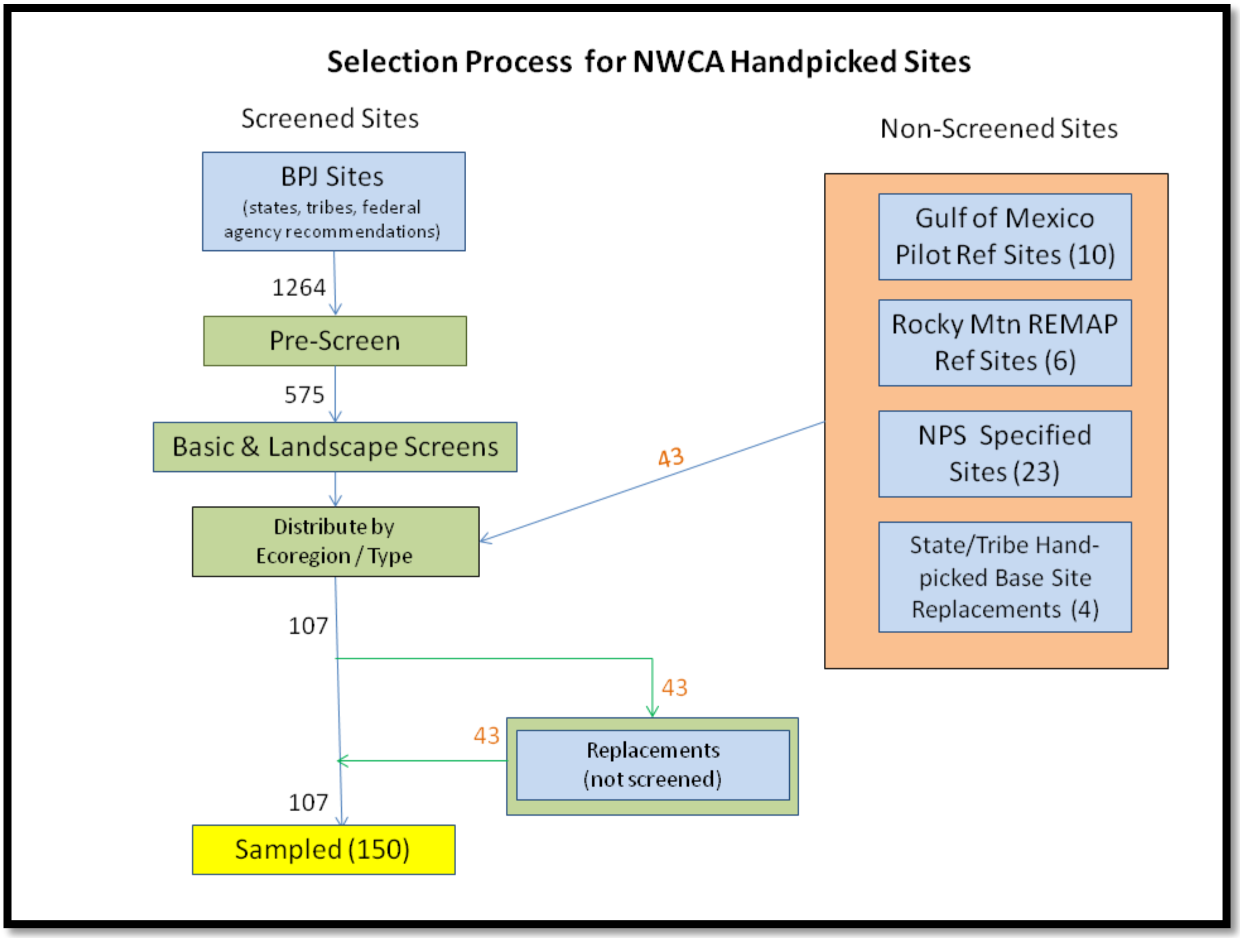

Figure 4-2. Flowchart presenting the process resulting in the 150 hand-picked sites sampled in the 2011 NWCA. The green boxes are the components of the selection process. The blue boxes are the sources of the sites considered. The orange box lists the collaborations with partners conducting wetland assessments who recommended sites. The numbers with each arrow are the number of sites considered at that point of the process. Black numbers are BPJ sites; orange, non-screened sites. The number of sites from each non-screened source is listed in parenthesis following the source. BPJ = Best Professional Judgment; REMAP = USEPA Regional Environmental Monitoring and Assessment Program.

The handpicked sites were divided into two groups—screened and unscreened. The screened sites were recommended by a number of sources whose definition of reference either was not consistent with the definition of least disturbed used in NARS or was not given, hence the use of the term Best Professional Judgement (BPJ) in **Figure 4-2**. The unscreened sites came from sources from which there was sufficient information to proceed without the screening.

The pre-sampling selection of the BPJ handpicked sites had five components (**Figure 4-2**):

1) The Pre-Screen was used to eliminate BPJ sites unlikely to meet the desired characteristics and to reduce the number of sites needing manual evaluation;

2) The Basic Screen assured that a BPJ site was part of the target population, then determined if the site was accessible, a minimum distance from a probability site, and sampleable;

3) The Landscape Screen was a three-step evaluation to eliminate BPJ sites likely to have an undesirable level of impact due to stressors that could be identified using aerial photography;

4) The sites passing the screening process and those not screened were evaluated to assure, to the greatest extent possible, the 150 handpicked sites selected for sampling in 2011 were distributed across the NWCA Wetland Types and the Nine Aggregated Ecoregions used by other NARS (i.e., combined from Level III Ecoregions; Omernik 1987; USEPA 2011a); and

5) Replacement of handpicked sites not meeting the desired characteristics, with difficult or unsafe access or site conditions, or for which access was denied by property owner.

Details of the process for selecting the 150 handpicked sites sampled in the 2011 NWCA are described in **Sections 4.2.1 through 4.2.6**.

4.2.1 *Pre-Screen*

The pre-screen step reviewed 1,264 BPJ sites to eliminate those not likely to meet the criteria for NWCA sampling and to reduce the number of sites to a reasonable size for a manual evaluation employing analysis of maps and aerial photos. Information provided by the person who suggested each site was considered, and included wetland size and type, as well as data supporting whether a site was least disturbed, e.g., scores from a Floristic Quality Assessment Index or Landscape Development Index. Wetlands eliminated were typically small, rare types. In cases where a number of sites were submitted by an entity, those ranking lower than others, given the data submitted, were eliminated from further consideration.

All BPJ sites in the West and Xeric ecoregions (from the Nine Aggregated Ecoregions) were eliminated because it was anticipated there would be an adequate number of least disturbed sites in these regions, particularly with the sites from collaborations with partner organizations in the area, e.g., the Rocky Mountain Assessment funded through USEPA's Regional Environmental Monitoring and Assessment Program (REMAP) (e.g., **Figure 4-2**).

4.2.2 *Basic Screens*

Readily available information (e.g., aerial photos, maps, local contacts (e.g., **Figure 4-3**)) was used to determine if:

- The wetland at the site was part of NWCA target population, i.e.,
    - *Tidal and nontidal wetlands of the conterminous US, including farmed wetlands not currently in crop production. The wetlands have rooted vegetation and, when present, open water less than 1m deep;*
    - *The site is described by the source or other supporting information as containing one or more of the US Fish and Wildlife Service's (USFWS) Status and Trends (S&T) Wetland Categories in NWCA the target population (hereafter NWCA Wetland Types; see **Chapter 1, Section 1.2** for details);*

- The site was accessible (within 10km of a road or trail);

- The site was >1km away from a probability site; and

- The site could contain a sampleable Assessment Area (AA) (see USEPA (2011a)), i.e.,
    - *The wetland is ≥ 0.1ha and at least 20m wide (to accommodate the vegetation plots)*
    - *< 10% of the area*
        - Contains water >1m deep,
        - Has conditions that are unsafe or would make effective sampling impossible (e.g., likely unstable substrate), and/or
        - Is upland
    - *No hydrogeomorphic boundaries are crossed.*

If all these criteria were met, the BPJ site was retained and the Landscape Screens were performed.

Figure 4-3. Example of a candidate site that met the criteria of the Basic Screen. Yellow dot is the center of the assessed area. PEM = Palustrine Emergent wetland; PFO =Palustrine Forested wetland PUB = Palustrine Unconsolidated Bottom wetland; NWI = USFWS National Wetland Inventory

4.2.3 *Landscape Screens*

GIS land cover data and aerial photos were used to evaluate the presence of anthropogenic impact within a circular buffer defined by a 1-km radius centered on the likely location of the Assessment Area (AA) that would be used during field sampling. Coordinates for the AA Center were provided by those recommending the BPJ site. The location could be shifted within the 1-km buffer during screening to decrease the amount of anthropogenic disturbances within the circular area being evaluated and, thus, keeping the site in consideration as least disturbed.

STEP 1: Evaluate the 1-km radius buffer around a site for presence of anthropogenic impact, specifically:

- Hydrologic modifications (e.g., linear features that would indicate the presence of ditches, dams, or levees);
- Forestry activities (e.g., rows of trees, tree stumps and debris, logging roads, tree regeneration);
- Agricultural development (e.g., farm structures, row crops, horticultural fields, pastures);
- Recreational development (e.g., campsites visible on aerials or indicated on the topographic maps, public docks, location in a state or national recreation area or park);
- Residential and urban development (e.g., houses, retail malls, commercial buildings, parking lots); and,
- Industrial development (oil and gas structures, mines, gravel pits, industrial facilities).

The level of impact was scored using the scale in **Table 4-1**. Examples of photo interpretation based on this scoring are illustrated in **Figure 4-4** and **Figure 4-5**.

Table 4-1. Scoring associated with the level of anthropogenic impact within the 1-km radius buffer around a site.

Score	Impact	Anthropogenic Impact
0	None	No visual evidence
1	Low	Disturbance feature is present, but only appears to impact a small (<10%) portion of the 1-km radius buffer
2	Moderate	Disturbance feature appears to impact 10-25% of the 1-km radius buffer
3	High	Disturbance feature appears to impact >25% of the 1-km radius buffer

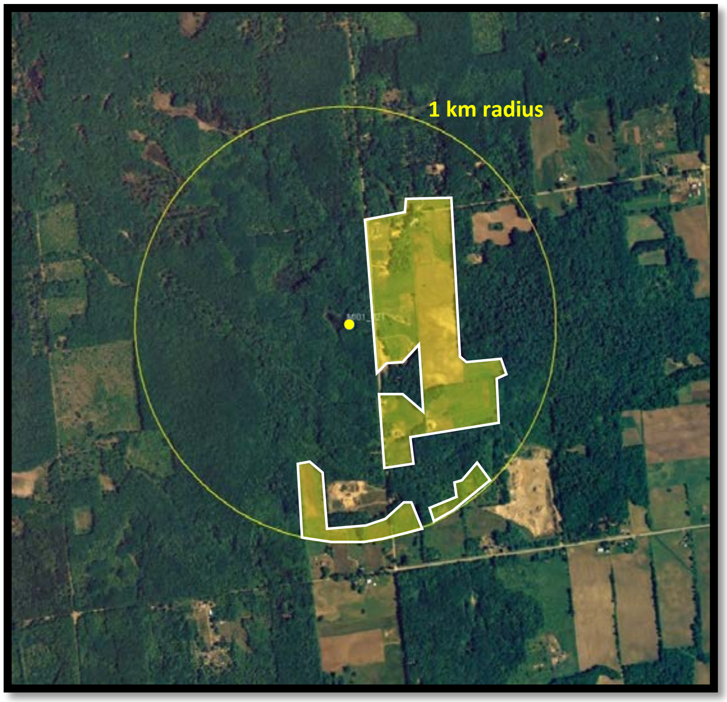

Figure 4-4. Example of photo interpretation used in Step 1. The yellow dot is the AA Center within the 1-km radius area evaluated. Agricultural development (yellow polygons) comprised >25% of the area for a score of 3.

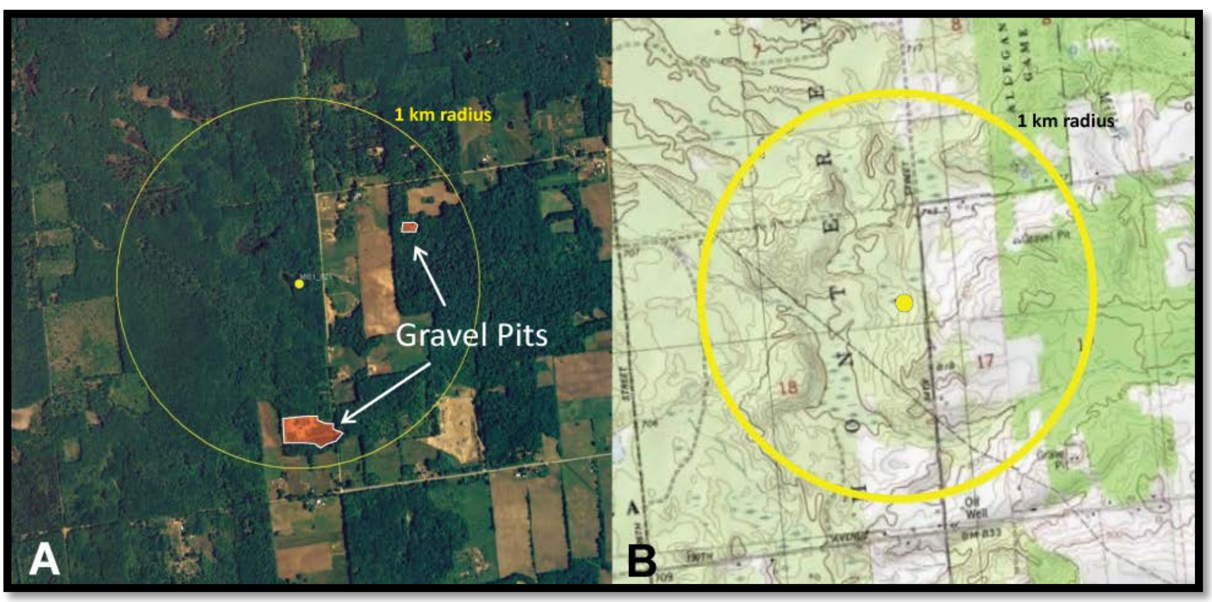

Figure 4-5. Example of photo interpretation used in Step 1. The yellow dot is the AA Center within the 1-km radius area evaluated. Industrial development (orange polygons in A) comprised <10% for a score of 1. A US Geologic Survey Topographic map (B) was used to interpret and corroborate the presence of gravel pits found in A.

STEP 2: Search for the presence/absence of roads and trails within the 1-km radius buffer. Score the level of impact using the scale in **Table 4-2**. **Figure 4-6** illustrates an example application of the scoring procedure.

Table 4-2. Scoring associated with the presence of roads and trails within the 1-km radius buffer around a site.

Score	Impact	Presence of Roads
0	None	No visual evidence
1	Low	Visual evidence of trails only
2	Moderate	Visual evidence of non-paved roads only
3	High	Visual evidence of paved roads

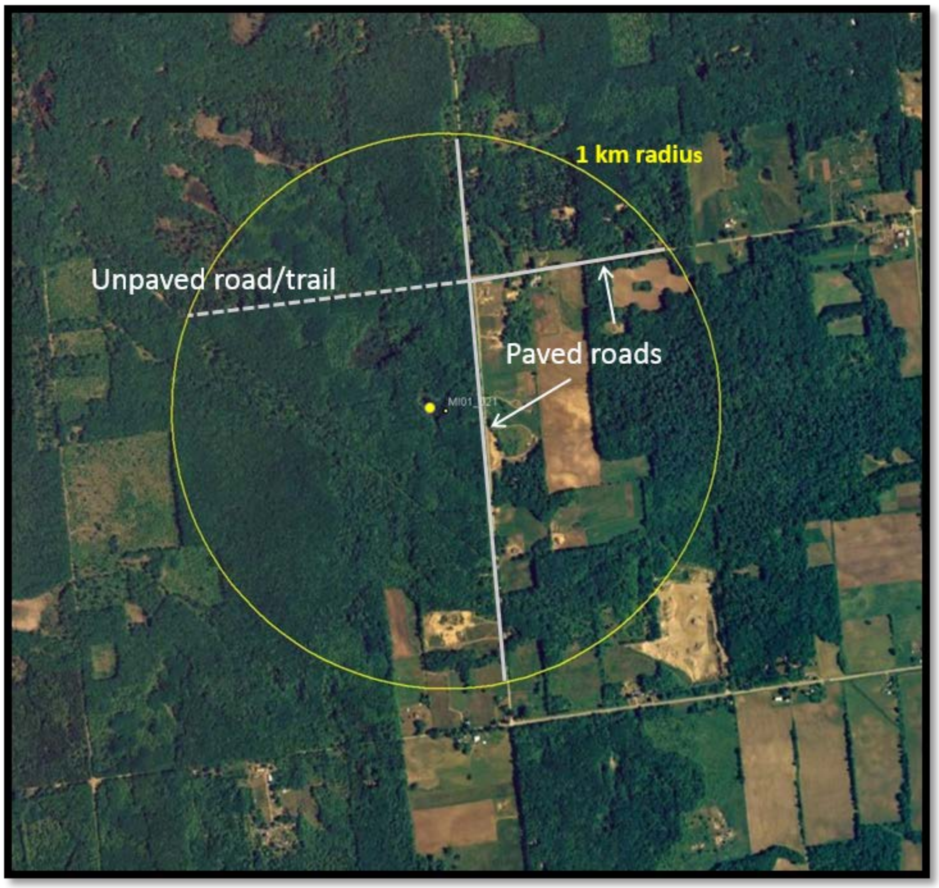

Figure 4-6. Example of photo interpretation used in Step 2. The yellow dot is the AA Center within the 1-km radius area evaluated. The site received a score of 3 due to the presence of paved roads.

STEP 3: Determine the distance from the center of the candidate AA to the following disturbances:

- Ditches or channels created by humans,
- Edge of human disturbance identified in Step 1, and
- Paved or non-paved roads and trails identified in Step 2.

Score the level of impact for each disturbance using the scale in **Table 4-3** (also see **Figure 4-7**).

Table 4-3. Scoring associated with the distance from disturbance within the 1-km radius buffer around a site.

Score	Impact	Distance to Disturbance
0	None	> 1 km
1	Low	200 m – 1 km
2	Moderate	140 m – 200 m
3	High	< 140 m

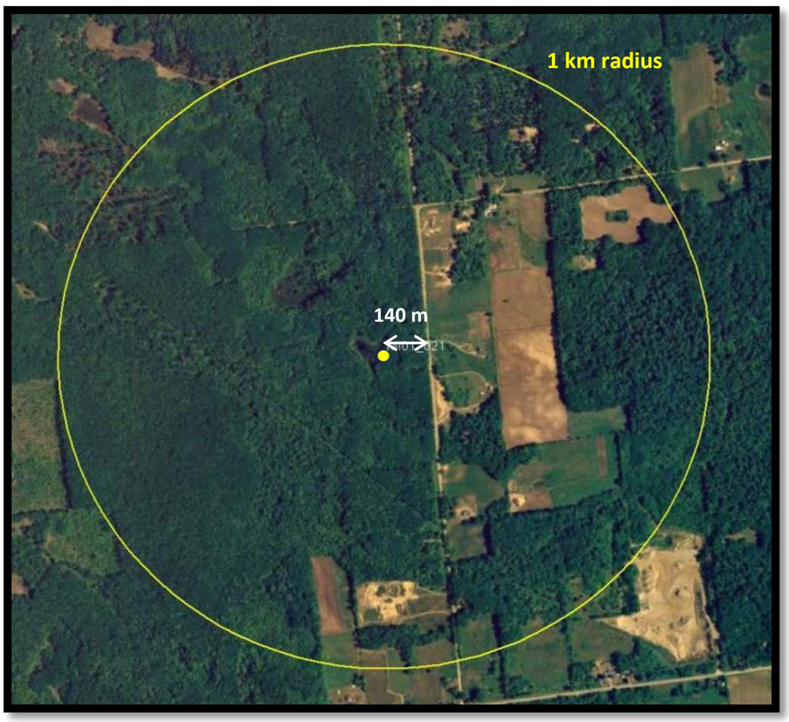

Figure 4-7. Example of photo interpretation and scoring used in Step 3. The yellow dot is the AA Center within the 1-km radius area evaluated. The nearest disturbance was the presence of the paved road 140 m from the AA Center so the site received a score of 2 for distance to the nearest road and 2 for the distance to the first edge of human disturbance.

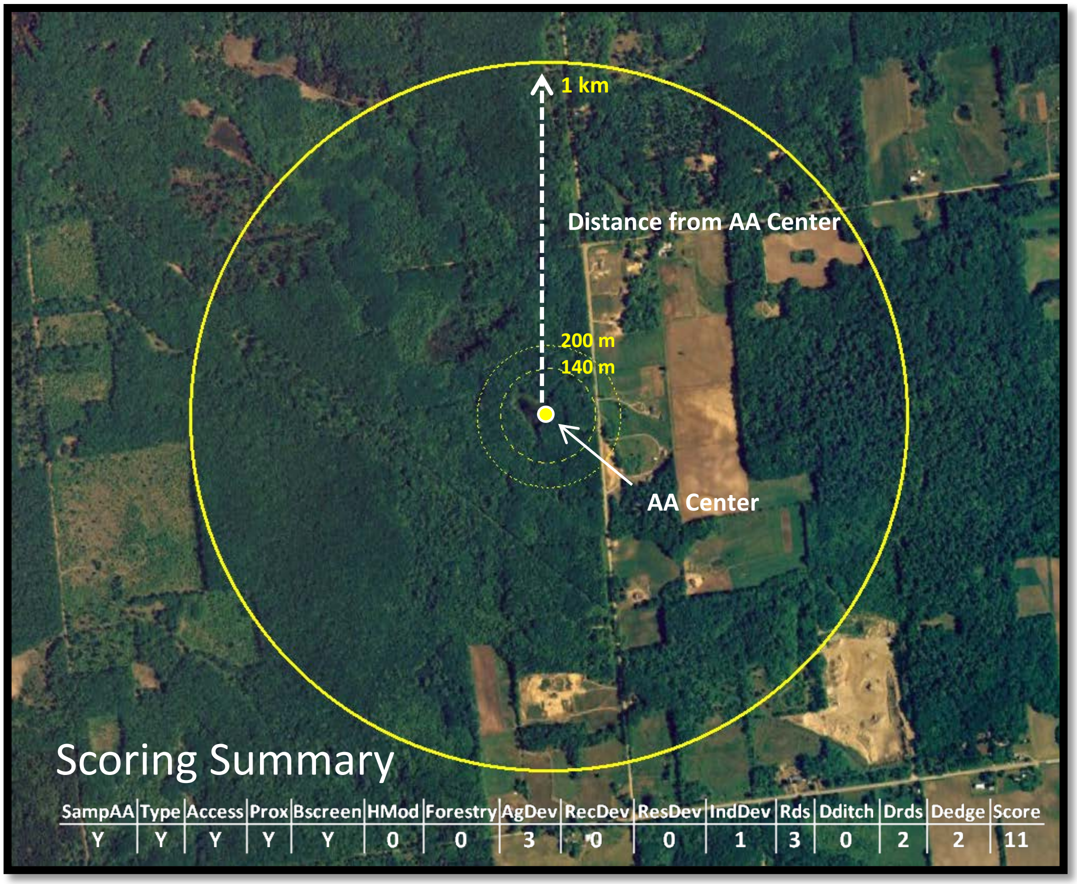

Figure 4-8. Summary of the scoring for the site in **Figure 4-3** through **Figure 4-7**. The yellow dot is the AA Center within the 1-km radius area evaluated. The area marked by the circles with a radius of 140m and 200m were assessed in Step 3. The aggregate score of all disturbances for this candidate site was 11 as indicated by the summary of the scores for each factor evaluated displayed along the bottom of the photo.

A total of the scores from Steps 1 through 3 of less than or equal to 11 was needed to keep a BPJ site on the list for further evaluation and potential sampling in 2011 (**Figure 4-8**). Thus, the example site in **Figure 4-8** would have been retained as a potential reference site.

4.2.4 *Distribution of Sites by Wetland Type and Ecoregion*

The BPJ sites passing the screening process and those not screened were evaluated to assure, to the greatest extent possible, the 150 handpicked sites selected for sampling in 2011 were distributed across the NWCA Wetland Types and the Nine Aggregated Ecoregions (Omernik 1987; USEPA 2011a) used by NARS. All non-screened sites were retained, while some BPJ sites were eliminated to get the desired number and distribution of handpicked sites (**Figure 4-2**).

4.2.5 *Replacement of Sites Not Sampleable*

At times, it was necessary to replace sites during the reconnaissance checks performed before sampling or at the time of sampling. Sites were replaced during reconnaissance due to access issues, but also because the Field Crew Leader acquired additional information that either (1) eliminated the site as a candidate for use as reference (e.g., presence of invasive species) or (2) documented there was a better, more appropriate candidate reference site. Sites were replaced at time of sampling primarily due to access issues (e.g., too difficult to get to the exact location, last minute refusals by property managers).

4.2.6 *Results*

Table 4-4 lists the final distribution of the handpicked sites by the Nine Aggregated Ecoregions used in previous NARS, and the NWCA Wetland Types (**Table 1-1**). The NWCA target population is composed of seven NWCA Wetland Types, which are a subset of wetland categories used in the USFWS Status and Trends reporting (Dahl 2006). **Figure 4-9** shows the distribution of the handpicked sites in relation to the probability sites by Nine Aggregated Ecoregions.

Table 4-4. Distribution of 150 handpicked sites sampled in 2011 by Nine Aggregated Ecoregions and NWCA Wetland Types. Acronyms for the Nine Aggregated Ecoregions (in parentheses) are used in tables and figures in this chapter. See **Table 1-1** for definitions of acronyms and description of characteristics for NWCA Wetland Types.

Nine Aggregated Ecoregions	E2EM	E2SS	PEM	PFO	PSS	PUBPAB	Pf	Total
Coastal Plain (CLP)	14	4	8	23	3	2	0	**54**
Northern Appalachians (NAP)	0	0	5	10	14	0	0	**29**
Northern Plains (NPL)	0	0	5	0	3	0	0	**8**
Southern Appalachians (SAP)	0	0	1	5	1	0	0	**7**
Southern Plains (SPL)	0	0	5	1	1	0	0	**7**
Temperate Plains (TPL)	0	0	8	3	0	3	0	**14**
Upper Midwest (UMW)	0	0	8	8	5	3	0	**24**
Western Mountains (WMT)	0	0	3	0	4	0	0	**7**
Xeric (XER)	0	0	0	0	0	0	0	**0**
Sum	**14**	**4**	**43**	**50**	**31**	**8**	**0**	**150**

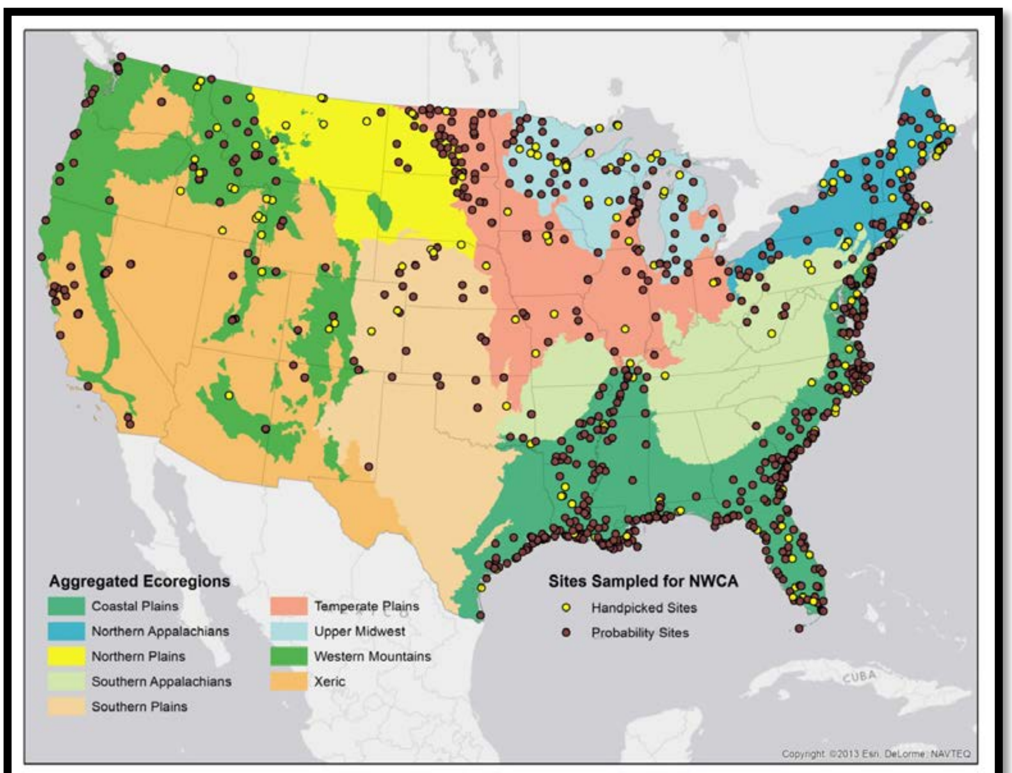

Figure 4-9. Map of the conterminous US showing distribution of handpicked sites (yellow) in relation to probability sites (dark red) sampled in the 2011 NWCA. The Nine Aggregated Ecoregions are based on combinations of Level III Ecoregions (Omernik 1987, USEPA 2011a) and are used in other NARS assessments.

4.3 Overview of the Post-Sampling Evaluation of Site Disturbance

Post-sampling site evaluation was conducted using the 2011 NWCA sample data to develop quantitative definitions of reference and disturbance. All sample sites were categorized by these definitions for use in the ecological condition analyses (see **Chapter 7**) and in determination of stressor extent (**Chapter 9**). Post-sampling site evaluation involved:

- Defining groups for reporting on ecological condition and stressor status (**Section 4.4**),
- Establishing a disturbance gradient (**Section 4.5**), and
- Defining disturbance category thresholds (**Section 4.5**).

The general approach followed the process used by Herlihy et al. (2008) for defining reporting groups and least disturbed reference sites in the National Wadeable Streams Assessment (USEPA 2006).

4.4 Reporting Groups

The conterminous United States is the broadest-scale at which the 2011 NWCA results are reported. However, the diversity in the Nation's landscape makes it important to assess aquatic resources in the appropriate geographic setting. Regional variation in species composition, environmental conditions, and human-caused disturbance often necessitates a finer scale, i.e., sub-national, to:

- Define quantitative criteria for least disturbed and most disturbed condition;
- Develop indicators for reporting on ecological condition and stressor extent; and
- Define thresholds for categories of ecological condition and disturbance.

These tasks and the need for sub-national, geographic reporting units are inherent to all NARS assessments. In some previous NARS, the Nine Aggregated Ecoregions (**Figure 4-9**) have been used as the geographic basis for reporting units in assessments.

USEPA's Environmental Monitoring and Assessment Program (EMAP) recommends as a general rule that, absent any information on the variability in the target population, 50 sites *per reporting unit* should be assessed to increase the likelihood that the sample will be sufficient to make population estimates[6]. For example, the EPA Level III Ecoregions (Omernik 1987, USEPA 2011a) of the US were aggregated for the Wadeable Streams and National Lakes Assessments (USEPA 2006, 2009) to assure an adequate number of sites per reporting unit.

The structure of the NWCA required the use of both ecoregions and wetland types to create Reporting Groups. The combination of the Nine Aggregated Ecoregions (ECO_9, see **Figure 4-9**) and the seven

[6] See www.epa.gov/nheerl/arm/surdesignfaqs.htm for information on sample size and other monitoring design issues.

NWCA Wetland Types (see **Table 1-1** for definitions) resulted in 56 potential groups for analysis. Examination of the distribution of all sampled NWCA sites across the 56 potential groups determined further aggregation was needed because most groups included fewer than 50 sampled sites and 16 groups had no sites. The next step was to use vegetation data to suggest aggregations, as vegetation is the primary NWCA indicator of ecological condition.

A series of ordinations were performed to evaluate the relationships between plant species composition, NWCA Wetland Type (see **Table 1-1** for definitions), and ECO_9. Key ordinations included 1) all sampled sites, 2) all estuarine wetland sites (E2EM – emergent, E2SS – shrub or forested), 3) all woody (PSS – shrub or PFO forested) palustrine or shallow riverine or lacustrine wetland sites, and 4) all herbaceous (PEM – emergent, PUBPAB – open-water ponds and aquatic bed, Pf – farmed wetlands not in current crop production) palustrine or shallow riverine or lacustrine wetland sites. Ordinations were based on site-level species composition and abundance for all observed taxa and results were plotted with wetland type or ECO_9 overlain as symbol types. Ordinations for subsets of sites by wetland type groups were conducted using Nonmetric Multidimensional Scaling (NMS) (R Statistical Software, version 3.1.1, 'Vegan: metaMDS', R Core Team 2014). The dataset for all sampled sites was so large and complex that it was difficult to obtain a stable solution using NMS, thus, when all sites were evaluated, Detrended Correspondence Analysis (DCA) was used for the ordinations (PC-ORD, Version 6.20, McCune and Mefford 2011).

The ordinations resulted in similar, intergrading groups, which, when viewed together, suggested an interaction between NWCA Wetland Type and ECO_9. An example overview of these patterns is provided by DCA ordinations with overlays of symbols for ECO_9 and the NWCA Wetland Types in **Figure 4-10**. Next, ordinations were performed to evaluate whether there were advantages to using a regionalization created for wetlands. Specifically, the US Army Corps of Engineers regions associated with the national wetland plant list (Lichvar et al. 2012) were compared with ECO_9. The boundaries of regions for both geographic groups and the analysis results were very similar, so the ECO_9 were chosen for NWCA reporting to maintain consistency with the other NARS assessments.

The vegetation patterns from the ordination analyses, along with sample sizes within each of the 56 potential groups were used to inform aggregation of:

- The ECO_9 into four NWCA Aggregated Ecoregions (**Figure 4-11**), and
- The seven NWCA Wetland Types into four NWCA Aggregated Wetland Types (**Table 4-5**).

Indicator species analyses (R Statistical Software, version 3.1.1, 'indicspecies, version 1.7.4' using multi-level pattern analysis, R Core Team 2014) were conducted for various combinations of the four NWCA Aggregated Ecoregions and the four NWCA Aggregated Wetland Types to identify native and nonnative species that uniquely indicated particular regions and wetland types or that overlapped between specific groupings. Detailed presentation of the ordination and classification results for the 2011 NWCA data is beyond the scope of this report; however, the results were used, along with sample size limitations, to develop 10 Reporting Groups for the NWCA based on the combination of the four NWCA Aggregated Ecoregions and the four NWCA Aggregated Target Wetland Types (**Table 4-5**). These aggregations produced adequate sample sizes to allow reference site selection and analyses supporting indicator development within each Reporting Group.

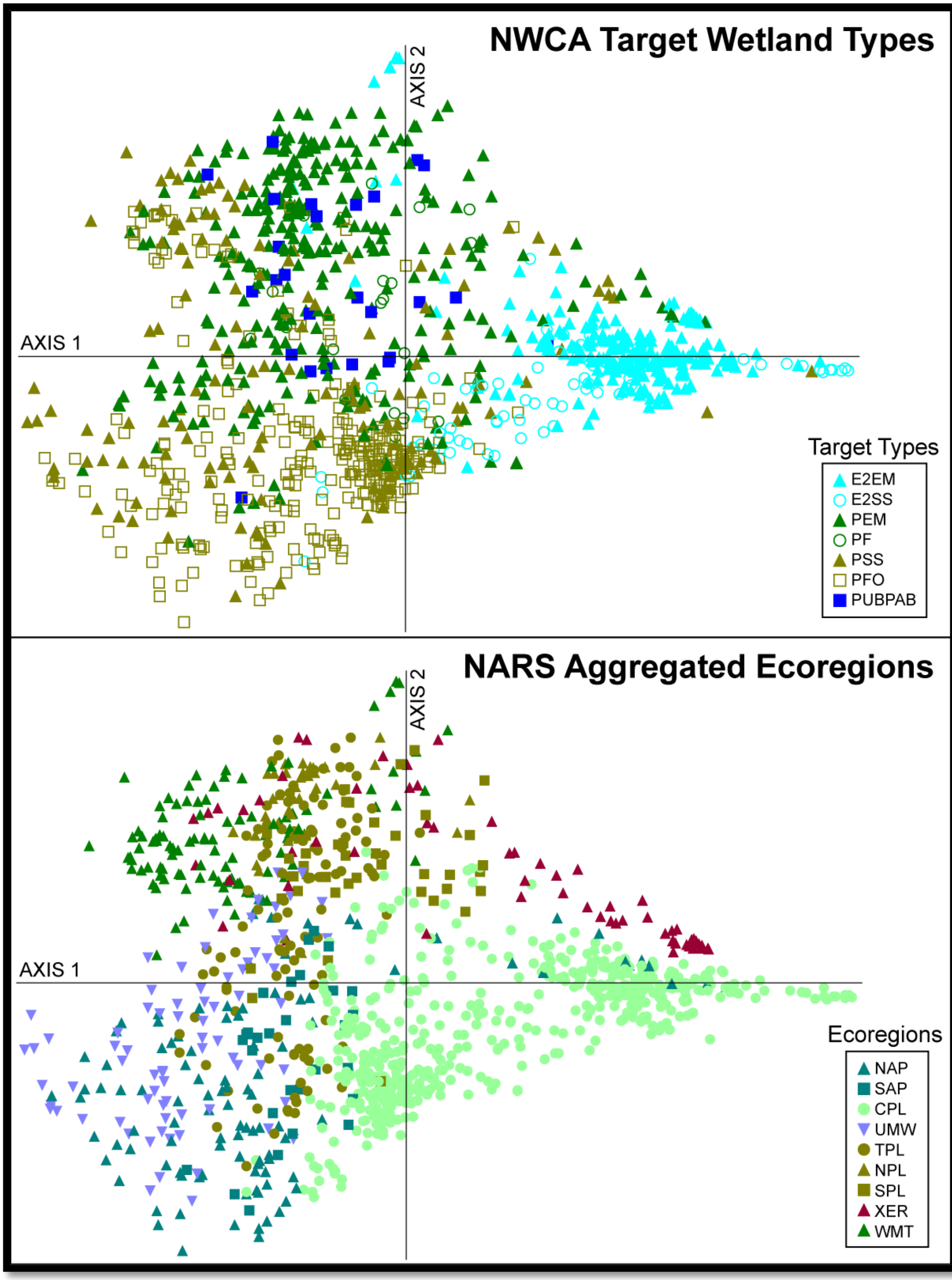

Figure 4-10. Ordinations of species composition relative to the seven NWCA Wetland Types and the Nine Aggregated Ecoregions (ECO_9) resulted in similar, intergrading groups. For definitions of acronyms in the keys to the figures, see **Table 4-4** and **Figure 4-9** (ECO_9) and **Table 1-1** (NWCA Wetland Types).

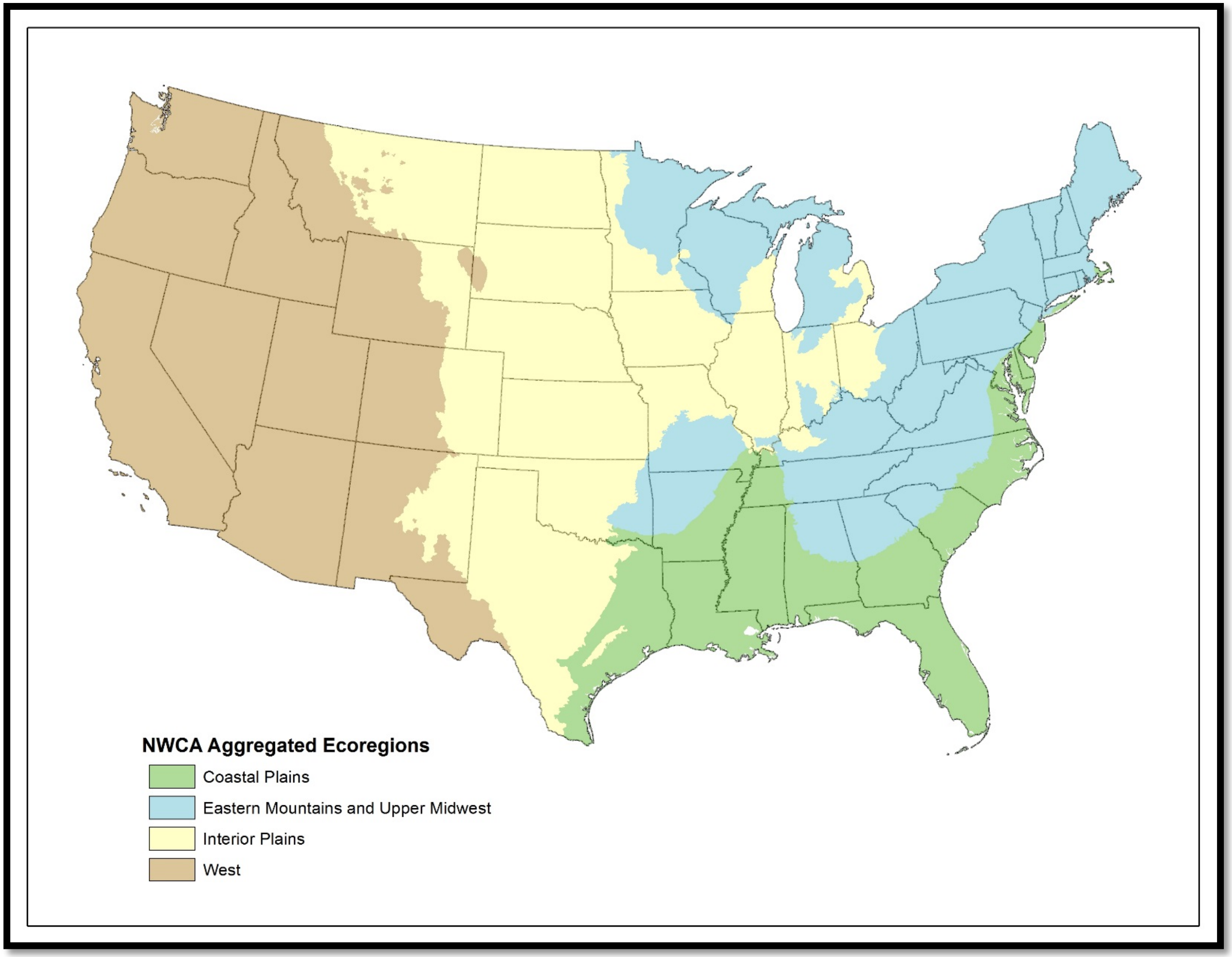

Figure 4-11. The four NWCA Aggregated Ecoregions that are based on combinations of Omernik's Level III Ecoregions (Omernik 1987; USEPA 2011a).

Table 4-5. Matrix showing the four NWCA Aggregated Ecoregions (**Figure 4-11**) and the four NWCA Aggregated Wetland Types combined into 10 NWCA Reporting Groups. Note that estuarine wetland types are not reported by ecoregions due to insufficient samples. Acronyms for the NWCA Aggregated Ecoregions, NWCA Aggregated Wetland Types, and the 10 Reporting Groups are in parentheses following their names. Red text gives the number of sites sampled, i.e., the sum of the number of sites NWCA probability designs (i.e., the national assessment and some state intensifications) and from not-probability designs (i.e., the handpicked sites and some state intensifications).

NWCA Aggregated Ecoregions ↓ / **NWCA Aggregated Wetland Types** →	**Palustrine, Riverine, and Lacustrine Herbaceous (PRLH)** *Aggregates PEM, PF, PUBPAB*	**Palustrine, Riverine, and Lacustrine Woody (PRLW)** *Aggregates PFO, PSS*	**Estuarine Herbaceous (EH)** *Includes E2EM*	**Estuarine Woody (EW)** *Includes E2SS*
Coastal Plains (CPL) *Same as Coastal Plains (CPL) in Nine Aggregated Ecoregions; includes Eastern and Gulf Coastal Plains*	1. Coastal Plains Herbaceous (CPL-PRLH) *72 Sites Sampled*	2. Coastal Plains Woody (CPL-PRLW) *189 Sites Sampled*	9. Estuarine Herbaceous (ALL-EH) *272 Sites Sampled*	10. Estuarine Woody (ALL-EW) *73 Sites Sampled*
Eastern Mountains & Upper Midwest (EMU) *Aggregates Northern Appalachains (NAP), Southern Appalachains and Piedmont (SAP), and Upper Midwest (UMV)*	3. Eastern Mountains & Upper Midwest Herbaceous (EMU-PRLH) *73 Sites Sampled*	4. Eastern Mountains & Upper Midwest Woody (EMU-PRLW) *127 Sites Sampled*		
Interior Plains (IPL) *Aggregates Temperate Plains (TPL), Northern Plains (NPL), and Southern Plains (SPL)*	5. Interior Plains Herbaceous (IPL-PRLH) *138 Sites Sampled*	6. Interior Plains Woody (IPL-PRLW) *52 Sites Sampled*		
West (W) *Aggregates Western Mountains (WMT), and Xeric (XER)*	7. West Herbaceous (W-PRLH) *67 Sites Sampled*	8. West Woody (W-PRLW) *75 Sites Sampled*		

Note: The Estuarine reporting group encompasses estuarine wetlands in all ecoregions (hence, the prefix "ALL"). However, estuarine wetlands only occur in CPL, EMU, and W ecoregions. There are no estuarine wetlands in IPL.

4.5 Selecting Reference Sites and Defining the Disturbance Gradient

Data from least disturbed reference sites are needed to set thresholds and to anchor the disturbance gradient. A disturbance gradient is needed in the development of condition (**Chapter 7**) and stressor indicators (**Chapter 8**) to evaluate how well metrics and versions of a particular index, e.g., a multi-metric index (MMI), distinguish between least and most disturbed sites.

Data from the first sampling visit for NWCA probability and not-probability sites were used in a screening process to establish a disturbance gradient. The probability sites were either from the national assessment or a related probability design produced by NARS for a state intensification. The not-probability sites were handpicked sites (see **Section 4.2**) or from a state intensification that did not have a probability design produced by NARS but used the same target population, protocols, data forms, and index period as the 2011 NWCA (USEPA 2011b).

4.5.1 *Overview of Approach*

The steps in the process of establishing a disturbance gradient are:

- Develop indices or metrics for each category of disturbance data, as needed,
- Set thresholds for least and most disturbed for each disturbance index or metric, and
- Establish the ends of the gradient.

Data collected in the field and laboratory were evaluated for use in screening sites to establish the disturbance gradient. Screens were chosen based on evidence of a strong association with anthropogenic stress and on the robustness of the data. Four categories of disturbance were used as screens:

- Disturbance in the Buffer and AA (six indices developed),
- Hydrologic alteration in the AA (two indices developed),
- Soil chemistry in the AA (one index developed), and
- Relative cover of alien plant species in the AA (one metric developed).

Although water chemistry was part of the NWCA field protocol, only 56% of the wetlands sampled had sufficient surface water to collect and analyze. For this reason, and because wetland hydroperiod– especially during the growing season when NWCA sampling occurred – can greatly influence water chemistry (e.g., nutrients can become highly concentrated during drawdowns), water chemistry was excluded from the generation of the disturbance gradient. However, water chemistry was retained as a research indicator and specific results are discussed in **Chapter 11** of this report.

Finally, while we were able to gather landscape data (e.g., land use within a 1-km buffer of the AA) using GIS layers, we opted not to use these data to screen sites. This was for two reasons: 1) the GIS layers are less precise than the data we were able to gather in the field, and 2) it is possible that wetlands in good condition exist in what is considered an “impacted” landscape. Therefore, we used only information directly measured by Field Crews on the ground to establish the disturbance gradient.

4.5.2 *Indices of Disturbance Buffer and AA*

Development of indices of disturbance in the Buffer and AA was based on data collected from 13 10mX10m plots (12 in the buffer; 1 in the center of the AA). Data were recorded on Form B-1 within 100m from the edge of the AA using the Buffer Protocol (USEPA 2011b).

Database files (hereafter Buffer database) derived from scanned data forms were cross checked with approximately 200 of the original forms to ensure data integrity. No errors were identified in this subsample of the translation from paper to electronic data.

The Buffer database was used to develop metrics and indices to describe disturbance. R Statistical Software, version 3.1.1 (R Core Team 2014) was used to develop program code and make calculations for these metrics and indices. The metrics were reviewed using a number of screens including range tests (e.g., within acceptable ranges for the data being entered), normality, and skew. Additional checks were conducted to see if the data fit expectations based on other NARS assessments and the degree of disturbance by location. For a limited number of sites, buffer and AA metrics were hand-calculated to determine concurrence with computer calculations made using R code.

Whenever large quantities of data are collected, it is not surprising for some errors related to data or sample collection, recording, sample analysis, or data entry to occasionally occur. Therefore, the NWCA established a number of cross-checks in the data collection and processing procedures within the protocols and field forms, to allow identification and resolution of potential errors. Once the data were entered, quality assurance review was critical to identifying and resolving any errors to ensure high quality data.

Initially, the disturbance information hand-written by the Field Crews in the “Other” category on the data form was not included in the analysis. Upon examination it was noted the entries comprised a diverse set of anthropogenic and natural disturbance with many single occurrences survey-wide that did not fit neatly into the categories listed on Form B-1. In an effort to include all data collected by the Crews, these data were reclassified to fit into the most appropriate disturbance metric so all data collected in the field were included in the disturbance indices and site disturbance classification.

Results from the stressor tallies were proximity-weighted by plot (**Figure 4-12:** Kaufmann et al. 2014). The score for the five disturbance indices was calculated as the proximity-weighted sum of the average number of observations per plot. The score for the summary index (i.e., B1H_ALL) was the sum of the scores of the other five indices (**Table 4-6**).

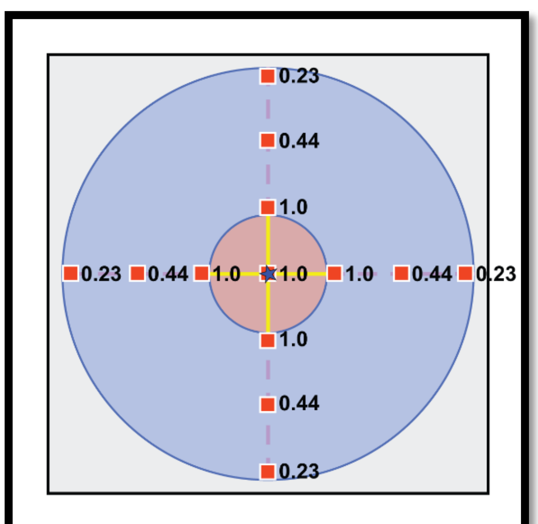

Figure 4-12. Proximity weights assigned to the 13 plots evaluated as part of the Buffer Protocol.

Table 4-6. Six disturbance indices generated from the Buffer Protocol data.

Index Code	Stressor	Disturbance Index with Buffer Variables Used
B1H_AGR	Agriculture Stressors	Σ[Pasture/Hay, Range, Row crops, Fallow field, Nursery, Dairy, Orchard, CAFO, Rural residential, Gravel pit, Irrigation]
B1H_RESURB	Residential and Urban Stressors	Σ[Road (gravel, two lane, four lane), Parking lot/Pavement, Golf course, Lawn/Park, Suburban Residential, Urban/Multifamily, Landfill, Dumping, Trash]
B1H_IND	Industrial Stressors	Σ[Oil drilling, Gas well, Mine (surface, underground), Military)]
B1H_HYD	Hydrologic Modifications	Σ[Ditches/Channelization, Dike/Dam/Road/Railroad Bed, Water level control structure, Excavation, Fill, Fresh sediment, Soil loss/Root exposure, Wall/Riprap, Inlets, Outlets, Pipes (effluent/stormwater), Impervious surface input (sheetflow)]
B1H_HAB	Habitat Modifications	Σ[Forest clear cut & Selective cut, Tree plantation, Canopy herbivory, Shrub layer browsed, Highly grazed grasses, Recently burned forest, Recently burned grassland, Herbicide use, Mowing/ Shrub cutting, Trails, Soil compaction, Off road vehicle damage, Soil erosion]
B1H_ALL	**Summary**	**Σ[B1H_AGR, B1H_RESURB, B1H_IND, B1H_HYD, B1H_HAB]**

4.5.3 *Indices of Hydrologic Disturbance in the AA*

The data used for the development of indices of hydrologic disturbance were collected from the entire AA and recorded on Form H-1 using the Hydrology Protocol (USEPA 2011b).

As with the Buffer database, a portion of the Hydrology database was cross checked with field forms to determine if scanning software correctly noted bubbles marked on the form. No scanning errors were found. Metrics derived from the raw data were checked for appropriate range, and metrics were hand calculated to confirm the R computer code was correctly calculating metric and index scores. As with the buffer data, validated data sets were developed and converted to a matrix format from the files used in data storage. This was done so subsequent recalculation of the metrics and indices would correspond to the verified calculations regardless of database software and statistical package used. When no stressor was identified as present in a plot at a site, zeros were entered into the matrix file, as appropriate.

Two indices were developed based on the best professional judgment of the analysts as to the relative impact of the types of hydrologic alterations documented by Field Crews. The score for each of the indices was calculated by summing the number of hydrologic stressors observed at each AA (**Table 4-7**).

Table 4-7. Two indices generated from the Hydrology Protocol data.

Index Code	Stressor	Disturbance Index with Hydrology Variables Used
HDIS_HIGH	High Impact Hydrologic Disturbances	Σ[Damming features (dikes, berms, dams, railroad bed, roads), Impervious surfaces (road, concrete, asphalt), Pumps, Pipes, Culverts, Ditches, Excavation, Field tiling]
HDIS_MED	Moderate Impact Hydrologic Disturbances	Σ[Shallow channels (animal trampling, vehicle ruts), Recent sedimentation]

4.5.4 *Index of Disturbance Indicated by Soil Chemistry*

There were three steps in developing an index of disturbance based on soil chemistry. First, the soil data were evaluated to determine the best samples collected at each site to use for the evaluation of soil chemistry. Next, we examined which soil chemistry parameters might effectively reflect anthropogenic stress. Once these two determinations were made, an index was developed.

The index reflecting disturbance indicated by soil chemistry was developed based on data collected from one of four soil pits dug at each site and chosen by the Field Crew to represent the entire AA according to the Soils Protocol in the *NWCA Field Operations Manual* (USEPA 2011b). Soil samples were shipped to the Kellogg Soil Survey Laboratory for analysis following the procedures in the *NWCA Laboratory Operations Manual* (USEPA 2011c). The Kellogg Laboratory is located in Lincoln, Nebraska, and is part of the Natural Resources Conservation Service (NRCS) of the US Department of Agriculture.

Soil chemistry data returned from NRCS were merged with soil profile data collected by Field Crews from the representative pit (i.e., the only pit from which soil was analyzed for chemistry). The soil chemistry database, consisting of soil layers from the representative pits and associated soil chemistry for sites sampled, was thoroughly inspected for quality assurance. Using both manual screening and customized R code, potential data errors were identified. Whenever large quantities of data are collected, it is not surprising for some errors related to data or sample collection, recording, sample analysis, or data entry to occasionally occur. Therefore, the NWCA established a number of cross-checks in the data collection and processing procedures within the protocols and field forms, to allow identification and resolution of potential errors. Once the data were entered, quality assurance review was critical to identifying and resolving any errors potentially impacting data quality.

For the soils data, errors were primarily associated with two variables, Depth (recorded on the Soil Profile form) and Bulk Density (collected in the field and measured by NRCS), and included the following:

- Final Pit Depth was shallower than called for in the protocol (often because of field conditions that prohibited digging or sampling beyond a certain depth);

- Depth (i.e., layer depth) was not reported;

- Depth for all layers of the representative pit was recorded incorrectly;

- Value recorded for Depth failed logic checks;

- Errors occurred in scanning data from the field forms into an electronic format;

- All soil chemistry data was missing for a described layer, presumably because a soil sample could not be collected;

- Bulk Density value was inconsistent with the layer position (i.e., the bulk density was much lighter or heavier than surrounding layers);

- Bulk Density was outside the valid range of 0.06-2.53 g/cc; and

- Core volume for bulk density collection recorded in the field failed logic checks.

Errors that could be resolved by inspecting the original field data forms were corrected in an annotated soil chemistry database, with detailed notes of how the error was corrected. If the error could not be resolved, the associated data were removed from the database (resulting in an “NA” in place of the value) or flagged if the datum was suspect but could not be identified as being absolutely incorrect.

NRCS performed internal quality assurance on soil chemistry data. Some soil chemistry data returned by NRCS was flagged if it was below the practical quantitation limit (PQL) or minimum detection limit (MDL) of the equipment using to analyze the samples. Aside from identifying which samples were below limits, the flags also specified the limits for each analyte. Values below the MDL were changed to half the specified MDL in the soil chemistry database.
To develop an index of disturbance based on soil chemistry, the data were evaluated to determine the best of the numerous soil samples and the related chemistry to use.

Soil chemistry data were generated for each soil layer greater than 8 cm in thickness at the representative soil pit. Deciding on which soil layer(s) to use proved to be difficult because:

- The number of soil layers at each site differed (ranging from 1 to 9 layers).

- Soil layers varied in thickness (ranging from 1 to 170 cm).

- Nearly one-quarter of the described soil layers (948 of 4444) were less than 8 cm thick and, therefore, not sampled for soil chemistry as directed in the NWCA Soils Protocol (USEPA 2011b).

- The first layer, containing the most biologically active soil and most indicative of recent human impacts, was not sampled at nearly one-third of the sites for soil chemistry because Layer 1 was less than 8 cm thick (347 of 1082 sites). Even though the NWCA Soils Protocol (USEPA 2011b) directed crews to combine Layer 1 and Layer 2 when Layer 1 was less than 8 cm thick, this was not done for every site.

- The soil at 60 wetland sites was not sampled due to site constraints (e.g., deep water, unconsolidated soils, and shallow bedrock).

Based on the Soils Protocol in the *NWCA Field Operations Manual*, Field Crews were instructed to collect soil samples from boundary to boundary of the horizon of each layer regardless of layer thickness (**Figure 4-13**). Examination of the data showed that every site with soils data had at least one layer with soil chemistry measured within 50 cm of the surface. Because the upper part of the soil is the most biologically active and most indicative of human impacts in and around the AA, soil chemistry collected from the uppermost layer within 10 cm of the soil surface was used. By making the decision to use data associated with the uppermost layer, 97% of the sites sampled in the 2011 NWCA and soils most likely to reflect anthropogenic stressors are represented in the data used in the analysis.

Next, we considered the types of soil chemistry parameters to use. Parameters with natural concentrations spanning wide ranges that would overlap with anthropogenic signals were dropped from further consideration, (e.g., nitrogen, phosphorus, and sulfur species) for describing the disturbance gradient. While we expected bulk density to reflect anthropogenic impacts, problems in collecting and analyzing the samples resulted in an incomplete database that precluded its use in reference screening. Heavy metal concentrations were the best candidates for use because many have specific background ranges, above which anthropogenic impacts are indicated. The signal to noise ratio was examined for each candidate heavy metal measured at the same site during Visit 1 and Visit 2 (Kaufmann et al. 1999; Stoddard et al. 2008). Metals with high signal to noise ratios remained candidates for use in reference determination. Ultimately, 12 metals were chosen to develop a heavy metal index. These heavy metals, their primary anthropogenic associations, and their signal to noise ratios are reported in **Table 4-8**.

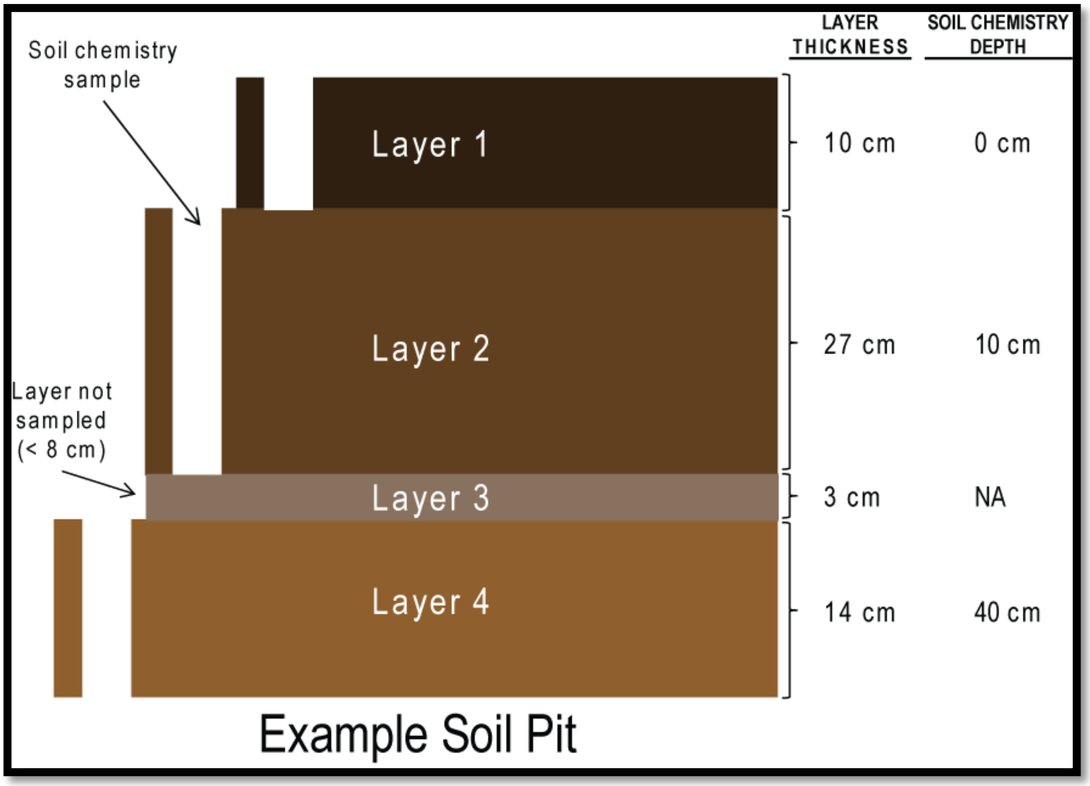

Figure 4-13. Example soil pit designating where soil chemistry samples were collected within the layer.

Table 4-8. Summary of the characteristics of the heavy metals considered for use in the stressor index based on soil chemistry. Natural backgrounds are based on Alloway (2013). Percent of sites exceeding the thresholds is based on data from Visit 1.

Metal	Primary Anthropogenic Associations	Signal:Noise	Natural Background (mg/kg)	Screening Threshold (mg/kg)	% Sites Exceeding Threshold
Silver (Ag)	Industry	9.66	0.05 – 1.00	1.0	0.7
Cadmium (Cd)	Agriculture	16.5	0.1 – 1.0	1.0	5.1
Cobalt (Co)	Industry	4.70	< 50	25	1.1
Chromium (Cr)	Industry	4.76	0.5 – 250	125	0.5
Copper (Cu)	Agriculture / Industry / Roads	13.8	2 – 50	50	5.5
Nickel (Ni)	Industry / Agriculture	6.15	0.2 – 450	225	0.1
Lead (Pb)	Roads / Industry	10.5	Mean of 18	35	17.0
Antimony (Sb)	Industry	7.93	0.1 – 1.9	1.0	4.0
Tin (Sn)	Industry / Agriculture	13.3	1.7 – 50	17	0.3
Vanadium (V)	Industry / Roads	9.09	36 – 150	150	0.2
Tungsten (W)	Industry / Agriculture	231	< 2	2.0	1.5
Zinc (Zn)	Industry / Agriculture	1.38	10 – 150	150	6.6

The heavy metal index was created and scored as the sum of the number of metals present at any given site with concentrations above a set threshold based on published values. To set the threshold for a metal, natural background concentrations (ranges or means) in terrestrial soils in, or as close to the US as possible, were determined, primarily from Alloway (2013) (**Table 4-8**) and compared to distributions in the data (**Figure 4-14**). This resulted in establishment of the following thresholds of human disturbance for NWCA:

- Ag, Cd, Cu, V, W, Zn: used the maximum of the natural range concentration;
- Co, Cr, Ni, Sb: halved the maximum of the natural range concentration;
- Pb: Doubled the mean natural concentration; and
- Sn: Used 10x the minimum of the natural range concentration.

It is important to note that the thresholds established for heavy metals do not reflect toxicity thresholds. These thresholds are indicators of human disturbance. The screening threshold established for each heavy metal is reported in **Table 4-8**. Most metal concentrations seldom exceeded the set thresholds in the NWCA sites (**Figure 4-14**).

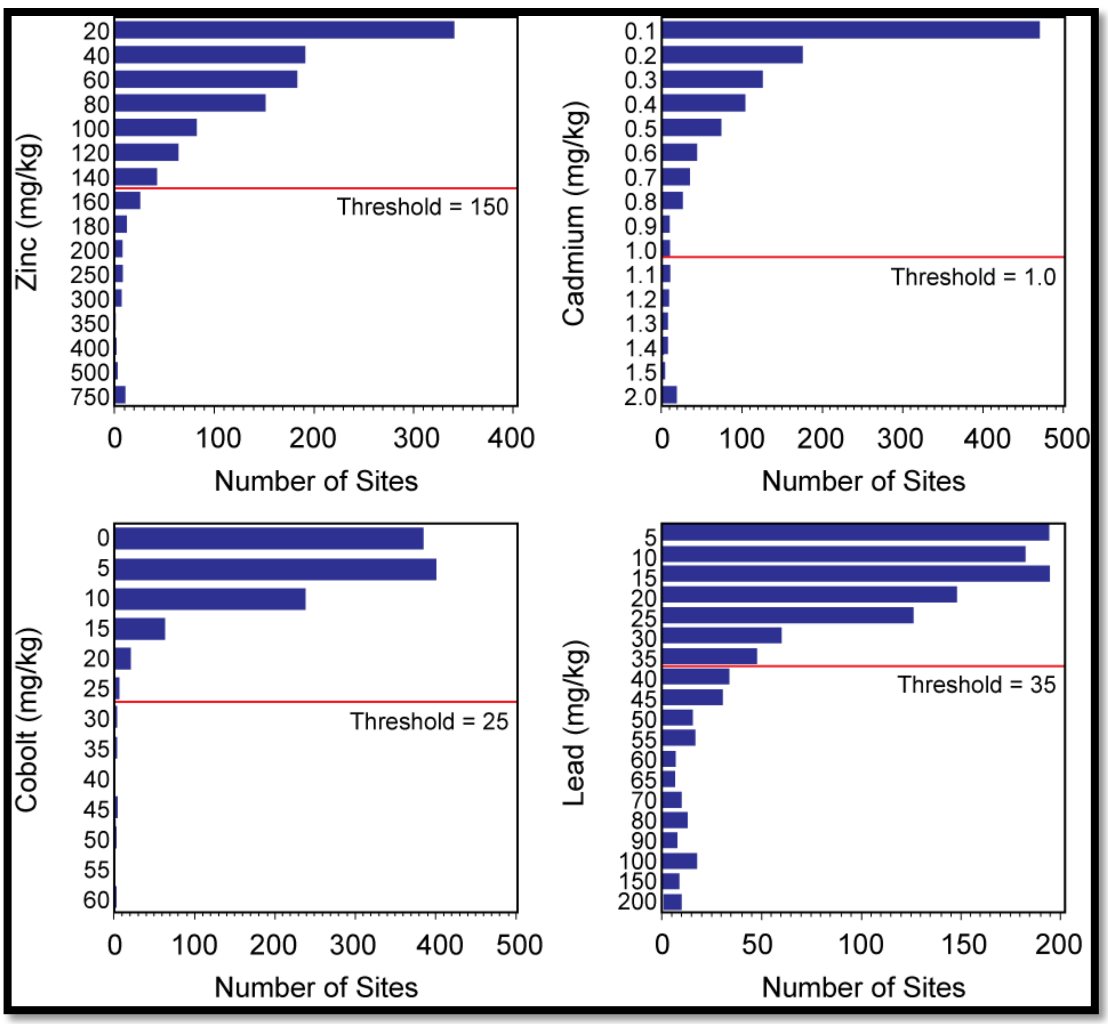

Figure 4-14. Examples of frequency histograms of soil metal concentrations used to set thresholds (designated by the red line and detailed in **Table 4-8**). Published values are primarily from Alloway (2013), and natural breaks in the data were considered.

4.5.5 *Metric of Plant Disturbance in the AA*

Alien plant species are recognized as important descriptors of disturbance and stress to wetlands (Mack and Kentula 2010; Magee et al. 2010). First, the presence and abundance of alien plant species are often positively related to human mediated disturbance (Lozon and MacIsaac 1997; Magee et al. 1999; Mack et al. 2000; Magee et al. 2008; Ringold et al. 2008), making them useful disturbance indicators. In addition, alien plant species can act as direct stressors to ecological condition by competing with or displacing native plant species or communities, or by altering ecosystem structure and processes (Sala et al. 1996; Lesica 1997; Vitousek et al. 1997; Ehrenfeld 2003; Dukes and Mooney 2004; Magee et al. 2010).

Consequently, we used a simple metric describing relative cover of alien plant species as one of the screens for determining the relative position of NWCA sites along a disturbance gradient, and to inform the determination of least and most disturbed conditions for the NWCA. Data describing the abundance (percent cover) of all vascular species were collected in five 100-m^2 vegetation plots systematically distributed within each NWCA Assessment Area according to the Vegetation Protocol (USEPA 2011b). Data collection methods are summarized in **Chapter 5, Section 5.3**. Mean relative cover of alien species is defined as a percentage of the total cover of all species observed in the five 100-m^2 vegetation plots sampled in the AA. The specific calculation method for this metric can be found in **Chapter 6, Section 6.8** (**Appendix D**) by referencing the metric name (XRCOV_ALIENSPP).

For the NWCA, alien plant species are defined as species that are either introduced to the conterminous United States or are adventive to the location of occurrence. Adventive species are native to some parts of the conterminous US, but introduced to the location of the particular NWCA site on which they were observed. Concepts describing native status categories and the procedures for determining native status for individual species are described in detail in **Chapter 5, Section 5.8**.

4.5.6 *Assignment of Sites along a Disturbance Gradient*

Sites were screened using threshold criteria for the nine disturbance indices and plant disturbance metric to assign each site to a place along a gradient of three categories of disturbance – least, intermediate, and most (**Figure 4-15**). Two types of NWCA sites were used in the screening: probability and not-probability (**Table 4-9**). The combination of both types of sites resulted in 1,138 sites being screened for level of disturbance.

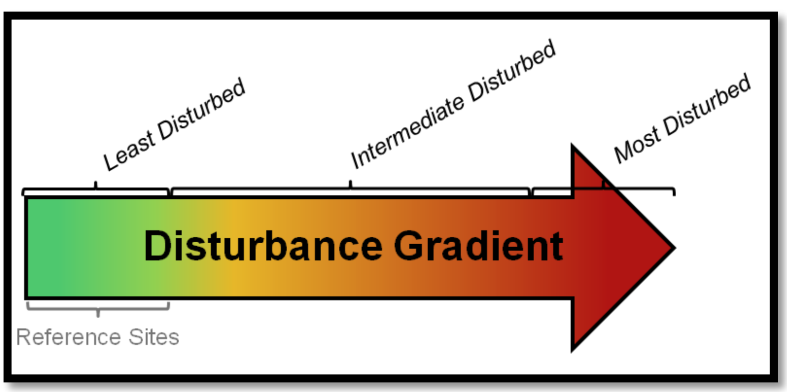

Figure 4-15. Diagram of the disturbance gradient used in the NWCA with categories of disturbance. Least disturbed according to the definition of a reference site used in the NWCA and NARS (Stoddard et al. 2006).

Table 4-9. The types and numbers of sites sampled from probability and not-probability survey designs used in the establishment of the NWCA disturbance gradient.

NWCA PROBABILITY	NWCA NOT-PROBABILITY
876 sites – NWCA probability design	150 sites – Handpicked
91 sites – State intensifications	21 sites – Intensifications
TOTAL = 967	**TOTAL = 171**

A filtering process was used to define least disturbed reference sites (Herlihy et al. 2008). Nine indices and a plant metric were generated from the NWCA data that captured a wide variety of wetland disturbances (**Table 4-10** and **Table 4-11**). For each of these ten measures of disturbance, a least disturbed threshold was set and every site screened to test for exceedance. If any single disturbance threshold was exceeded at a site, it was not considered a least disturbed reference site. Thus, the least disturbed reference sites were those that were below the thresholds for all ten measures.

Table 4-10. Threshold values for sites to be categorized as least disturbed by Reporting Group for the Buffer Indices. If any single threshold was exceeded at a site, the site was ***not*** considered least disturbed. Numbers in red are thresholds relaxed to achieve about 20% of the sites in the Group as least disturbed. An index score of 0 indicates disturbance not present. See **Table 4-5** for definitions of Reporting Group acronyms.

Reporting Group	B1H_AGR (Agriculture)	B1H_RESURB (Residential/ Urban)	B1H_HYD (Hydrology)	B1H_IND (Industry)	B1H_HAB (Habitat)	B1H_ALL (Summary)
ALL-EW	>0	>0	>0	>0	>0	**>0**
ALL-EH	>0	>0	>0	>0	>0	**>0**
EMU-PRLW	>0	>0	>0	>0	>0	**>0**
EMU-PRLH	>0	**>0.1**	>0	>0	**>0.1**	**>0.1**
CPL-PRLW	>0	>0	>0	>0	>0	**>0**
CPL-PRLH	>0	>0	>0	>0	**>0.2**	**>0.2**
IPL-PRLW	**>0.1**	**>0.1**	**>0.1**	>0	**>0.2**	**>0.2**
IPL-PRLH	**>0.15**	**>0.15**	**>0.15**	>0	**>0.15**	**>0.3**
W-PRLW	**>0.1**	**>0.1**	**>0.1**	>0	**>0.1**	**>0.1**
W-PRLH	**>0.6**	**>0.6**	**>0.6**	>0	**>1.0**	**>1.2**

Table 4-11. Threshold values for sites to be categorized as least disturbed by Reporting Group for the Hydrology and Soil Chemistry Indices, and the relative cover of alien plant species metric. If any single threshold was exceeded at a site, the site was ***not*** considered least disturbed. Numbers in red are thresholds relaxed to achieve about 20% of the sites in the Group as least disturbed. A Hydrology or Soil Chemistry Index score of 0 indicates disturbance not present. See **Table 4-5** for definitions of Reporting Group acronyms.

Reporting Group	Hydrology High Impact	Hydrology Moderate Impact	Soil Chemistry Heavy Metal Index	Relative Cover of Alien Plant Species
ALL-EW	>0	>0	>0	>5%
ALL-EH	>0	>0	>0	>5%
EMU-PRLW	>0	>0	>0	>5%
EMU-PRLH	>0	>0	**>1**	>5%
CPL-PRLW	>0	>0	>0	>5%
CPL-PRLH	>0	**>1**	>0	>5%
IPL-PRLW	>0	**>1**	**>2**	>5%
IPL-PRLH	**>1**	**>1**	**>2**	**>20%**
W-PRLW	>0	**>1**	**>2**	>5%
W-PRLH	**>1**	**>1**	**>1**	**>20%**

Thresholds were set independently for all ten NWCA Reporting Groups (see **Table 4-5**) as the extent of human disturbance can vary greatly among regions and wetland types. Initially, thresholds were set to zero human disturbance with the exception of a 5% alien plant species cover threshold. These thresholds became the definition of a minimally disturbed reference site (Stoddard et al. 2006). If a Reporting Group had a sufficient number of sites not exceeding these thresholds, as was the case in four of the Reporting Groups, then these zero thresholds were used to define reference sites. In the other six Reporting Groups, we had to relax our thresholds to obtain a sufficient number of reference sites for data analysis. Thresholds were relaxed so that approximately 15-25% of the sites in the Reporting Group passed the filters and these sites were used as the least disturbed reference sites for that Reporting Group. The nine indices and plant metric and their least disturbed thresholds in each of the ten NWCA Reporting Groups are shown in **Table 4-10** and **Table 4-11**. The number of least disturbed sites by Reporting Group is listed in **Table 4-12**.

Table 4-12. Results of screening for least disturbed. See **Table 4-5** for definitions of Reporting Group acronyms. Key to Font color for Reporting Group: Green = Not relaxed; Black = Relaxed; Red = Most Relaxed.

Reporting Group	Total Number of Sites Screened	Number of Least Disturbed Sites	Percent Least Disturbed Sites
ALL-EW	73	16	22%
ALL-EH	272	100	37%
EMU-PRLW	127	21	17%
EMU-PRLH	73	16	22%
CPL-PRLW	189	37	20%
CPL-PRLH	72	16	22%
IPL-PRLW	52	12	23%
IPL-PRLH	138	26	19%
W-PRLW	67	16	24%
W-PRLH	75	17	23%
Totals	**1138**	**277**	24%*

*Percent of all sites screened, i.e., 1138

Most disturbed sites on the disturbance gradient were defined using a filtering process in the same manner as for least disturbed sites. The same ten measures of disturbance were used and thresholds for most disturbed were set for each of the measures. If any single threshold for any measure was exceeded, the site was considered a most disturbed site. As “most disturbed” is a relative definition, our objective was to define approximately 20-30% of the sites in a Reporting Group as most disturbed and thresholds were set accordingly. Measures and their most disturbed thresholds in each of the ten NWCA Reporting Groups are shown in **Table 4-13** and **Table 4-14**. The total number of most disturbed sites by Reporting Group is listed in **Table 4-15**.

Finally, we classified the sites not falling in to either least or most disturbed into the intermediate disturbance category. **Table 4-15** also lists the total number of intermediate disturbed sites by Reporting Group.

Table 4-13. Threshold values for sites to be categorized as most disturbed by Reporting Group for the Buffer Indices. If any single threshold was exceeded at a site, the site ***was*** considered most disturbed. See **Table 4-5** for definitions of Reporting Group acronyms.

Reporting Group	B1H_AGR (Agriculture)	B1H_RESURB (Residential/ Urban)	B1H_HYD (Hydrology)	B1H_IND (Industry)	B1H_HAB (Habitat)	B1H_ALL (Summary)
ALL-EW	>0.25	>0.25	>0.25	>0.25	>0.25	**>0.75**
ALL-EH	>0.25	>0.25	>0.25	>0.25	>0.25	**>0.75**
EMU-PRLW	>0.25	>0.25	>0.25	>0.25	>0.50	**>1.00**
EMU-PRLH	>0.30	>0.30	>0.30	>0.30	>0.60	**>1.00**
CPL-PRLW	>0.25	>0.25	>0.25	>0.25	>0.50	**>1.00**
CPL-PRLH	>0.60	>0.60	>0.60	>0.60	>1.00	**>1.50**
IPL-PRLW	>0.30	>0.30	>0.30	>0.30	>0.60	**>1.00**
IPL-PRLH	>0.60	>0.60	>0.60	>0.60	>1.20	**>1.80**
W-PRLW	>0.60	>0.60	>0.60	>0.60	>0.80	**>1.00**
W-PRLH	>0.75	>0.75	>0.75	>0.75	>1.50	**>2.50**

Table 4-14. Threshold values for sites to be categorized as most disturbed by Reporting Group for the Hydrology and Soil Chemistry Indices and the relative cover of alien plant species metric. If any single threshold was exceeded at a site, the site ***was*** considered most disturbed. See **Table 4-5** for definitions of Reporting Group acronyms.

Reporting Group	Hydrology High Impact	Hydrology Moderate Impact	Soil Chemistry Heavy Metal Index	Relative Cover of Alien Plant Species
ALL-EW	>1	>1	>2	>50%
ALL-EH	>1	>1	>2	>50%
EMU-PRLW	>1	>1	>2	>50%
EMU-PRLH	>2	>2	>2	>50%
CPL-PRLW	>1	>1	>2	>50%
CPL-PRLH	>2	>2	>2	>50%
IPL-PRLW	>1	>2	>2	>50%
IPL-PRLH	>1	>2	>2	>50%
W-PRLW	>2	>2	>3	>50%
W-PRLH	>3	>3	>3	>50%

Table 4-15. Number and percent of sites in the most and intermediate disturbance categories by NWCA Reporting Group. See **Table 4-5** for definitions of Reporting Group acronyms.

Reporting Group	Number of Sites Screened	Number of Most Disturbed Sites	Percent Most Disturbed	Number of Intermediate Disturbed Sites	Percent Intermediate Disturbed Sites
ALL-EW	73	19	26%	38	52%
ALL-EH	272	82	30%	90	33%
EMU-PRLW	127	27	21%	79	62%
EMU-PRLH	73	24	33%	33	45%
CPL-PRLW	189	55	29%	97	51%
CPL-PRLH	72	20	28%	36	50%
IPL-PRLW	52	14	27%	26	50%
IPL-PRLH	138	42	30%	70	51%
W-PRLW	67	21	31%	30	45%
W-PRLH	75	27	36%	31	41%
Totals	**1138**	**331**	**29%***	**530**	**47%***

*Percent of all sites screened, i.e., 1138

4.5.7 *Least and Most Disturbed Site Distribution*

As wetlands are not uniformly distributed across the US, sample sites in the NWCA are also not distributed uniformly (see **Figure 4-16**). In general, the distribution of least disturbed reference sites and most disturbed sites are spread out reasonably well across the NWCA sample. There is a tendency in some regions to have more least-disturbed reference sites in relatively undisturbed places (e.g., northern New England versus southern New England (**Figure 4-17**)) but in others (Great Plains (**Figure 4-18**), Gulf Coastal Plain (**Figure 4-19**), Western Mountains) they are very well distributed across the area. Unfortunately, some skew in distribution cannot be completely avoided at this scale of analysis.

In terms of NWCA Wetland Types (**Table 4-16**), it is not surprising that palustrine farmed (Pf) wetlands have a larger proportion of disturbed sites than the other types, whereas estuarine (E2EM and E2SS) and palustrine unconsolidated bottom/aquatic bed (PUBPAB) types tended to have fewer disturbed sites than the other types. The distribution of least and most disturbed sites across HGM classes (**Table 4-17**) was similar among the classes. Tidal and fringe wetlands tended to be a bit less disturbed than the other classes.

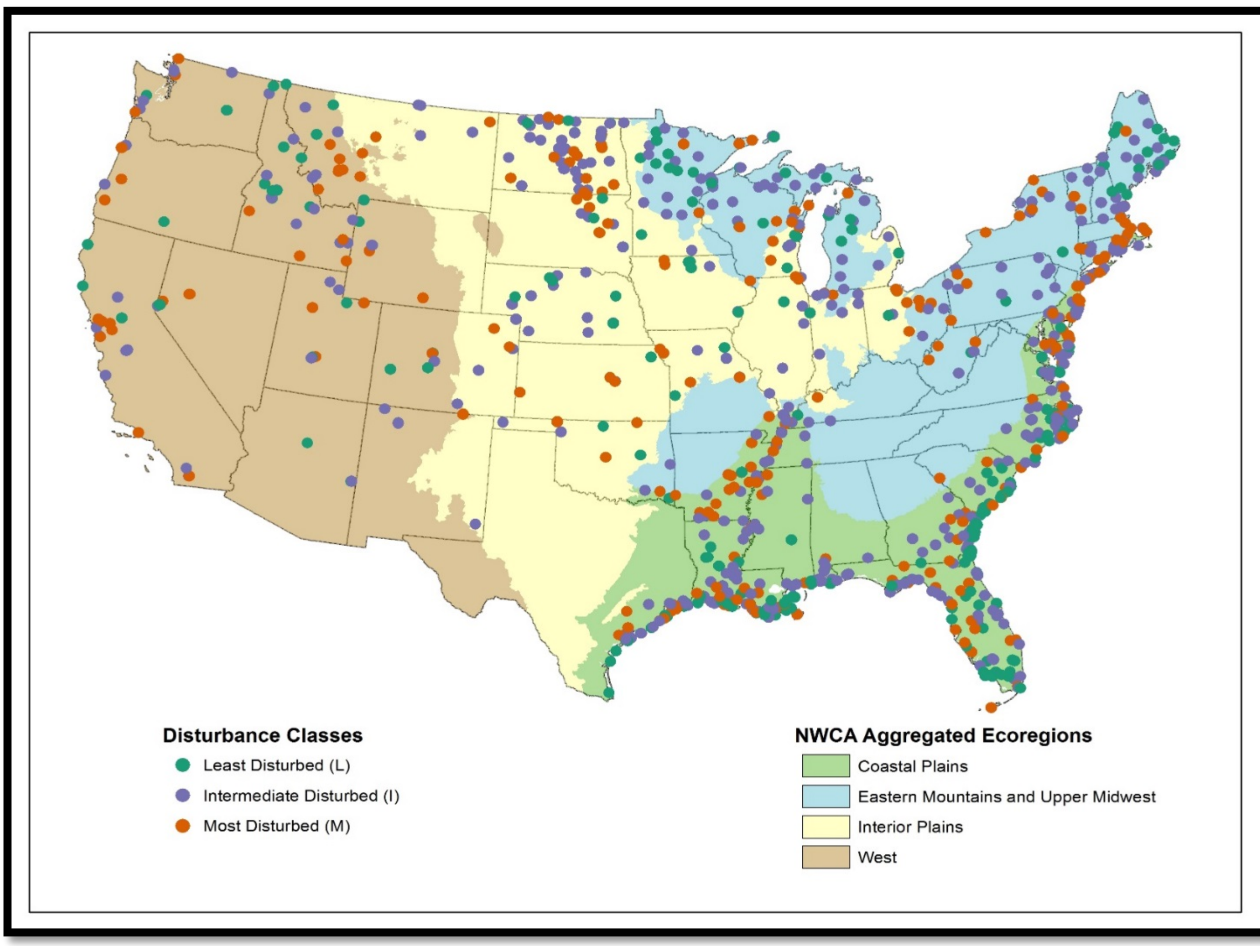

Figure 4-16. Illustration of the distribution of NWCA sites by disturbance category across the conterminous US.

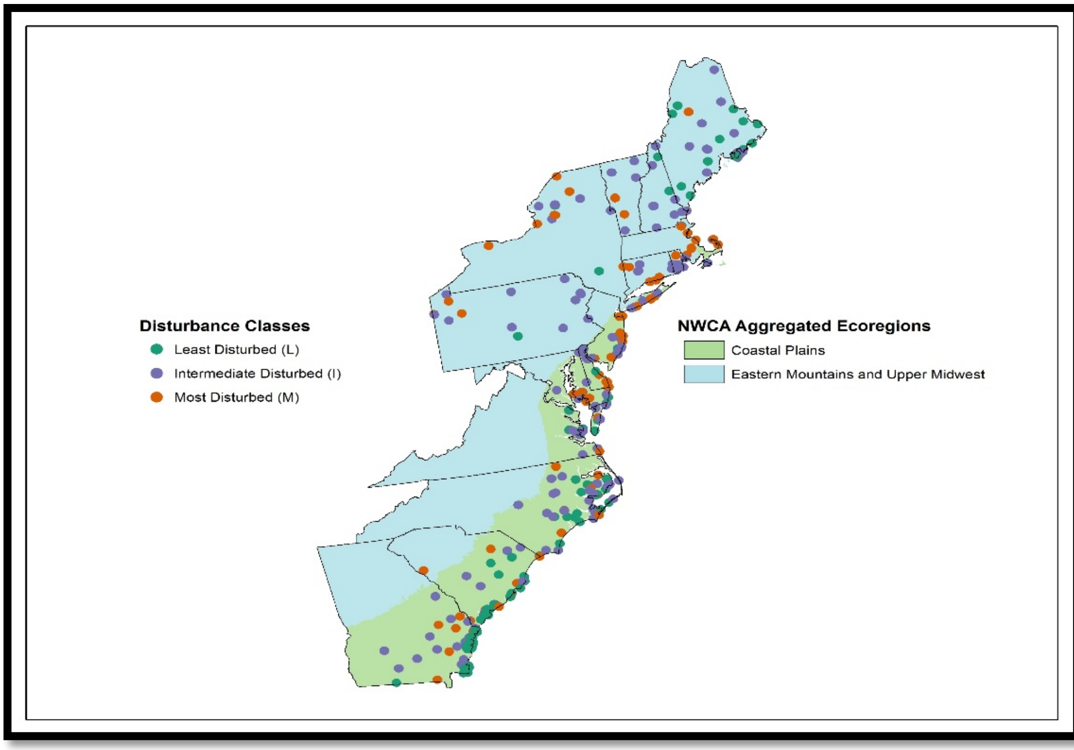

Figure 4-17. Illustration of the distribution of NWCA sites by disturbance category in the eastern US.

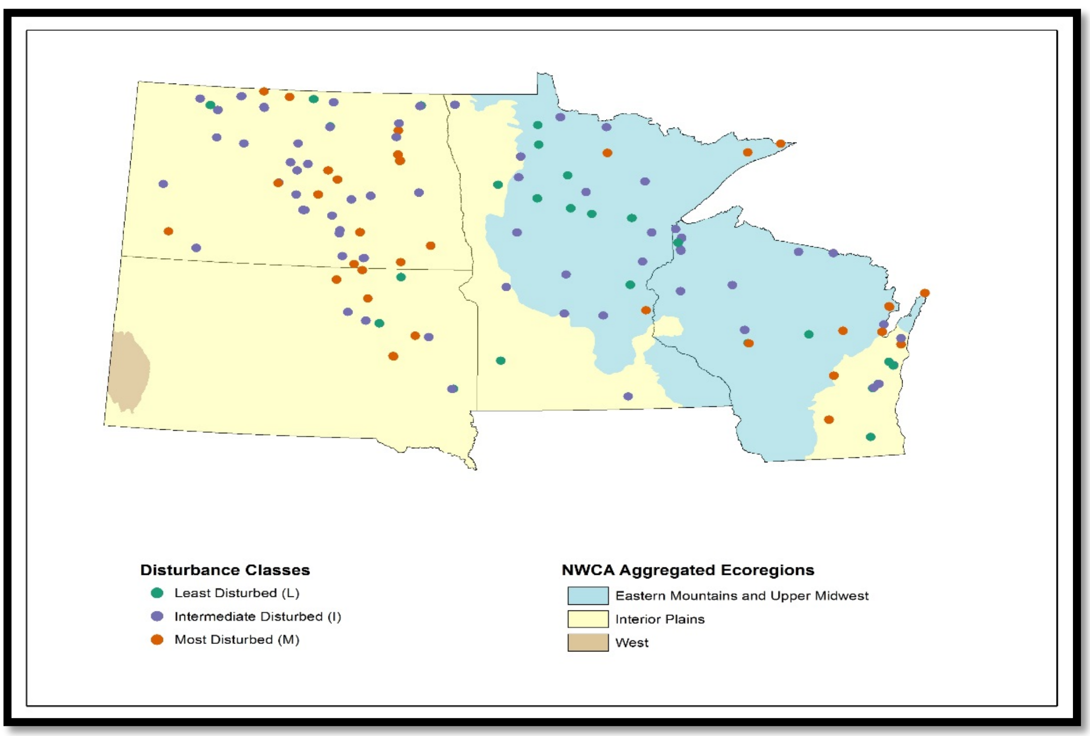

Figure 4-18. Illustration of the distribution of NWCA sites by disturbance category in the upper Midwest area of the US.

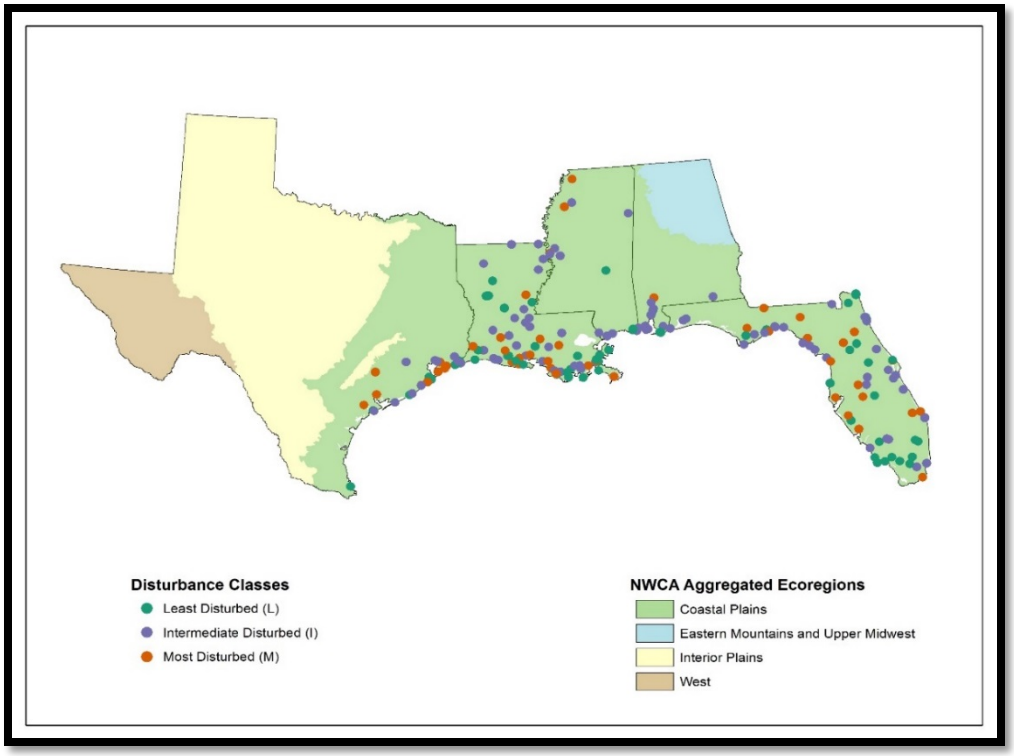

Figure 4-19. Illustration of the distribution of NWCA sites by disturbance category in the Gulf Coastal Plains of the US.

Table 4-16. Percent of the 1138 sites screened in each disturbance category by NWCA Wetland Types. Numbers are rounded and may not add to 100 percent. See **Table 1-1** for descriptions of the NWCA Wetland Types, which include PRL (Palustrine, Riverine, and Lacustrine) and E (Estuarine) wetlands.

NWCA Target	% Least	% Intermediate	% Most
PEM	21	48	32
Pf	5	55	41
PFO	23	54	23
PSS	14	53	33
PUBPAB	38	38	23
E2EM	37	33	30
E2SS	22	52	26

Table 4-17. Percent of the 1138 sites screened in each disturbance category by Hydrogeomorphic (HGM) Class (Brinson 1993). Numbers are rounded and may not add to 100 percent.

HGM Class	% Least	% Intermediate	% Most
Depression	13	55	31
Flats	24	48	28
Fringe	41	41	18
Riverine	20	51	28
Slope	24	43	33
Tidal	35	35	30

4.5.8 *A Research Tool*

Examination of the least disturbed sites revealed that a number of the sites met the definition of minimally disturbed. Minimally disturbed was defined by Stoddard et al. (2006) as the absence of significant human disturbance. Minimally disturbed sites were identified by setting the thresholds for the nine disturbance indices and plant disturbance metric to zero, i.e., indicating that none of the indicators of stress considered in **Table 4-10** and **Table 4-11** were present in the AA and buffer of the sites being screened. This resulted in a gradient with four disturbance categories **Figure 4-20**. Of the original 277 least disturbed sites (**Table 4-12**) 170 are minimally disturbed. Comparisons of the characteristics of minimally and least disturbed sites will be informative to future NWCA analyses and to management and policy decisions.

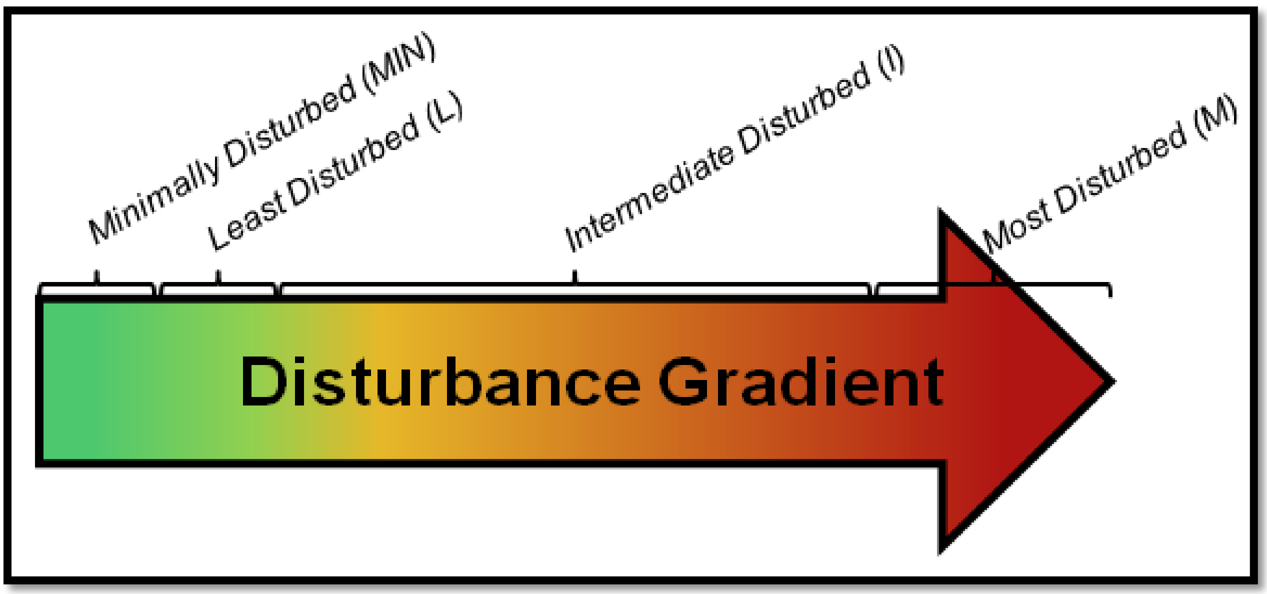

Figure 4-20. The NWCA disturbance gradient with the minimally disturbed category.

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Chapter 5: Vegetation Indicators – Background, Analysis Approach Overview, Data Acquisition and Preparation

5.1 Background

The status of natural vegetation has been increasingly and effectively used as an indicator of ecological condition in wetlands (Mack and Kentula 2010). In wetland ecosystems, vegetation provides biodiversity, primary productivity, habitat for organisms in other trophic levels, and contributes to energy, nutrient, and sediment or soil dynamics (Mitsch and Gosselink 2007; Tiner 1999). Wetland vegetation both responds to and influences hydrology, water chemistry, soils, and other components of the biophysical habitat of wetlands. Because plants respond directly to physical, chemical, and biological conditions at multiple temporal and spatial scales, they can be excellent indicators of ecological condition or stress (McIntyre and Lavorel 1994; McIntyre et al. 1999). For example, wetland plant species 1) represent diverse adaptations, ecological tolerances, and life history strategies, and 2) integrate environmental conditions, species interactions, and human-caused disturbance. As a result, many human-mediated disturbances are reflected in shifts in the presence or abundance of particular plant species, plant functional groups (Quétier et al. 2007), plant communities (Galatowitsch et al. 1999; DeKeyser et al. 2003), and vegetation structural elements (Mack 2007).

Data describing plant species composition (species identity, presence, and abundance) and vegetation structure (horizontal and vertical) were collected in the 2011 NWCA (see **Section 5.3**). Such data are powerful, robust, relatively easy to gather and can be summarized into myriad candidate metrics or indices of ecological condition (USEPA 2002; Mack and Kentula 2010; USEPA 2011a). In addition to reflecting ecological condition, some plant species or groups can be indicators of stress to wetlands. Nonnative plant species, in particular, are recognized as indicators of declining ecological condition, or as stressors to ecological condition (Magee et al. 2008; Ringold 2008; Magee et al. 2010).

Vegetation metrics or indices that distinguish least from most disturbed sites are increasingly used for:

1) Documenting baseline ecological condition,
2) Assessing trends in condition over time,
3) Identifying stressors to condition and predictors of condition decline.

Two kinds of condition indicators and one indicator of stress were considered for use in the NWCA:

Vegetation Indicators of Condition

- A **Vegetation Multi-Metric Index (VMMI)** is comprised of several metrics describing different components or functional traits of the vegetation (see **Section 7.2**) that together reflect overall wetland condition. Candidate metrics of vegetation condition are evaluated for utility in distinguishing least disturbed sites from those that are most disturbed. The most effective metrics are then combined into a VMMI as an indicator of wetland condition. VMMIs that combine a suite of vegetation metrics (representing aspects of plant communities, vegetation structure, and functional or life history guilds) have been developed for several states and regions within the United States and elsewhere (e.g., DeKeyser et al. 2003; Miller et al. 2006; Reiss 2006; Rocchio 2007; Veselka et al. 2010; Euliss and Mushet 2011; Genet 2012; Rooney et al. 2012; Deimeke et al. 2013; Wilson et al. 2013). The multimetric index approach has also been widely used for other biological assemblages (e.g., fish, birds, periphyton, macroinvertebrates) and forms the cornerstone of the USEPA National Aquatic Resource Surveys (NARS) (e.g., USEPA 2006; 2009). Condition assessment approaches based on biotic assemblages assume that when species composition and abundance are similar to reference (or least disturbed) conditions, ecological integrity is also maintained (Karr 1991; Dale and Beyeler 2001).

- **Floristic Quality (FQ) indices** can be stand-alone indicators of condition or used as a component of a VMMI (see **Section 7.2**). Floristic quality describes the complement of plant species occurring at a site, and is based on summarization of species-specific, regional Coefficients of Conservatism that rank the responsiveness of each species to disturbance (Swink and Wilhelm 1979; Wilhelm and Ladd 1988). FQ indices have proven utility as indicators of wetland condition in many regions of the US (e.g., Lopez and Fennessy 2002; Cohen et al. 2004; Bourdaghs 2006; Miller and Wardrop 2006; Milburn et al. 2007; Bried et al. 2013; Gara 2013; Bourdaghs 2014). Several kinds of FQ indices have been used to describe wetland condition; the two most common are ***Mean Coefficient of Conservatism (Mean C)*** and the ***Floristic Quality Assessment Index (FQAI)***. Both can be based on species presence only or weighted by species abundance.

Vegetation Indicator of Stress

- **Nonnative Plant Stressor Indicator (NPSI)** incorporates attributes of richness, occurrence, and abundance for nonnative plant species (see **Section 5.8**), and is used to assess extent of potential stress to wetlands (see **Chapter 8, Section 8.5**).

5.2 Overview of Vegetation Analysis Process

As the primary biotic indicator for the NWCA, vegetation is a major component of the analysis pathway (**Figure 5-1**). Data acquisition, preparation, and quality assurance are covered in this chapter (orange outlined box in **Figure 5-1**). **Chapter 6** provides detail on prerequisite analysis steps that use validated data and least and most disturbed site designations for candidate metric development and generation of data tables for analysis. Development of the NWCA VMMI (green open and filled boxes in **Figure 5-1**) is described in **Chapter 7**, and creation of the Nonnative Plant Stressor Indicator (purple open and filled boxes in **Figure 5-1**) is outlined in **Section 8.5**. Note, both the VMMI and the NPSI are based on vegetation data, consequently, the NPSI is used only for stressor extent estimates (purple filled box), and not for determining relative and attributable risk (teal filled box), which combine information from the VMMI and a particular stressor indicator (see **Section 9.4**).

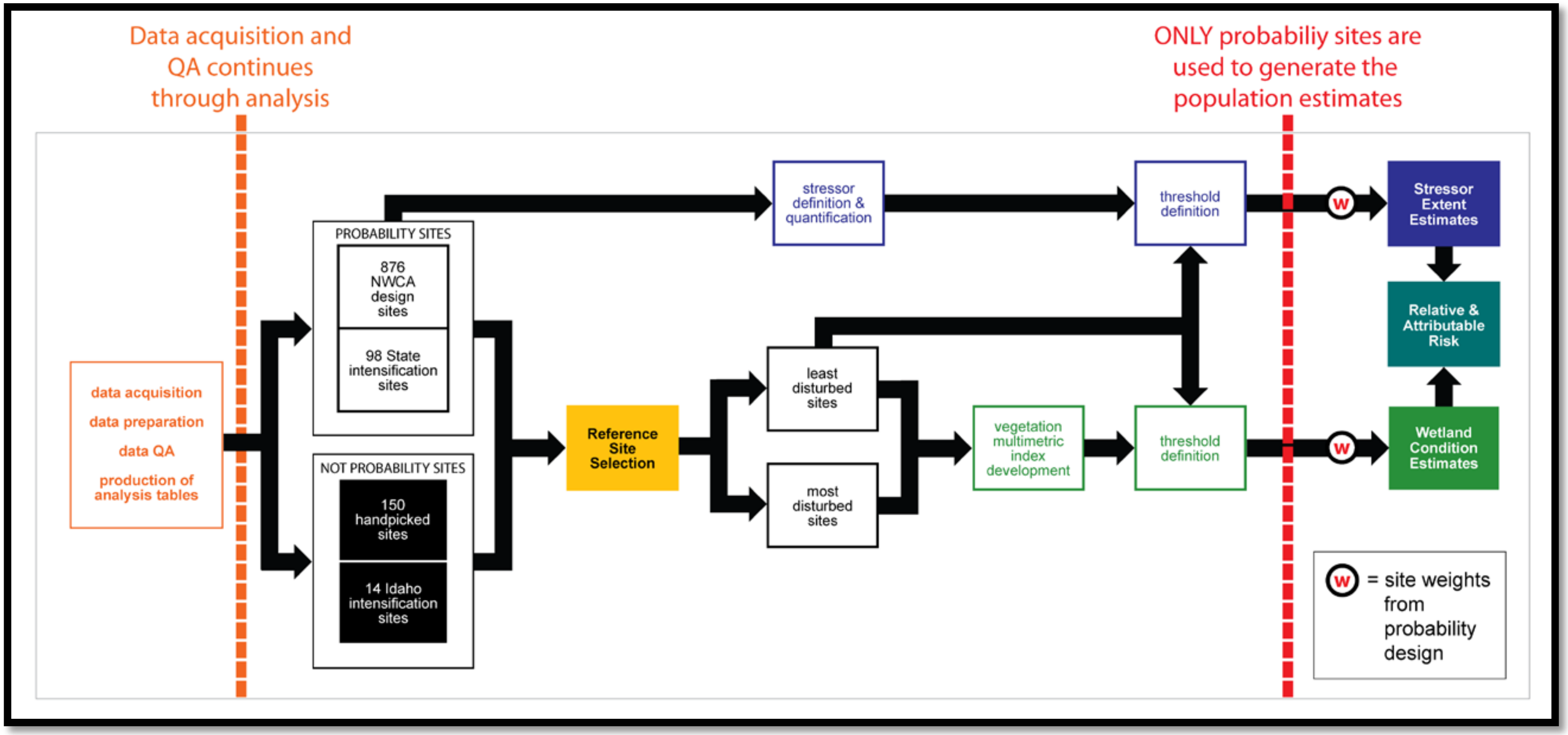

Figure 5-1. The 2011 National Wetland Condition Assessment Analysis Pathway. The orange outlined box on left of diagram highlights the data preparation activities. Some prerequisite analysis steps involve the use of validated data and the least and most disturbed site designations. Green outlined and filled boxes represent the analysis path for the development of vegetation indicators of condition. Development of the vegetation indicator of wetland stress follows the stressor analysis path indicated by the purple open and filled boxes.

Evaluating vegetation in the NWCA included three primary components, each with several major analysis steps (**Figure 5-2**). These three components were necessarily completed in sequence beginning with data preparation and acquisition, then moving on to prerequisite steps needed before indicator development could begin. The final stage of analysis was describing wetland condition and stress as indicated by vegetation. This involved development of vegetation indices of wetland condition and a nonnative plant indicator of wetland stress, followed by calculation of wetland extent estimates for condition or stress classes.

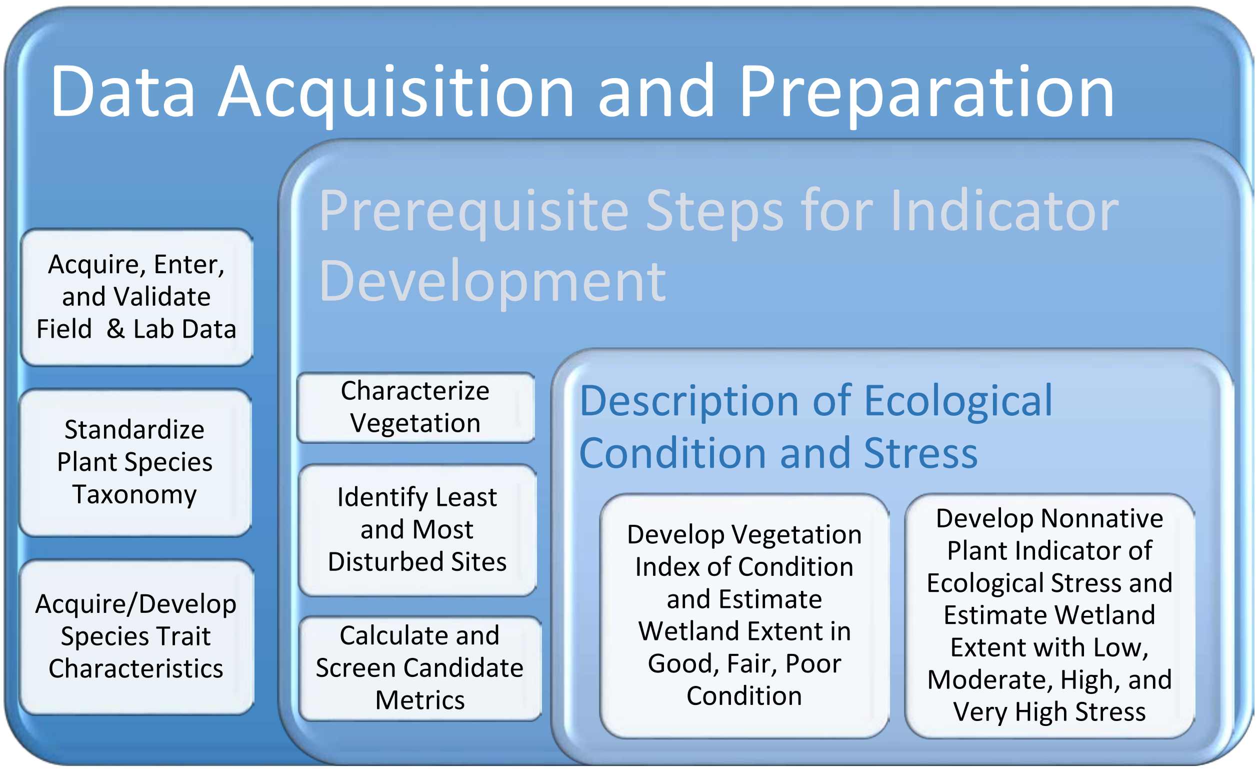

Figure 5-2. Overview of data preparation and analysis steps for evaluating vegetation condition in the 2011 NWCA.

Key elements for each of the three analysis components and the Chapters or Sections in which they are discussed are listed in the following text.

Data Acquisition and Preparation

- Collect field data (**Section 5.3**)
- Enter and validate raw data (**Section 5.3.2**)
  - *Scan field data into raw data tables*
  - *Merge laboratory identifications of unknown plant species into vegetation raw data tables*
  - *Range and legal value checks*
  - *Logic checks*
- Standardize plant species taxonomy (**Section 5.5**)
- Acquire plant species trait information needed to summarize raw plant species data and develop candidate vegetation metrics. Trait or autecology information was gathered or developed under six major categories:

- *Growth habit, Duration, Plant category (**Section 5.6**)*
  - *Wetland Indicator Status (**Section 5.7**)*
  - *Native status (**Section 5.8**)*
  - *Coefficients of Conservatism (**Section 5.9**)*

Prerequisite Steps for Indicator Development

- Characterize vegetation to help identify appropriate groups of sites for which to report results for the NWCA (**Chapter 4**)
- Define disturbance gradients and identify least and most disturbed sites within NWCA Reporting Groups (**Chapter 4**)
- Develop candidate metrics of vegetation condition or stress (**Section 5.12**)
  - *Develop and calculate candidate metrics from raw vegetation data and species trait information*
  - *Develop an analysis data set including metric values for all NWCA sampled sites*

Description of Ecological Condition and Stress

- Evaluate candidate metrics for utility as indicators of vegetation condition or stress (**Chapter 7**)
- Develop a vegetation index or indices that describe wetland condition (**Chapter 7**)
- Calculate extent estimates for wetlands in good, fair, and poor condition (**Chapter 9** and *National Wetland Condition Assessment 2011: A Collaborative Survey of the Nation's Wetlands* (USEPA *In Review*))
- Develop plant stressor indicator based on alien and cryptogenic plant species (**Chapter 8**)
- Calculate extent estimates for wetlands with low, moderate, high, and very high stress (**Chapter 9** and *National Wetland Condition Assessment 2011: A Collaborative Survey of the Nation's Wetlands* (USEPA *In Review*))

5.3 Vegetation Data Collection

The Vegetation Protocols for the NWCA are described in detail in the *NWCA Field Operations Manual* (USEPA 2011a), and were designed to address the survey objectives, while meeting logistics constraints of completion in one sampling day per site by a four-person Field Crew. Development of vegetation sampling methods for the NWCA was informed by numerous existing vegetation sampling methods that have been applied to wetlands (e.g., Lee et al. 2008; Mack 2007; Magee et al. 1993; Peet et al. 1998; Rocchio 2007) and by extensive discussions and workshops with the many wetland scientists and managers who were NWCA partners. An overview of NWCA field sampling and plant specimen identification protocols follows in the next two subsections.

5.3.1 *Field Sampling*

Vegetation data for the NWCA were collected during the peak growing season when most plants are in flower or fruit to optimize species identification and characterization of species abundance. At each NWCA sample point location (see **Chapter 1** for details about the survey design), data were gathered in five 100-m^2 Vegetation (Veg) Plots. The five Veg Plots were placed systematically in a ½ hectare Assessment Area (AA) at each site. The standard AA and Veg Plot layout is illustrated in **Figure 5-3** and the configuration of each plot is shown in **Figure 5-4**. Alternate configurations for AA shape and layout of the plots were used when necessary as determined by rules related to specific site conditions (USEPA 2011). A flowchart describing the vegetation data collection protocol is provided in **Figure 5-5**.

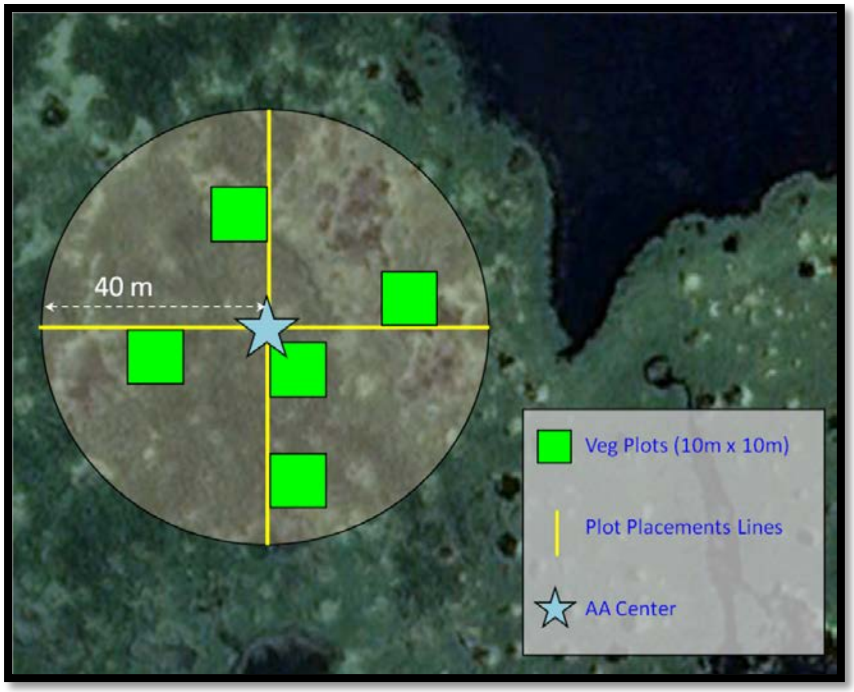

Figure 5-3. Standard NWCA Assessment Area (AA) (shaded circular area) and standard layout of Vegetation Plots.

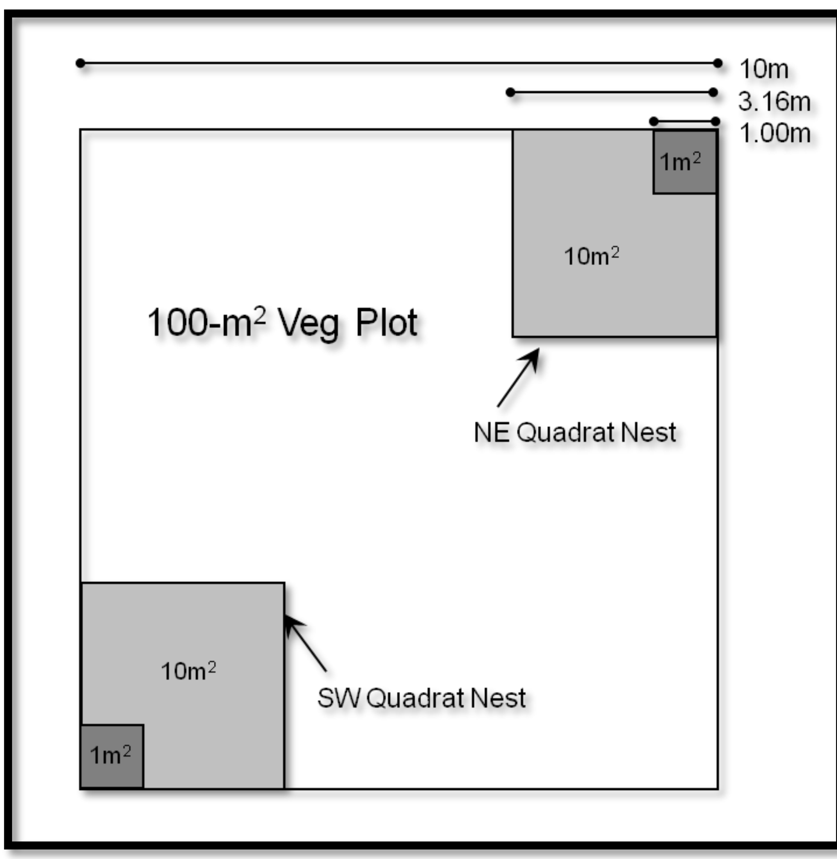

Figure 5-4. Detail of Vegetation Plot illustrating plot boundaries and positions of nested quadrats.

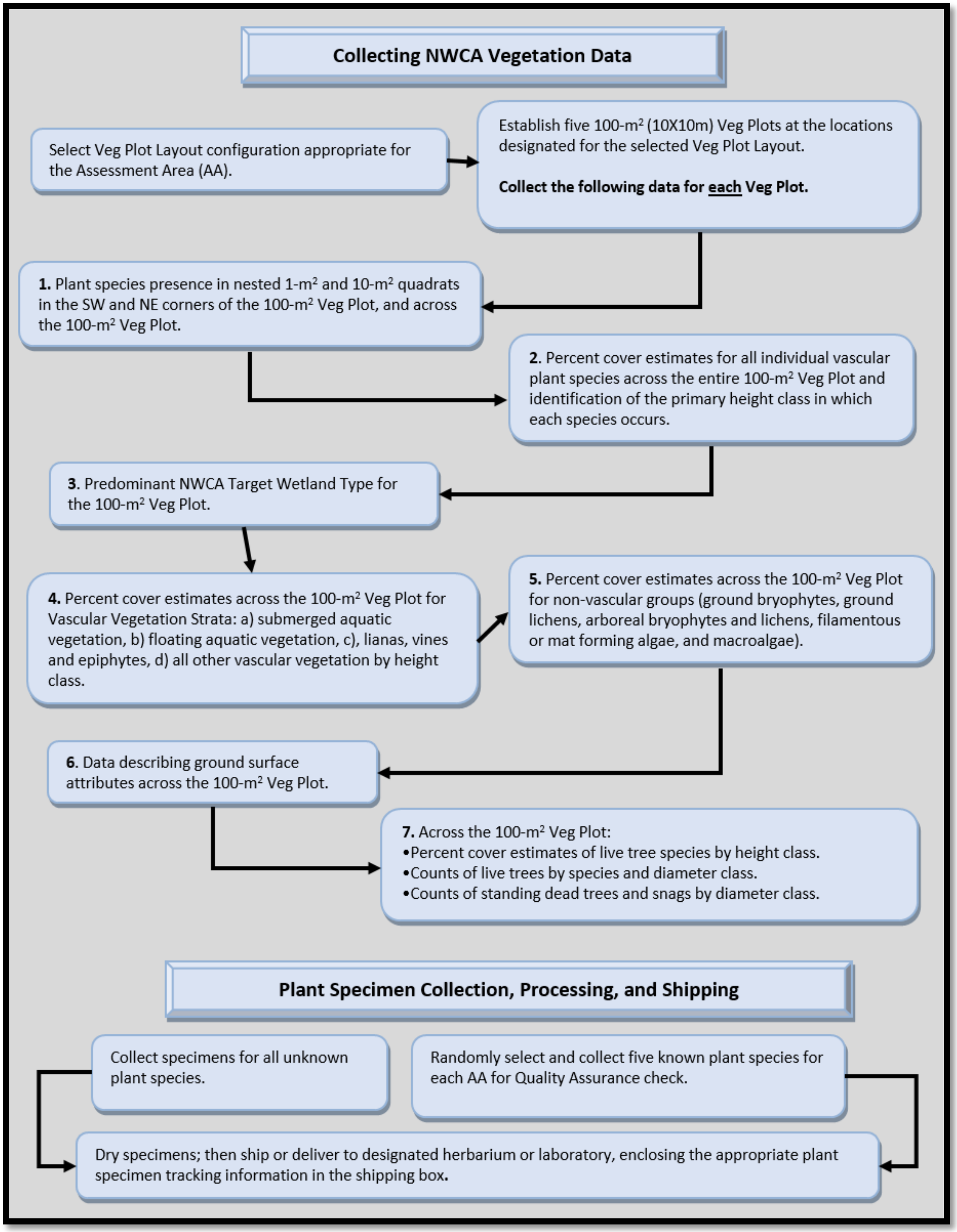

Figure 5-5. Overview of vegetation data collection protocol for the 2011 NWCA (USEPA 2011a).

5.3.2 *Identification of Unknown Plant Species*

Plant species, observed across the five sampled Veg Plots at each site, which could not be identified by the botanist in the field, were collected for later identification. Specimen collection, labeling, specimen preservation (pressing and drying), shipping or delivering dried specimens to a designated laboratory or herbarium, and specimen tracking were completed according to standard protocols described in the *NWCA Field Operations Manual* (USEPA 2011a).

Identification of unknown plant taxa was guided by protocols in the *NWCA Laboratory Operations Manual* (USEPA 2011b). Unknown plant specimens from each Field Crew were identified at a specific designated regional laboratory or herbarium (hereafter, lab) by a lab botanist. As quality control for the identification process, ten percent of the lab identifications for unknowns were independently verified by another botanist at the lab. Lab botanists maintained a detailed spreadsheet that included for each unknown specimen collected in the field: the collection number and pseudonym from the field collection, the location of collection (plot and site number), date of sampling, the name assigned during lab identification based on a regional flora, and any notes related to the identification. The identification spreadsheets were forwarded to the NWCA Data Management and Analysis Teams. The Analysis Team reviewed the lab identification spreadsheets and addressed any recording errors. The validated identifications were integrated with the NWCA raw data tables for plants, replacing the pseudonyms recorded by the Field Crews with the corresponding scientific name (see **Section 5.4.2**).

5.4 Data Preparation – Parameter Names, Legal Values or Ranges, and Data Validation

5.4.1 *Description of Vegetation Field Data Tables*

The data from the completed vegetation field forms were electronically scanned into several predefined long format, raw data tables in the NWCA database. A separate table was created for each of the three primary vegetation data forms:

- <u>tblPLANT table</u> – data originated from Form V-2: NWCA Vascular Species Presence and Cover
- <u>tblVEGTYPE table</u> – data originated from Form V-3: NWCA Vegetation Types (Front) and NWCA Ground Surface Attributes (Back)
- <u>tblTREE table</u> – data originated from Form V-4: NWCA Snag and Tree Counts and Tree Cover

Examples of the three field forms can be found in **Section 5.11, Appendix A**.

Form V-2 data describe vascular plant species identity, presence, cover, and height for each observed taxon and were collected in each 100-m^2 Veg Plot. Taxa typically represent species or lower level (e.g., subspecies, variety) classification, but occasionally individual taxa were identified only to genus, family or growth form. For convenience, in this report, vascular plant taxa are generally referred to as species even though in some cases lower or higher taxonomic levels are reflected. Form V-2 data used in candidate metric development for the 2011 NWCA included taxon name (SPECIES), presence, and percent cover (COVER).

Other species level data were collected using Form V-2, but were reserved for further research and not incorporated in the analysis of condition for the 2011. These other data included predominant height for each species across each plot, and presence of individual species at different spatial scales within the plot (i.e., within the quadrats (S = 1-m^2 quadrat, M = 10-m^2 quadrat) nested in the corners of plot and the within the overall plot (L = 100-m^2 plot), see **Section 5.3.1**). The former can reflect vegetation structure and volume by species or guild groups. The latter address fine scale diversity patterns.

Form V-3 data encompass descriptors of wetland type, structure of vascular vegetation, non-vascular groups, and ground surface attributes which are each sampled in the five 100-m^2 Veg Plots. All these data were used in developing candidate metrics.

Form V-4 data include counts by diameter class of dead trees/snags, as well as cover by height classes and by diameter classes for individual tree species in each 100-m^2 Veg Plot. Tree data were used in candidate metric development.

Parameter names and legal values or ranges for the field collected vegetation data are listed in **Section 5.12, Appendix B**. The quality of all the vegetation field data was carefully examined during data validation.

5.4.2 *Data Validation*

Whenever large quantities of data are collected, it is not surprising for errors related to data or sample collection, recording, sample analysis, or data entry to occasionally occur. Therefore, the NWCA established a number of cross-checks in the data collection and processing procedures, within the protocols and field forms, to allow identification and resolution of potential errors. Once the data were entered, quality assurance (QA) review was critical to identifying and resolving any errors to ensure high quality data. Verification and update of the scanned vegetation data involved several QA steps conducted by members of the information management team and the Vegetation Analysis Team. Some checks required manual evaluation of the paper forms or data; others involved the use of specific R Code written to identify records with specific kinds of potential errors.

Information Management Team:

- Verified that the data from the Vegetation Forms scanned properly
- Where possible, verified spelling of plant species name with USDA PLANTS database
- Conducted quality assurance checks for valid ranges and legal values for all data

Vegetation Analysis Team:

- Updated names for unknown taxa based on plant specimen identification (see **Section 5.3.2**)
- Reviewed and resolved all instances of missing, out of range or non-legal values identified by the IM Team:
    - *Review of the field forms often indicated a scanning or recording error that was readily resolved and the data updated*
    - *Where no resolution was apparent the data were flagged and the error described*
- Resolved species name spelling errors or use of alternative names as part of the nomenclatural standardization (see **Section 5.5**)
- Conducted logic checks and data type specific checks to identify:
    - *Recording errors*
    - *Instances of plant species recorded multiple times at one site*
- Determined the cause of each instance of deviation revealed by logic checks
    - *Resolved these issues manually or used R code to effect updates*
    - *Where no resolution was apparent the data were flagged and the error described*

The vast majority of concerns identified by these QA screenings were readily resolved allowing accurate updates to the data. For the instances where specific issues could not be corrected the data were flagged with restrictions for use. Where corrections were needed, all original data values were retained as inactive records in the NWCA database.

5.5 Nomenclatural Standardization

During 2011 field sampling, approximately 140 regional floras and field guides were used by Field Crews for identification of plants, thus, a wide range of taxonomies were applied to the occurrences of taxa-site pairs observed across the United States. Consequently, a critical step in data preparation was standardization of plant nomenclature to ensure that each taxonomic entity was called by the same name throughout the NWCA study area. The PLANTS nomenclatural database (USDA-NRCS 2013) was selected as the national standard for taxonomy for the NWCA.

In the NWCA, plant species names originated from raw data records collected using Form V-2: NWCA Vascular Species Presence and Cover, Form V-4: NWCA Snag and Tree Counts and Tree Cover, and from lab identifications of unknown taxa that were collected in the field. The process for reconciliation of nomenclature outlined in **Section 5.5.1** was used for all three data types. **Section 5.5.2** provides a brief description of the procedures for taxonomic review and documentation of name assignments that were used for data from Form V-2. The documentation process for the tree data (Form V-4) and the lab identifications were similar, but tailored to the structures of these data.

Nomenclatural standardization was a complex undertaking, and in this section we provide a basic overview of the methods and process used for the 2011 NWCA.

5.5.1 *Nomenclature Reconciliation Methods*

We developed a method to reconcile names for NWCA observed plant taxa, at each location of their occurrence, to the PLANTS nomenclatural database. First, we identified the steps required to ensure accurate name reconciliation (**Figure 5-6**) and refined the process in collaboration with taxonomists at the PLANTS database program (hereafter, PLANTS). A series of automated filters, paralleling components in this figure, were developed using code written for R software (R Core Team 2014) to compare recorded names for NWCA observations to PLANTS accepted names and identify names and records that required further evaluation by a botanist. In **Figure 5-6**, medium blue boxes reflect steps completed using automated filters, light blue boxes represent steps that required review by a botanist, purple boxes indicate the type of name resolution applied, and the dark blue central box reflects the final name resolution.

Step 1: Identify NWCA name-location pairs directly matching PLANTS accepted names

A large proportion of the plant name-plot pairs recorded in the NWCA could be directly matched to PLANTS accepted names. These included records where:

1) The original NWCA name was the same as the accepted PLANTS name and there were no synonyms for the name.
2) The original NWCA name pointed to one or more synonyms that all pointed to the same, single accepted PLANTS name.

Step 2: Identify NWCA name-location pairs needing botanical review to reconcile to PLANTS accepted names

Even though most NWCA names could be directly matched to PLANTS nomenclature in Step 1, a large number required botanical review to select the correct PLANTS accepted name. There were three primary types of name issues which necessitated further botanical review:

1) <u>Unmatched Names</u> – no PLANTS accepted name or synonym matched a particular NWCA name-plot pair. Common reasons for unmatched names were misspelling or mis-scanning of the record, or use of an abbreviation or common name. Rarely, the taxon represented a name or taxon not included in the PLANTS database.
2) <u>Same Name with Different Authorities</u> (shorthand terminology = Multiple Authorities) – refers to a NWCA name which pointed to synonyms with exactly the same genus and species epithets, but which had different botanical authorities for the name.
3) <u>Species Concept Unclear</u> – NWCA binomial name was contained in multiple potential PLANTS accepted names or multiple synonym names that point to multiple possible PLANTS accepted names.

Step 3: Review name-plot pairs identified in Step 2 and determine correct name assignment

The set of names and records identified as requiring further evaluation were reviewed by the NWCA lead botanist/ecologist, using a general stepwise procedure for nomenclatural determination:

1) Identify and correct spelling errors or abbreviated names.
2) Identify all synonyms and accepted PLANTS name(s) that could apply to each ambiguous taxa-plot pair name.
3) Compare geographic distribution of potential synonyms and accepted PLANTS names with location of the observed NWCA taxon.
4) Review field records and notes from the NWCA Field Crew regarding the observed NWCA taxon.
5) Review the species concept for the taxon based on flora(s) used by field botanist, as well as other pertinent taxonomic resources and databases.

Items 1 – 4 in the list above allowed determination of the PLANTS nomenclature accepted name for the majority of taxa-plot pairs that needed botanical review. For taxa where the appropriate PLANTS accepted name could not be definitively resolved using these procedures, a taxonomist at the PLANTS database was consulted for final name determination. This consultation involved discussions between the NWCA lead botanist/ecologist and the PLANTS taxonomist to review floras, historical records, and floristic/taxonomic databases pertinent to each taxon-location pair considered. In a few cases, the PLANTS taxonomist consulted with other botanists with specific expertise regarding a particular taxonomic group (e.g., species, genus, family) to resolve a naming issue.

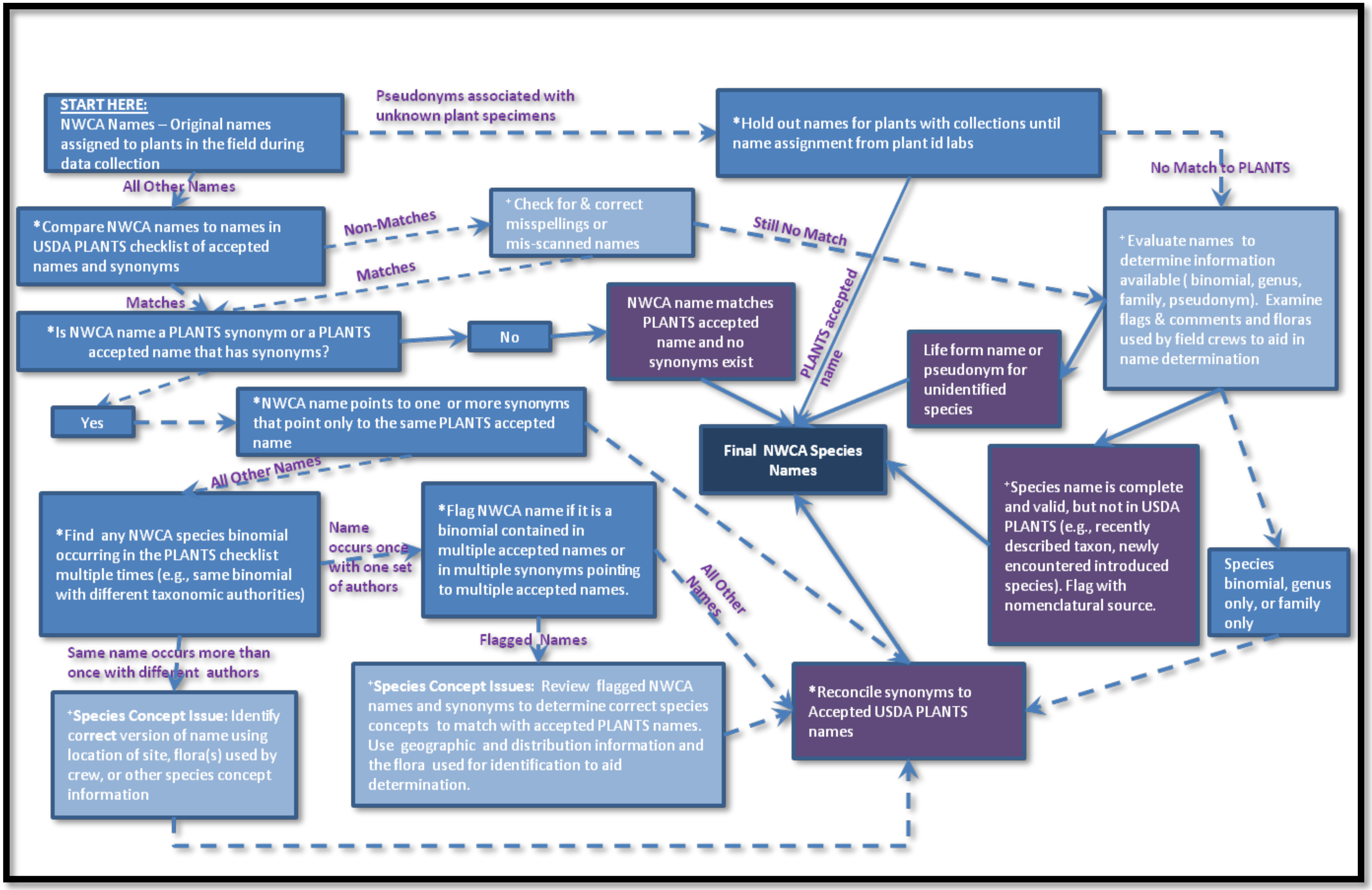

Figure 5-6. Process for screening and reconciling names of plant taxa observed in the NWCA. Dark blue boxes = steps completed using R code, light blue boxes = steps requiring botanical review, purple boxes = type of name resolution applied, and the dark blue central box = final name resolution.

5.5.2 *Nomenclature Standardization Results and Documentation*

A standard approach for organizing, resolving, and documenting the name reconciliations, for plant name-plot pairs needing review, was developed and applied. Specific NWCA species records (including name, cover value, and other data), along with information from the PLANTS database, were exported into an Excel Workbook. This gathered key information in one location to facilitate review of the taxonomy and to highlight when other information was needed. Important NWCA data elements included in the Excel Workbook were NWCA SITE_ID and UID, state, county, a list of the floras used by the Field Crew collecting the data for a particular site, and a link to the scanned field form image. Access to the scanned field form allowed easy viewing of any notes Field Crews may have made in relation to a particular species, as well as a view of other taxa present at a site. Critical information from the PLANTS database included synonyms and accepted names that could potentially correspond to the specific taxon-plot pairs.

The Excel Workbook format included separate spreadsheet tabs for reviewing unresolved names in three categories: Unmatched Names, Multiple Authorities, and Species Concept Issues (see Step 2 in **Section 5.5.1**, for definitions). For each taxon-plot pair to be evaluated (rows in spreadsheets), the associated columns (NWCA data and taxonomic information from the PLANTS database) informed name resolution. An instruction page accompanying the Excel Workbook described the associated data included in each of the spreadsheets and the ways this information might aid in name determination. During the review process, the rationale for the final assignment of the correct PLANTS accepted name for each name-plot pair was documented by specifying a reason code and, where needed, providing narrative notes and citations of floras or databases.

Once the NWCA name-plot pairs were reconciled to the PLANTS nomenclature, the accepted PLANTS names for each NWCA record was applied to the active NWCA data. The original names as recorded by the Field Crew or lab identifications were retained as inactive data. Following taxonomic standardization, the master list of plants observed in the 2011 NWCA across the conterminous United States included:

- 3,640 unique taxa which were distributed as:
    - *12,970 unique taxa-state pairs*
    - *32,363 unique taxa-site pairs*
    - *171,475 unique taxa-plot pairs*

The majority of the NWCA taxa were identified to the species or subspecies/varietal level, with a small number identified only to the genus, family, or growth form level.

5.6 Species Traits – Life History: Growth Habit, Duration, and Plant Category

Life history guilds can provide important ecological information about wetlands and have proven to be useful components in metrics describing vegetation condition in other studies. Traits reflecting species life history based on growth habit, duration, and plant category for all vascular taxa observed in the NWCA were downloaded from the PLANTS database (USDA-NRCS 2012). This trait information was used in combination with data describing presence, frequency, and cover for individual species to develop candidate metrics that reflected the distribution of life history traits across each sampled site. These candidate metrics serve as descriptors of richness and abundance for all species, native species only, or for nonnative species only, within specific life history groups (see **Appendix D** (**Section 6.8**)).

5.6.1 *Growth Habit*

The primary growth habit types describing plant species observed in the 2011 NWCA include forb/herb, graminoids, subshrub, shrub, tree, and vine. However in the PLANTS database, individual species were frequently identified as spanning more than one of these growth habit types. As a result, many additional combined categories are implicit across the growth habit descriptors for specific taxa. This creates a diversity of growth habit categories, many of which represent only a few taxa. To facilitate data analysis, we merged some multiple type groups from the PLANTS database into larger categories for the NWCA data analysis (**Table 5-1**).

Table 5-1. Growth habit categories used in NWCA analysis with a crosswalk to PLANTS database growth habit designations observed across the 2011 NWCA species list. Capitalized Growth Habit Category Names are used in descriptions of Growth Habit metrics in **Section 6.8**, **Appendix D**.

NWCA Growth Habit Category Groupings for Metric Calculation	PLANTS Database Growth Habit 'Designations' for NWCA Observed Species
GRAMINOID	'Graminoid'; 'Subshrub, shrub, graminoid'
FORB	'Forb/herb'; 'Forb/herb, shrub'; 'Forb/herb, shrub, subshrub'; 'Forb/herb, subshrub'
SUBSHRUB-FORB	'Subshrub, forb/herb'; 'Subshrub, shrub, forb/herb'
SUBSHRUB-SHRUB	'Subshrub'; 'Subshrub, shrub'; 'Shrub, subshrub'
SHRUB	'Shrub'; 'Shrub, tree'; 'Tree, subshrub, shrub'
TREE-SHRUB	'Tree, shrub'; 'Tree, shrub, vine'
TREE	'Tree'
VINE	'Vine'; 'Vine, forb/herb'; 'Subshrub, forb/herb, vine'; 'Forb/herb, vine'
VINE-SHRUB	'Vine, shrub'; 'Vine, subshrub'; 'Subshrub, vine'; 'Shrub, vine'; 'Shrub, forb/herb, subshrub, vine'; 'Shrub, subshrub, vine'

5.6.2 *Duration*

Duration or longevity for plants is described by annual, biennial, and perennial life cycles. Some individual species may exhibit different durations depending on growing conditions. Consequently, in addition to the individual duration classes, a variety of mixed duration categories occur in the PLANTS trait database. To facilitate data analysis, we merged some multiple type groups from the PLANTS database into larger categories for the NWCA data analysis (**Table 5-2**).

Table 5-2. Duration categories used in the NWCA analyses and a crosswalk to PLANTS database duration designations observed across the 2011 NWCA species list. Capitalized Duration Category Codes (listed in parentheses) are used in descriptions of Duration Metrics in **Section 6.8**, **Appendix D**.

NWCA Duration Category Groupings for Metric Calculation	PLANTS Database Duration 'Designations' for NWCA Observed Species
Annual (ANNUAL)	'Annual'
Annual-Biennial (ANN_BIEN)	'Annual, biennial'; 'Biennial'
Annual-Perennial (ANN_PEREN)	'Annual, biennial, perennial'; 'Annual, perennial'; 'Perennial, annual'; 'Biennial, perennial'
Perennial (PERENNIAL)	'Perennial'

5.6.3 *Plant Categories*

Several major plant categories were considered in summarizing raw data to develop guild-based candidate metrics. Categories assigned for individual NWCA taxa from designations provided in the PLANTS database were:

- Dicots
- Monocots
- Gymnosperms
- Ferns
- Horsetails
- Lycopods

5.7 Species Traits – Wetland Indicator Status

The hydrophytic status of the plant species occurring in wetlands can be useful indicators of ecological condition. However, the specific values reflecting good condition will vary with the normal hydrology of each wetland type. Wetland Indicator Status for each observed NWCA species was obtained from the US Army Corps of Engineers (USACE) 2013 update of the National Wetland Plant List (NWPL) (Lichvar 2013), via the PLANTS database (USDA-NRCS 2013). Wetland Indicator Status was downloaded from the PLANTS database because it reconciles species taxonomy for the NWPL to PLANTS nomenclature, which is the NWCA standard.

Wetland Indicator Status ratings are defined in **Table 5-3**. WIS status for each species is regionally specific based on USACE Wetland Regions (USACE 2014). Upland (UPL) status includes all NWCA observed taxa not listed in the NWPL.

Table 5-3. Descriptions of Wetland Indicator Status (WIS) ratings (from Lichvar 2013). WIS Category Codes (listed in parentheses) are used in descriptions of Hydrophytic Status Metrics in **Section 6.8**, **Appendix D**. Numeric Ecological Value for each indicator status used in calculating some metrics.

Wetland Indicator Status	Designation	Qualitative Description	Numeric Ecological Value
Obligate (OBL)	Hydrophyte	Almost always occur in wetland	1
Facultative Wetland (FACW)	Hydrophyte	Usually occur in wetlands, but may occur in non-wetlands	2
Facultative (FAC)	Hydrophyte	Occur in wetlands and non-wetlands	3
Facultative Upland (FACU)	Nonhydrophyte	Usually occur in non-wetlands, but may occur in wetlands	4
Upland (UPL)	Nonhydrophyte	Almost never occur in wetlands	5

Candidate metrics that were calculated to represent particular hydrologic indicator status or hydrologic indices based on species composition are described in **Appendix D** (**Section 6.8**). These metrics represent various descriptors of richness and abundance for all species or for native species only for specific hydrophytic groups.

5.8 Species Traits – Native status

The proportion or abundance of native vs. nonnative flora at a given location can help inform assessment of ecological condition and stress (see **Section 5.1**, **Chapter 6, and Chapter 8, Section 8.5**). To calculate metrics describing native and nonnative components of the flora, it was first necessary to determine the native status of the vascular plant taxa observed in the NWCA. For the NWCA, state-level native status was determined for the approximately 13,000 taxa-state pairs observed across 1138 sampled wetlands in the conterminous United States. This was a challenging task across the scale of the NWCA for several reasons. First, there is currently no comprehensive national standard for native status of plant species at the local or state level. Next, existing native status designations and the understanding of original species distributions can be ambiguous. In addition, defining the concepts for native and nonnative is not always straightforward. Nonnative species may originate from other countries or continents. Some species are native in one part of the United States, but nonnative in another. Other taxa have alien and native components (e.g., genotypes, lower taxonomic levels).

Consequently, our first step in determining native status for the observed taxa-state pairs was to define several concepts describing native status for the NWCA (**Table 5-4**).

Table 5-4. Definition of state-level native status designations for NWCA taxa-state pairs.

Native Status Codes	Native Status Designations
NAT	***Native*** to a specific state
INTR	***Introduced*** from outside the United States
ADV	***Adventive:*** Native to some areas or states of the United States, but introduced the location of occurrence
ALIEN	***Introduced + Adventive***
CRYP	***Cryptogenic:*** Both native and introduced genotypes, varieties, or subspecies
UND	***Undetermined***: Growth forms, families, genera with native and alien species

Using these definitions to determine state-level native status for each of the NWCA taxa-state pairs, we reviewed existing native status designations of all NWCA taxa-state pairs from a variety of taxonomic and ecological sources:

1) The PLANTS Database (USDA-NRCS 2013): Native status in the Lower 48 (conterminous United States Floristic Region)
2) Other Floristic Databases (state and national levels)
3) State and Regional Floras and Checklists
4) Consultation with the PLANTS nomenclatural team

Items 1 through 3 above included approximately 85 floristic sources that were used in the primary review. A bibliography is retained with the NWCA native status review database. Additional taxonomic sources were consulted as needed.

The native status review process was conducted by the NWCA Lead Ecologist/Botanist and another member of the Vegetation Analysis Team with strong botanical expertise. One key element of the review was to search native status designations based on the NWCA accepted name (see **Section 5.5**) and where needed, on all of its synonyms. Many native status determinations were clear-cut, but others were more complex and required more extensive review of distributions and floristic sources. For taxa with particularly complex origins, the nomenclature team at the PLANTS Database provided input based on their expertise and access to numerous resources describing species distributions and first collections to help inform difficult native status designations.

Native Status determinations were made for all species-state pairs, and wherever possible for genus-state pairs. Family- and growth form-state pairs were designated as 'Undetermined'. The distribution of native status groups based on site occurrences of individual taxa across the 1138 sites sampled in the 2011 NWCA is illustrated in **Figure 5-7**. Native status was used in conjunction with validated field collected vegetation data and with other species trait information to calculate numerous candidate metrics, which are described in **Appendix D** (**Section 6.8**).

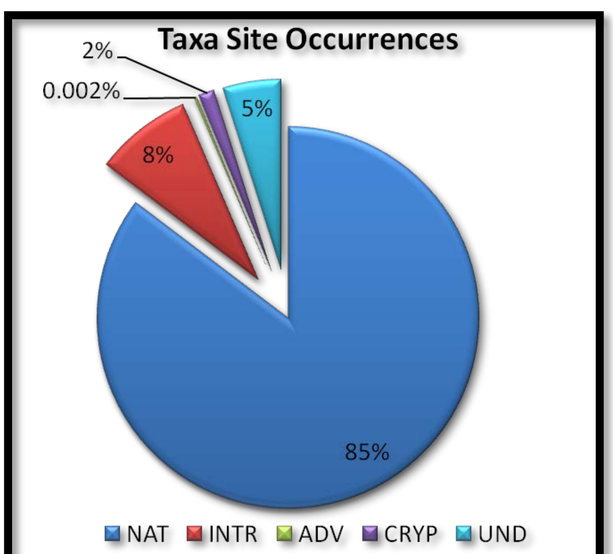

Figure 5-7. Percentage site occurrences of individual plant taxa observed in the 2011 NWCA by native status categories (see **Table 5-4** for definitions) across 1138 probability and not-probability sampled sites of native status.

5.9 Species Traits – Coefficients of Conservatism

Coefficients of Conservatism (C-values, also called CCs) describe the tendency of individual plant species to occur in disturbed versus near pristine conditions. They are state or regionally specific and scaled from 0 to 10.

- A C-value of 0 or 1 indicates a widespread generalist species that thrives under disturbed conditions.
- A C-value of 10 indicates a species that occurs in specific habitats that are minimally disturbed (i.e., largely unaltered).
- For the NWCA, alien taxa were assigned a C-value of 0.

C-values are the primary building blocks of 1) floristic quality indices (see **Section 5.1**), and 2) metrics describing sensitivity or tolerance of plant species to disturbance. Sensitivity and tolerance are often key attribute categories used in MMIs for other biological assemblages and for some wetland VMMIs. For plants, sensitivity can be described based on presence or abundance of high C-value taxa, whereas, tolerance may be based on presence or abundance of low C-value taxa.

We investigated several floristic quality indices as descriptors of condition for the NWCA, including versions of the Floristic Quality Assessment Index (FQAI) and of Mean Coefficient of Conservatism (Mean C). Metrics describing sensitivity and tolerance to disturbance were screened as potential components of the Vegetation MMI. See **Appendix D** (**Section 6.8**) for lists of metrics based on C-values and for details of their calculation and evaluation.

Unfortunately, C-values for individual plant species were not available for all states or regions, nor were existing C-value lists compiled together in a readily accessible format. Thus, to use this powerful trait in the NWCA, it first was necessary to obtain or develop state-level C-values for all plant taxa observed during the 2011 NWCA. This required the:

- Creation of a database of existing C-value lists from the conterminous US that included state-specific C-values for individual plant species,
- Assignment of existing C-values to each taxon-state pair observed in the NWCA, and
- Identification of NWCA taxa-state pairs lacking existing C-values and development of C-values for these taxa-state pairs.

5.9.1 *Creating a Database of C-Values for the Conterminous United States*

The first step was to develop a National Floristic Quality Database (NFQD, *unpublished*) which collects together the C-value lists, existing in 2014, that represented individual states or regions within the conterminous United States. Creating the NFQD involved a large collaborative effort to locate existing C-value lists, and then compile the lists into a single database with uniform formats. The NWCA gratefully acknowledges the existing body of work on C-values and the numerous partners who contributed new or updated C-value lists (**Section 5.13, Appendix C**).

5.9.1.1 *Gathering Existing Lists of Coefficients of Conservatism*

First, a literature search was conducted to gather all state and regional C-value lists published through 2013. In addition, state agencies and other researchers involved in floristic assessment were contacted to request access to unpublished lists of C-values. The map in **Figure 5-8** illustrates the states for which C-value lists were obtained, and the states for which no C-values existed at the time the NFQD was compiled. In states where C-value lists are indicated on the map, the existing lists may represent all or part of a state's area and the entire flora or the wetland flora only. Most C-value lists were developed for individual states, but some states are represented by regional lists. **Section 5.13, Appendix C** provides citations for the C-value lists included in the NFQD. The complete database contains records for over 115,000 taxa-state pairs from the state and regional C-value lists (a taxa-state pair refers to a specific plant taxon in a specific state).

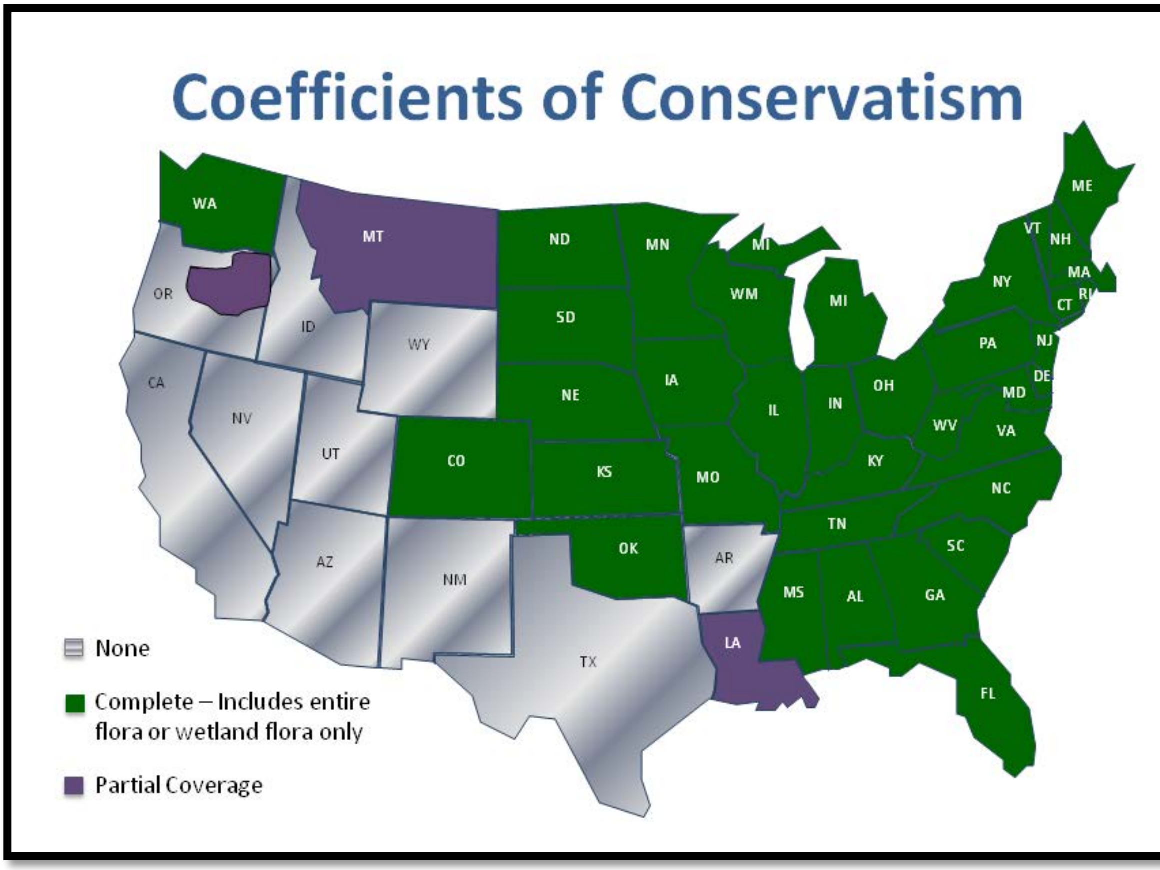

Figure 5-8. States with complete or partial published or unpublished lists of Coefficients of Conservatism (C-values) that were included in the National Floristic Quality Database (NFQD) and used to inform C-Value assignment for NWCA taxa-state pairs.

5.9.1.2 *Developing and Compiling the National Floristic Quality Database (NFQD)*

All available C-value lists were incorporated into the National Floristic Quality Database (NFQD), which was built using a relational database management system called 4th Dimension (4D) version 12.4. All records in the database are arranged in trait tables comprised of fields that are linked by taxonomy and geographic location. Each record includes the taxon name, C-value, the location where the list was originally developed (state or region), along with a variety of other ancillary information.

Several important considerations apply to the development and use of the NFQD:

1) Diverse approaches to list organization, data formats, and field names were used across the original C-value lists, so it was necessary to standardize data formats and field names to allow the separate lists to be imported into one database.

2) During the compilation of the NFQD, C-value updates or additions were often required as new data became available from states actively updating existing C-values or developing C-values for the first time.

3) Items 1 and 2 and the complexity of the merger of data from numerous C-value lists required detailed quality assurance steps and validation cross-checks to ensure the C-values were accurately imported.

4) The component C-value lists within the NFQD used diverse taxonomic nomenclatures. The C-value lists typically referenced scientific names for plant taxa using local or regional taxonomic sources appropriate to each state; but these were not necessarily consistent between states or with the USDA PLANTS nomenclatural database (USDA-NRCS 2013). Thus, whenever using the NFQD to consider geographic scales that span multiple states or regions, it is imperative to reconcile the nomenclature to one taxonomic standard. For example, for the NWCA it was necessary to examine the NFQD for all possible synonyms of the NWCA taxa-state pairs and reconcile the taxonomy for pertinent C-values to PLANTS nomenclature, the NWCA standard, before the C-values could be assigned to the NWCA taxa-state pairs (see **Section 5.9.2.1**).

5) States did not treat alien plant species uniformly. Some included nonnative species in their C-value lists and others did not. Among those that did, the methods used to assign C-values for alien species were not standardized. For example, many states assigned a C-value of zero to all alien taxa, but occasionally alien taxa were ranked on a gradient of invasiveness using a range of negative integers for C-values to indicate increasing potential impact. Consequently, to use C-values across multiple states or regions the manner in which C-values are assigned to alien taxa-state pairs had to be standardized.

5.9.2 *Assigning C-values to Plant Taxa Observed in the NWCA*

There were approximately 13,000 taxa-state pairs recorded by the NWCA Field Crews, including 3640 taxa observed across the 1138 sites sampled in the conterminous United States. C-value records for each of these taxa-state pairs were exported from the full National Floristic Quality Database into a separate table for use in developing C-value assignments for the NWCA. C-value assignments for the NWCA taxa-state pairs involved several steps:

- Identification and taxonomic standardization of taxa-state pairs from the NFQD that corresponded to NWCA taxa-state pairs,
- Standardization of C-value formats to whole numbers,
- Standardization of C-value scoring for alien plant species,
- Assignment of existing C-values to NWCA taxa-state pairs, and
- Development of C-values for NWCA taxa-state pairs that lacked existing values.

5.9.2.1 *Taxonomic Reconciliation*

C-value records in the NFQD that were matches to the PLANTS accepted name (USDA-NRCS 2013), or to all possible synonyms of the accepted name, for each NWCA taxa-pair were exported to a table for making NWCA C-value assignments. The taxonomy of this subset of C-value records was reconciled with the PLANTS database accepted names. This standardization process was completed using nomenclatural reconciliation procedures similar to those described in **Section 5.5**. Many taxa-state pairs in the NFQD could be directly matched to the NWCA taxa-state pairs. However, there were approximately 390 taxa-state pairs with synonymy issues that required botanical review to determine how to apply the C-values for these synonyms to the correct accepted PLANTS names of the relevant NWCA taxa-state pairs. For example, *Aster macrophyllus* is a synonym for the PLANTS accepted name *Eurybia macrophylla*. Consequently, the C-value recorded for *Aster macrophyllus* in the Michigan C-value list was applied to the NWCA taxa-state pair represented by *Eurybia macrophylla* and occurring in Michigan.

5.9.2.2 *Standardization of C-values for NWCA Taxa-State Pairs*

The methods and formats used for presentation of C-values between states and regions varied. To standardize the meaning of C-values, a 'Final C-value' field was created for the NWCA taxa-state pairs. The original C-value for each these records was also retained in the NFQD database. The Final C-values for the NWCA reflected the following modifications:

- C-values expressed as decimals were rounded to the nearest integer; for example, a C-value of 5.5 or higher was rounded to 6.
- Native status for the NWCA taxa-state pairs was determined using procedures discussed in **Section 5.8**. For purposes of C-value assignments, all alien taxa (introduced + adventive species) were assigned a value of 0.
- All taxa without C-value assignments were designated 'UA' (unassigned) in the 'Final C-value' field to identify NWCA taxa-state pairs that still required development of C-values.

5.9.2.3 *Assigning C-values for NWCA Taxa-State Pairs*

C-values were assigned to approximately 10,300 NWCA taxa-state pairs, including both species-state and genus-state pairs, based on the existing state and regional C-values included in the NFQD. This left approximately 2,700 taxa-state pairs for which C-values were needed. This remaining set of taxa-state pairs was represented by two groups: taxa occurring in states for which C-values have not yet been developed and taxa representing higher level taxonomic categories (genera, families, and growth form) without C-values. These 2,700 taxa-state pairs included approximately:

- 250 identified only to family or growth form and were designated as undetermined for C-value
- 1,050 identified only to genus
- 1,400 identified to species

For the NWCA taxa-state pairs where C-values were unavailable, it was necessary to develop methods for assigning them. There were several important criteria for this effort; it had to:

- be rigorous and repeatable,
- account for ecoregional differences in C-values for species, and
- be possible to complete relatively rapidly.

This C-value development process had two major components (described in the following subsections), one for the species-state pairs and one for the genus-state pairs lacking C-values.

5.9.2.3.1 Species-State Pair Assignments

C-value Assignment: The approximately 1400 NWCA species-state pairs lacking C-values were evaluated to determine whether an appropriate C-value could be assigned to each of them using an ecoregional extrapolation approach. C-values for the same species from neighboring states with similar ecological conditions were evaluated for application to each species-state pair without a C-value. This was done by overlaying the locations of the NWCA field sites with a map of the nine NARS Aggregated Ecoregions (see **Figure 5-9**) to determine ecologically similar states based on presence in the same ecoregion and geographic proximity to states where C-values were missing. Ecologically similar states were queried, in order of distance from the target state, for a matching species record. If a C-value existed in ecologically similar neighboring states for a given species, the C-value from the nearest state was assigned to the species-state pair for which no existing C-value was available. If no ecologically supported C-value could be assigned, then a taxa-state pair received a value of 'Undetermined'.

Example: Notice that in Texas most 2011 NWCA sites occurred along the Gulf Coast, so for a particular Texas species lacking a C-value, Louisiana might have served as an ecologically similar neighboring state (i.e., in the same NARS Aggregated Ecoregion) with an existing C-value for that species. If the species in question had no counterpart in Louisiana, but a C-value was available from the Florida Coast Plain, that C-value would have been applied to the Texas species.

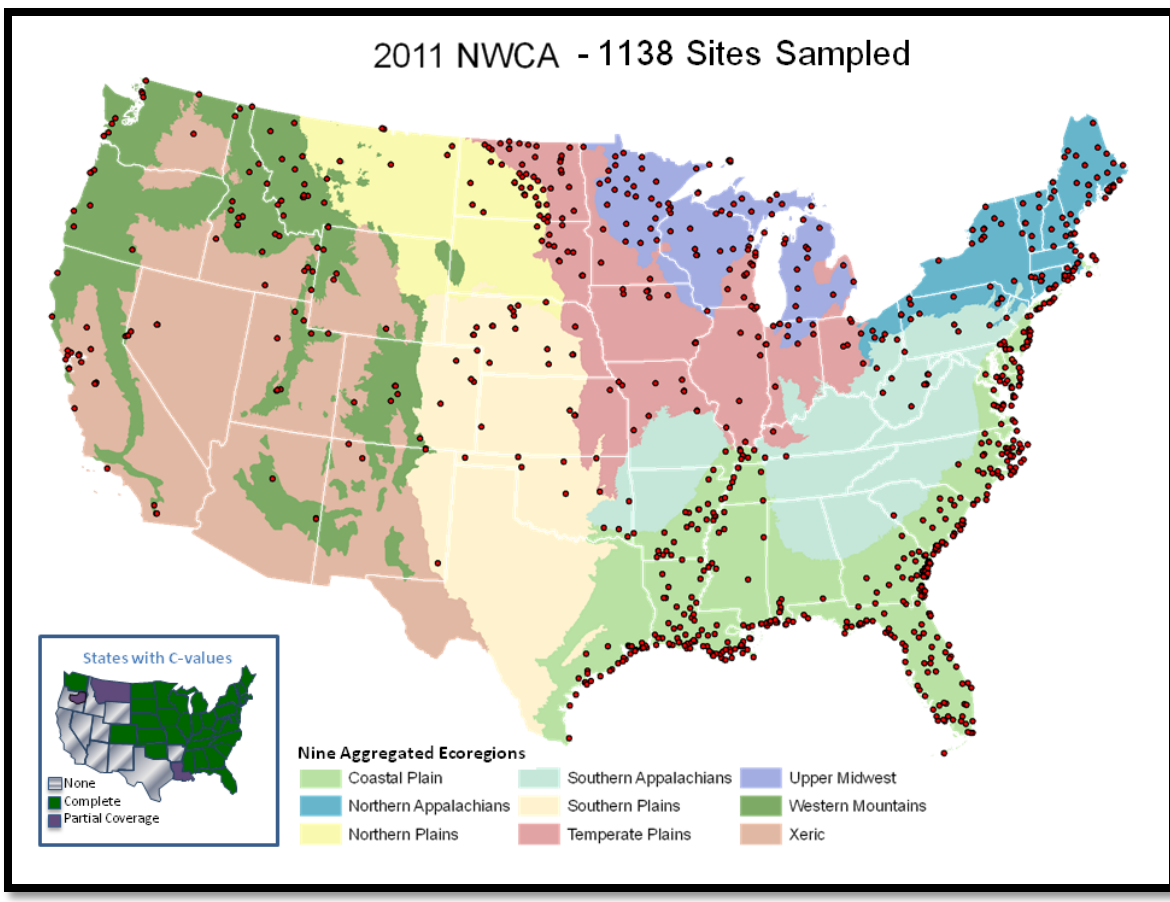

Figure 5-9. 2011 NWCA sampled sites plotted on Nine Aggregated Ecoregions used by other NARS. Inset shows status of available C-values.

Quality Assessment of C-value Assignment Procedures: To provide a quantifiable assessment of the C-value assignments made by extrapolation from adjacent states, another botanist independently assigned C-values to a subsample of 302 taxa-state pairs using a similar procedure, but considered two or three neighboring states in the C-value assignment. Differences between the C-values obtained by the two groups of botanists were calculated for each species-state pair. The absolute value of the mean difference in C-value assignments for all species was 0.6, thus, on average, the assignments were within 0.6 of one another. The low degree of variability observed between the two independent assignments of C-value scores indicates strong repeatability of the C-value assignment procedure.

C-value Assignments in California: California presented a special case in C-value assignment because the proximity of neighboring states with existing C-value lists was limited. C-values for California taxa-state pairs were drawn primarily from Washington, Oregon, and Colorado. This approach still left 54 species with no C-value from an ecoregionally-similar state. A large proportion of these 54 species were uncommon or endemic to California, though a few were introduced or weedy. The NWCA vegetation team assigned preliminary C-values for these 54 species based on review of floristic distribution maps, habitat descriptions, and ecological information from a variety of databases and floras.

5.9.2.3.2 Genus-State Pair Assignments

During the field surveys for the NWCA, crews were occasionally able to identify a plant specimen only to the genus level. Many of the state lists contained C-values for genera and these were applied to the pertinent NWCA genus-state pairs from the NFQD (see **Section 5.9.2.3**). In other situations C-values were not available for genera. This issue was addressed in several ways. First, for states with C-value lists, a genus-state pair C-value was assigned as the median of C-values for all species of that genus. For each NWCA genus-state pair from states without a C-value list, C-values were assigned using a variation of the procedures for assigning C-values to species-state pairs as described above (**Section 5.9.2.3.1**), assuming there was a genus C-value from an appropriate neighboring state. For the remaining genus-state pairs, a median C-value was calculated using the existing species records for that genus in the nearest-neighbor state. The median score became the final C-value assignment for the genus-state pair. The C-value was considered 'Undetermined' when an assignment could not be made with ecological confidence.

5.9.2.4 *Final NWCA C-value Assignments and Use*

The final NWCA C-value assignments incorporated into the NFQD for taxa-state pairs observed in the 2011 NWCA, and which were used in the NWCA vegetation analysis included approximately:

- 11,600 species state pairs with C-values
- 1000 genus-state pairs with C-values
- 370 taxa-state pairs lacking C-values
    - *260 of these representing family- or growth form-state pairs*
    - *110 representing species- or genus-state pairs for which no determination could be made*

The NWCA C-values were used in calculation of floristic quality indices (e.g., variations of FQAI and Mean C) and metrics describing sensitivity and tolerance to disturbance. See **Section 6.8, Appendix D** for a list of specific metrics. For taxa-state pairs lacking C-values, the NWCA adopted the standard practice of excluding these taxa from calculations of metrics of floristic quality and of disturbance sensitivity or tolerance. The 370 taxa-state pairs lacking C-values represented a very small proportion of NWCA taxa observed across all sites (i.e., ~ 2%), and where these taxa occurred, they typically had low abundance (e.g., most < 1% absolute cover), so their exclusion was expected to have little impact on metric values.

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5.11 Appendix A: Vegetation Field Data Forms

FORM V-2a: NWCA VASCULAR SPECIES PRESENCE AND COVER (Front)

Reviewed by (initial): ______

Site ID: NWCA11- Date: ___ / ___ / 2 0 1 1 Page 1 of ___

Instructions:

1. **General:** Print using ALL CAPITAL LETTERS. Write as neatly as possible, keeping all marks within data fields or workspace areas.
2. **Species Name**: List binomial name or pseudonym for each plant species observed in the Veg Plots (See the NWCA FOM for Pseudonym assignment rules).
3. **Presence Data:** For each species occurring in a *quadrat nest (SW or NE corners of Veg Plot)*, **record the smallest quadrat/plot size in which it occurs by filling in the appropriate bubble (S (small) = 1-m² quadrat, M (medium) = 10-m² quadrat.) If a species does not occur in a particular nest, but occurs in the 100-m2 Veg Plot, fill in the L (large) bubble for that nest.**
4. **Predominant Height Class:** For each species observed, note its predominant height across each 100-m² Veg Plot by recording the appropriate height class code (defined below).
5. **Cover Data:** Estimate cover across each 100-m² Veg Plot (0 to 100%; See NWCA-FOM) for each species observed and record in the *Cover* data field. If necessary, use the gray workspace to make preliminary cover estimates for each species in each of the four quarters of the Veg Plot, and then combine preliminary estimates to obtain total cover for the species in the Veg Plot and record in the Cover data field.
6. **Collect Specimens and Assign Collection Numbers:** For each Unknown Species (U) or designated Quality Assurance (QA) specimen collected fill in the appropriate bubble in the *Complete if Collecting* column. Once collected, assign collection numbers, beginning with 1, consecutively in order of observation or collection.

O Fill bubble to confirm empty data fields for a species in a particular plot mean 1) for presence or height class, species not present, or 2) for % Cover fields, cover = 0 zero.

Complete if Collecting

Height Classes (except E, which may occur in any vertical stratum):
1 = <0.5m, 2 = >0.5-2m, 3 = >2-5m, 4= >5-15m, 5 = >15-30m, 6 = >30m, and E = liana, vine or epiphyte species

U QA	Coll #	Species Name or Pseudonym	Plot 1 SW	Plot 1 NE	Plot 1 Ht. Class	Plot 1 % Cover	Plot 1 Work Space	Plot 2 SW	Plot 2 NE	Plot 2 Ht. Class	Plot 2 % Cover	Plot 2 Work Space	Plot 3 SW	Plot 3 NE	Plot 3 Ht. Class	Plot 3 % Cover	Plot 3 Work Space	Plot 4 SW	Plot 4 NE	Plot 4 Ht. Class	Plot 4 % Cover	Plot 4 Work Space	Plot 5 SW	Plot 5 NE	Plot 5 Ht. Class	Plot 5 % Cover	Plot 5 Work Space	Flag

Flag codes: E= End of species list, no more species observed (place in row following last recorded species on last page of Form V-2), K = No measurement made, U = Suspect measurement. F1,F2, etc. = misc. flags assigned by each field crew. Explain all flags in comment section on back side of form.

1795292803

NWCA Vascular Plant Species Presence and Cover (Front) 03/10/2011

FORM V-3: NWCA VEGETATION TYPES (Front)

Reviewed by (initial):____

Site ID: NWCA11-　　　Date: __ / __ / 2 0 1 1

Instructions:
1. Estimate the cover for each *Vascular Vegetation Stratum.*
2. Estimate cover and collect categorical data for *Non-Vascular Taxonomic Groups.*
3. Cover can range from 0 - 100% for each of the following groups: submerged aquatic vegetation, floating aquatic vegetation, lianas, vines, and epiphytes, each height class of other vascular vegetation and each Non-Vascular Group.

COVER DATA CELLS:
O Confirm that empty cells equal zero by filling in this bubble

CATEGORICAL DATA:
O Confirm a filled data bubble indicates Yes and an unfilled bubble indicates No by filling in this bubble

Predominant S & T Class	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Flag
If plot is **Pf - Palustrine Farmed (not currently in production)** fill Pf bubble **AND** indicate predominant S & T class each plot would be if never cropped.	O Pf	O Pf	O Pf	O Pf	O Pf	
If not Pf - Palustrine Farmed select the predominant S & T class for each plot. **E2EM** - Estuarine Intertidal Emergent **E2SS** - Estuarine Intertidal Scrub/Shrub/Forested **PEM** - Palustrine Emergent **PSS** - Palustrine Scrub Shrub **PFO** - Palustrine Forested **PUBPAB** - Palustrine UnconsolidatedBottom/Aquatic Bed (see **Reference Card AA-3, Side A** for definitions)	O E2EM O E2SS O PEM O PSS O PFO O PUBPAB	O E2EM O E2SS O PEM O PSS O PFO O PUBPAB	O E2EM O E2SS O PEM O PSS O PFO O PUBPAB	O E2EM O E2SS O PEM O PSS O PFO O PUBPAB	O E2EM O E2SS O PEM O PSS O PFO O PUBPAB	

% Cover Vascular Vegetation Strata	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Flag
COVER OF SUBMERGED AQUATIC VEGETATION (rooted in sediment, most plant cover submerged or floating on water) (0 - 100%)						
COVER OF FLOATING AQUATIC VEGETATION (not rooted in sediment) (0 - 100%)						
COVER OF LIANAS, VINES AND EPIPHYTES IN ANY HEIGHT CLASS (0 - 100%)						
COVER FOR ALL OTHER VASCULAR VEGETATION FOR EACH OF THE FOLLOWING HEIGHT CLASSES:						
>30m tall: e.g., very tall trees (0 - 100%)						
>15 to 30m tall: e.g., tall trees (0 - 100%)						
>5 to 15m tall: e.g., very tall shrubs; short to mid-sized trees (0 - 100%)						
>2 to 5m tall: e.g., tall shrubs; tree saplings (0 - 100%)						
0.5 to 2m tall: e.g., medium height shrubs; tree seedlings and saplings; tall emergent/terrestrial herbaceous species (0 - 100%)						
< 0.5m tall: e.g., low emergent/terrestrial; herbaceous species; low shrubs; tree seedlings (0 - 100%)						

% Cover and Categorical Data for Non-Vascular Taxa	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Flag
COVER OF BRYOPHYTES (mosses and liverworts) growing on ground surfaces, logs, rocks, etc.) (0 - 100%)						
Fill bubble if Bryophytes are dominated by *Sphagnum* or other peat-forming mosses	O	O	O	O	O	
COVER OF LICHENS growing on ground surfaces, logs, rocks, etc. (0 - 100%)						
COVER OF ARBOREAL EPIPHYTIC BRYOPHYTES AND LICHENS (see NWCA-FOM for cover estimation procedures for this group) (0 - 100%)						
COVER OF FILAMENTOUS OR MAT FORMING ALGAE (0 - 100%)						
COVER OF MACROALGAE (freshwater species/seaweeds) (0 - 100%):						
When Macroalgae is present, fill in all bubbles that apply for each Veg Plot:						
Algae occurs as wrack (detached, debris, stranded)	O	O	O	O	O	
Algae is attached/living	O	O	O	O	O	
Algae Status Unknown (Can't determine whether algae is wrack or attached/living)	O	O	O	O	O	

Flag	Comments	Flag	Comments

Flag codes: K = No measurement made, U = Suspect measurement., F1,F2, etc. = misc. flags assigned by each field crew. Explain all flags in comment section.

NWCA Vegetation Types　03/10/2011　　4741595533

2375

FORM V-3: NWCA GROUND SURFACE ATTRIBUTES (Back)

Reviewed by (initial): ______

Site ID: NWCA11-   Date: ___ / ___ / 2 0 1 1

Instructions: For each ground surface attribute carefully record the requested data.

1. **Water Cover** – Estimate total percent of Veg Plot area covered by water, then estimate cover for each subcategory of water. The sum of covers for water subcategories should equal the total water cover. Where floating/submerged and emergent vegetation occur together, classify water type based on vegetation type with greatest cover; if cover is equal classify as water and emergent vegetation.
2. **Water Depth** – Measure water depth with marked 1-m PVC pole or ruler at 3 locations representing the water level range across the plot.
3. **Litter** – Estimate total cover of litter, identify predominant types (all types with ≥25% cover), or if total litter is < 25% cover indicate primary litter type, measure litter depth in SW and NE most corners of Veg Plot in center of 1-m² quadrat.
4. **Bareground** – Estimate cover for exposed a) soil/sediment, b) gravel/cobble, c) rock. (The sum of a+b+c ≤100%).
5. **Dead Woody Material Cover** – Estimate cover (0 to 100%) for each category of dead woody material.

COVER DATA CELLS:
○ Confirm that empty cells equal zero by filling in this bubble

CATEGORICAL DATA:
○ Confirm a filled data bubble indicates presence and an unfilled bubble indicates absence by filling in this bubble

Water Cover	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Flag
1) Total Cover of Water (percent of Veg Plot area with water = a+b+c ≤ 100%)						
a) % Veg Plot area with water and no vegetation						
b) % Veg Plot area with water and floating/submerged aquatic vegetation						
c) % Veg Plot area with water and emergent vegetation						

Water Depth (make 3 depth measurements in a Veg Plot within a 10 minute period)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Flag
Minimum Depth (cm)						
Predominant Depth (cm)						
Maximum Depth (cm)						
Time of Day (24 hour clock)						

Cover of Bareground = a+b+c ≤100%	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Flag
a) Exposed soil/sediment						
b) Exposed gravel/cobble (~2mm to 25cm)						
c) Exposed rock (>25cm)						

Vegetative Litter	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Flag
Total Cover Vegetative Litter (0-100%)						
Predominant (>25% cover) or Primary Litter type(s) (see Instructions) (Fill in all that apply): T = Thatch (dead graminoid (e.g., grasses, sedges, rushes), leaves, rhizomes, or other material); F = Forb; D = Deciduous Tree; E = Broadleaf Evergreen Tree; C = Coniferous Tree; N = None	○T ○E ○F ○D ○C ○N	○T ○E ○F ○D ○C ○N	○T ○E ○F ○D ○C ○N	○T ○E ○F ○D ○C ○N	○T ○E ○F ○D ○C ○N	
Litter Depth (cm) in center of 1-m² quadrat at SW Veg Plot corner						
Litter Depth (cm) in center of 1-m² quadrat at NE Veg Plot corner						

Cover of Downed Dead Woody Material (angle of incline <45°)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Flag
Cover of Downed Coarse Woody debris (>5cm diameter) (0-100%)						
Cover of Downed Fine Woody debris (<5cm diameter) (0-100%)						

Flag	Comments

Flag codes: K = No measurement made, U = Suspect measurement., F1,F2, etc. = misc. flags assigned by each field crew. Explain all flags in comment section.

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NWCA Ground Surface Attributes 03/10/2011

FORM V-4a: NWCA SNAG AND TREE COUNTS AND TREE COVER (Front)

Reviewed by (initial): ____

Site ID: NWCA11-   Date: __ / __ / 2 0 1 1   Page 1 of __

Instructions for Recording Data:

1. **Fill out Header Information.**
2. **If Live Trees or Snags are Absent** from a Veg Plot, fill in the appropriate bubble in the *Tree or Snag Absence* field.
3. **If either Live Trees or Snags are Present** in a Veg Plot, collect data across the entire 100-m^2 area of each Veg Plot.
4. **Standing Dead Trees and Snags (angle of incline ≥ 45°)**: Count snags > 5cm DBH by diameter class and record the total number of snags for each DBH class in the white data column for the appropriate Veg Plot.
5. **For Each Live Tree Species:** Use one row for each plot in which each tree species is found. Be sure to indicate the Veg Plot number in the *Plot #* column next to each species name.
6. **Cover of trees in height classes:** Record species names or pseudonyms for each tree species. Ensure pseudonyms match those used on **Form V-2**. Record the percent cover (0-100%) for each tree species for each of the following height classes: < 0.5m, 0.5 to 2m, > 2 to 5m, > 5 to 15m, >15 to 30m, >30m.
7. **Live Trees:** Count trees > 5cm DBH in each Veg Plot by species in DBH classes and record the total number of trees for each diameter class in the white data column.
8. **Counting Trees or Snags:** If needed, for smaller DBH classes when many trees or snags are present, a running tally* of the numbers of all snags, or for each tree species, in each DBH class can be recorded in the gray shaded workspace in the DBH columns. Once all the snags or tree species are tallied for a plot, record the total number for each species in each DBH class in the white data field for each DBH column.

Tally format*: 1 2 3 4 5 6 7 8 9 10

O Fill in bubble to confirm that empty data cells equal zero.

TREES OR SNAGS ABSENCE: Fill in all that apply:
LTA=Live Trees Absent, DTA=Dead Trees/Snags Absent

Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
O LTA	O LTA	O LTA	O LTA	O LTA
O DTA	O DTA	O DTA	O DTA	O DTA

Standing Dead Tree/Snag Counts by DBH Class
(White box = data field, Gray box = tally workspace)

Plot	5 to 10cm		11 to 25cm		26 to 50cm		51 to 75cm		76 to 100cm	101 to 200cm	Flag
1											
2											
3											
4											
5											

Tree Cover by Height Class / **Tree Counts by DBH Class**
(White box = data field, Gray box = tally workspace) (DBH = diameter breast height)

Plot #	Live Tree Species Name/Pseudonym	<0.5m	>0.5-2m	>2-5m	>5-15m	>15-30m	>30m	5 to 10cm		11 to 25cm		26 to 50cm		51 to 75cm		76 to 100cm	101 to 200cm	>200 cm	Flag
O1 O2 O3 O4 O5																			
O1 O2 O3 O4 O5																			
O1 O2 O3 O4 O5																			
O1 O2 O3 O4 O5																			
O1 O2 O3 O4 O5																			
O1 O2 O3 O4 O5																			

Flag codes: K = No measurement made, U = Suspect measurement, F1, F2, etc = misc.flags assigned by each field crew. Explain all flags in comment section on back side of form.

NWCA Snag & Tree Counts (Front) 03/10/2011   2318393335

5.12 Appendix B: Parameter Names for Field Collected Vegetation Data

PARAMETER NAME	DESCRIPTION	RESULT	VALID RANGE/ LEGAL VALUES
Form V-2a and V-2b: NWCA Vascular Species Presence and Cover			
***Plant Species Data*: Cover, presence, and height data for each vascular plant species observed in each of five 100-m^2 (10x10m) Veg Plots. Presence of each species in four component nested quadrats for each Veg Plot.**			
SPECIES	Scientific Name for each species (taxon) encountered in the Veg Plot. Scientific names reconciled to USDA_PLANTS nomenclature. Unknowns are named using growth form codes.	Typically the genus and species name. In some cases: lower taxonomic levels (e.g., subspecies, varieties) or higher taxonomic levels (e.g., genus, family, growth form)	Taxon name
SW	For each species present, the smallest scale at which it is first observed: 1-m^2 or 10-m^2 quadrat in SW corner or in larger 100-m^2 Veg Plot	**One of:** S = 1-m^2 quadrat, M = 10-m^2 quadrat, or L = entire 100-m^2 Veg Plot	S, M, or L
NE	For each species present, the smallest scale at which it is first observed: 1-m2 or 10-m2 quadrat in NE corner or in larger 100-m^2 Veg Plot	**One of:** S = 1-m^2 quadrat, M = 10-m^2 quadrat, or entire L = 100-m^2 Veg Plot	S, M, or L
HEIGHT	Predominant height class for each species present across a Veg Plot	**One Height Class:** 1 = < 0.5m, 2 = > 0.5m-2m, 3 = > 2-5m, 4 = > 5-15m, 5 = > 15-30m, 6 = > 30m, or E = Liana, vine, or epiphyte species	1, 2,3, 4, 5, 6, or E
COVER	Percent cover of each species across a Veg Plot	Cover value for each species present is estimated as a direct percentage of the spatial area of the plot overlain by that species and can range from 0 to 100%.	0-100%
Form V-3: NWCA Vegetation Types (Front) and Ground Surface Attributes (Back)			
***Vegetation Type Data:* Observations from each of five 100-m2 (10x10m) Veg Plots**			
<u>Predominant Status & Trends Category</u>			
PAL_FARMED	Palustrine farmed (Pf) Class dominating Veg Plot	If Pf present, PF where present	PF
SANDT_CLASS	FWS Status Trends Class dominating Veg Plot	**One S&T Category: E2EM - E**stuarine Intertidal Emergent, **E2SS -** Estuarine Shrub/Forested, **PEM –** Palustrine, Lacustrine, or Riverine Emergent, **PSS –** Palustrine, Lacustrine, or Riverine Scrub/Shrub, **PFO -** Palustrine , Lacustrine, or Riverine Forested, **PUBPAB** - Palustrine, Lacustrine, or Riverine Unconsolidated Bottom	E2EM, E2SS, PEM, PSS, PFO, or PUBPAB

PARAMETER NAME	DESCRIPTION	RESULT	VALID RANGE/ LEGAL VALUES
% Cover Vascular Vegetation Strata			
SUBMERGED_AQ	% Cover Submerged Aquatic Vegetation	0-100 % Cover	0-100%
FLOATING_AQ	% Cover Floating Aquatic Vegetation	0-100 % Cover	0-100%
LIANAS	% Cover Lianas, vines, and vascular epiphytes	0-100 % Cover	0-100%
Cover for other vascular vegetation in height classes indicated below:			
VTALL_VEG	% Cover Vegetation > 30m tall	0-100 % Cover	0-100%
TALL_VEG	% Cover Vegetation > 15m to 30m tall	0-100 % Cover	0-100%
HMED_VEG	% Cover Vegetation > 5m to 15m tall	0-100 % Cover	0-100%
MED_VEG	% Cover Vegetation >2m to 5 tall	0-100 % Cover	0-100%
SMALL_VEG	% Cover Vegetation 0.5 to 2m tall	0-100 % Cover	0-100%
VSMALL_VEG	% Cover Vegetation < 0.5m tall	0-100 % Cover	0-100%
% Cover and Categorical Data for Non-Vascular Taxa			
BRYOPHYTES	% Cover of Bryophytes growing on ground surfaces, logs, rocks, etc.	0-100 % Cover	0-100%
PEAT_MOSS	Bryophytes dominated by Sphagnum or other peat forming moss	Y (yes), if present	Yes/No
LICHENS	% Cover of Lichens growing on ground surfaces, logs, rocks, etc.	0-100 % Cover	0-100%
ARBOREAL	% Cover of Arboreal Bryophytes and Lichens	0-100 % Cover	0-100%
ALGAE	% Cover of filamentous or mat forming algae	0-100 % Cover	0-100%
MACROALGAE	% Cover of macroalgae (freshwater species/seaweeds)	0-100 % Cover	0-100%
WRACK	Macroalgae occurs wrack (detached, debris, stranded)	Y (yes), if present	Yes/No
ATTACHED	Macroalgae is attached/living	Y (yes), if present	Yes/No
UNK_ALGAE	Macroalgae status unknown (can't determine whether wrack or living)	Y (yes), if present	Yes/No
Ground Surface Attributes			
Water Cover and Depth			
TOTAL_WATER	Total cover of water (percent of Veg Plot area with water = a+b+c ≤ 100%)	% Cover	0-100%

PARAMETER NAME	DESCRIPTION	RESULT	VALID RANGE/ LEGAL VALUES
WATER_NOVEG	a) % Veg Plot area with water and no vegetation	% Cover	0-100%, ≤ TOTAL_WATER
WATER_AQVEG	b) % Veg Plot area with water and floating/submerged aquatic vegetation	% Cover	0-100%, ≤ TOTAL_WATER
WATER_EMERGVEG	c) % Veg Plot area with water and emergent and/or woody vegetation	% Cover	0-100%, ≤ TOTAL_WATER
MINIMUM_DEPTH	Minimum water depth	depth in cm	Investigate if >100 cm
PREDOMINANT_DEPTH	Predominant water depth	depth in cm	Investigate if >100 cm
MAXIMUM_DEPTH	Maximum water depth	depth in cm	Investigate if >100 cm
TIME	Time water depth measurements were made	time on 24 hour clock	500 to 2100 (investigate if outside this range)
Bareground and Litter			
Total cover of bareground = a + b + c ≤ 100%			
EXPOSED_SOIL	a) Cover exposed soil/sediment	% Cover	≤ 100%
EXPOSED_GRAVEL	b) Cover exposed gravel/cobble (~2mm to 25cm)	% Cover	≤ 100%
EXPOSED_ROCK	c) Cover exposed rock (>25cm)	% Cover	≤ 100%
TOTAL_LITTER	Total cover of litter	% Cover	≤ 100%
Predominant Litter Types (>25% cover) or Primary Litter type (if all litter < 25%):			
LITTER_THATCH	Thatch (dead graminoid (e.g., grasses, sedges, rushes) leaves, rhizomes, or other material))	If present, THATCH	THATCH
LITTER_FORB	Forb litter	If present, FORB	FORB
LITTER_CONIFER	Conifer litter	If present, CONIFER	CONIFER
LITTER_DECID	Deciduous litter	If present, DECID	DECID
LITTER_BROADLEAF	Broadleaf evergreen litter	If present, BROADLEAF	BROADLEAF
LITTER_NONE	No litter	If litter absent, NONE	NONE
LITTER_DEPTH_SW	Litter depth (cm) in center of 1-m^2 quadrat at SW corner of Veg Plot	depth in cm	Investigate if >100 cm
LITTER_DEPTH_NE	Litter depth (cm) in center of 1-m^2 quadrat at NE corner of Veg Plot	depth in cm	Investigate if >100 cm
WD_FINE	Cover of fine woody debris (<5cm diameter)	% Cover	0-100%

PARAMETER NAME	DESCRIPTION	RESULT	VALID RANGE/ LEGAL VALUES
WD_COARSE	Cover of coarse woody debris (> 5cm diameter)	% Cover	0-100%
Form V-4a and V-4b: NWCA Snag and Tree Counts and Tree Cover			
Tree species (cover and counts) and Snag (counts) data for each of 5 100-m^2 (10x10m) Veg Plots			
Snag Data			
XXTHIN_SNAG	Dead trees/snags 5 to 10 cm DBH (diameter breast height)	Counts	Investigate if > 200
XTHIN_SNAG	Counts of dead trees/snags 11 to 25cm DBH	Counts	Investigate if > 200
THIN_SNAG	Counts of dead trees/snags 26 to 50cm DBH	Counts	Investigate if > 200
JR_SNAG	Counts of dead trees/snags 51 to 75cm DBH	Counts	Investigate if > 200
THICK_SNAG	Counts of dead trees/snags 76 to 100cm DBH	Counts	Investigate if > 200
XTHICK_SNAG	Counts of dead trees/snags 101 to 200 cm DBH	Counts	Investigate if > 200
Tree Data			
Tree Species Name			
TREE_SPECIES	Scientific Name for each tree species (taxon) encountered in the Veg Plot. All scientific names reconciled to USDA_PLANTS nomenclature. Unknowns are named using growth form codes.	Typically the genus and species name. In some cases: lower taxonomic levels (e.g., subspecies, varieties) or higher taxonomic levels (e.g., genus, family, growth form group)	Taxon name
Tree Species Cover by Height Class			
VSMALL_TREE	For each tree species, cover of trees < 0.5m tall	0-100 % Cover	0-100%
SMALL_TREE	For each tree species, cover of trees 0.5m to 2m tall	0-100 % Cover	0-100%
LMED_TREE	For each tree species, cover of trees > 2 to 5m tall	0-100 % Cover	0-100%
HMED_TREE	For each tree species, cover of trees > 5m to 15m tall	0-100 % Cover	0-100%
TALL_TREE	For each tree species, cover of trees > 15m to 30m tall	0-100 % Cover	0-100%
VTALL_TREE	For each tree species, cover of trees > 30m tall	0-100 % Cover	0-100%
XXTHIN_TREE	For each tree species, counts of trees 5 to 10 cm DBH (diameter breast height)	Counts	Investigate if > 200
XTHIN_TREE	For each tree species, counts of trees 11 to 25cm DBH	Counts	Investigate if > 100

PARAMETER NAME	DESCRIPTION	RESULT	VALID RANGE/ LEGAL VALUES
THIN_TREE	For each tree species, counts of trees 26 to 50cm DBH	Counts	Investigate if > 50
JR_TREE	For each tree species, counts of trees 51 to 75cm DBH	Counts	Investigate if > 20
THICK_TREE	For each tree species, counts of trees 76 to 100cm DBH	Counts	Investigate if > 10
XTHICK_TREE	For each tree species, counts of trees 101 to 200 cm DBH	Counts	Investigate if > 5
XXTHICK_TREE	For each tree species, counts of trees > 200 cm DBH	Counts	Investigate if > 5

5.13 Appendix C: Sources of C-values in the National Floristic Quality Database

State	Source of C-values used in National Floristic Quality Database
AL	Gianopulos, K. 2014. Coefficient of Conservatism Database Development for Wetland Plants in the Southeast United States. North Carolina Dept. of Environment and Natural Resources, Division of Water Resources. Wetlands Branch. Report to the EPA, Region 4.
AK	*No State or regional CC list available.*
AZ	*No State or regional CC list available.*
AR	*No State or regional CC list available.*
CA	*No State or regional CC list available.*
CO	Rocchio, J. 2007. Floristic Quality Assessment Indices of Colorado Plant Communities. Colorado ram, Colorado State University. Natural Heritage Program, Fort Collins, CO.
CT	New England Interstate Water Pollution Control Commission. 2011. Coefficients of Conservatism for the Vascular Flora of New York and New England (unpublished). http://www.neiwpcc.org/nebawwg/necocscores.asp.
DE	McAvoy, W. A. 2012. The Flora of Delaware Online Database. Delaware Division of Fish and Wildlife, Natural Heritage and Endangered Species Program, Smyrna, Delaware. http://www.wra.udel.edu/de-flora
FL	Gianopulos, K. 2014. Coefficient of Conservatism Database Development for Wetland Plants in the Southeast United States. North Carolina Dept. of Environment and Natural Resources, Division of Water Resources. Wetlands Branch. Report to the EPA, Region 4.
	Lane, C. R., M. T. Brown, M. Murray-Hudson, and M. B. Vivas. 2003. The Wetland Condition Index (WCI): Biological Indicators for Isolated Depressional Herbaceous Wetlands in Florida. A report to the Florida Department of Environmental Protection. HT Odum Center for Wetlands, University of Florida, Gainesville, Florida, USA.
	Mortellaro, S., M. Barry, G. Gann, J. Zahina, S. Channon, C. Hilsenbeck, D. Scofield, G. Wilder, and G. Wilhelm. 2012. Coefficients of Conservatism Values and the Floristic Quality Index for the Vascular Plants of South Florida. Southeastern Naturalist 11: 1-62.
	Reiss, K. C. and M. T. Brown. 2005a. The Florida Wetland Condition Index (FWCI): Developing Biological Indicators for Isolated Depressional Forested Wetlands. A report to the Florida Department of Environmental Protection. HT Odum Center for Wetlands, University of Florida, Gainesville, Florida, USA.
	Reiss, K. C. and M. T. Brown. 2005b. Pilot Study - The Florida Wetland Condition Index (FWCI): Preliminary Development of Biological Indicators for Forested Strand and Floodplain Wetlands. A report to the Florida Department of Environmental Protection. HT Odum Center for Wetlands, University of Florida, Gainesville, Florida, USA.
GA	Gianopulos, K. 2014. Coefficient of Conservatism Database Development for Wetland Plants in the Southeast United States. North Carolina Dept. of Environment and Natural Resources, Division of Water Resources. Wetlands Branch. Report to the EPA, Region 4.
	Zomlefer, W. B., L. Chafin, J. R. Carter, & D. E. Giannasi. 2013. Coefficient of conservatism rankings for the flora of Georgia: Wetland indicator species. Southeastern Naturalist 12: 790-808.
IA	Brudvig, L. A., C. M. Mabry, J. R. Miller, and T. A. Walker. 2007. Evaluation of Central North American Prairie Management Based on Species Diversity, Life Form, and Individual Species Metrics. Conservation Biology 21: 864-874.
ID	*No State or regional CC list available.*

State	Source of C-values used in National Floristic Quality Database
IL	Taft, J. B., G. S. Wilhelm, D. M. Ladd, and L. A. Masters. 2003. Floristic Quality Assessment for Vegetation in Illinois a Method for Assessing Vegetation Integrity. Reprinted with the permission of the Illinois Native Plant Society.
IN	Rothrock, P. E. 2004. Floristic Quality Assessment in Indiana: The concept, use, and development of coefficients of conservatism. EPA Wetland Program Development Grant, Taylor University.
KS	Freeman, C. C. 2012. Coefficients of conservatism for Kansas vascular plants (2012) and selected life history attributes. Kansas Biological Survey, University of Kansas. http://ksnhi.ku.edu/media/ksnhi/public-data resources/
KY	White, D., M. Shea., D. Ladd, and M. Evans. 1997. Kentucky Coefficients of Conservatism. The Kentucky State Nature Preserves Commission, the Kentucky Chapter of The Nature Conservancy, the Missouri Chapter of The Nature Conservancy, and the Kentucky State Nature Preserves Commission.
	Gianopulos, K. 2014. Coefficient of Conservatism Database Development for Wetland Plants in the Southeast United States. North Carolina Dept. of Environment and Natural Resources, Division of Water Resources. Wetlands Branch. Report to the EPA, Region 4.
LA	Cretini, K. F., J. M. Visser, K. W. Krauss, and G. D. Steyer. 2012. Development and use of a floristic quality index for coastal Louisiana marshes. Environmental Monitoring Assessment 184:2389-2403.
ME	New England Interstate Water Pollution Control Commission. 2011. Coefficients of Conservatism for the Vascular Flora of New York and New England (unpublished). http://www.neiwpcc.org/nebawwg/necocscores.asp.
MD	Sarah J. Chamberlain and Hannah M. Ingram. 2012. Developing coefficients of conservatism to advance floristic quality assessment in the Mid-Atlantic region. J. Torrey Bot. Soc. 139: 416-427.
MA	New England Interstate Water Pollution Control Commission. 2011. Coefficients of Conservatism for the Vascular Flora of New York and New England (unpublished). http://www.neiwpcc.org/nebawwg/necocscores.asp.
MI	Herman, K. D., L. A. Masters, M. R. Penskar, A. A. Reznicek, G. S. Wilhelm, W. W. Brodovich, and K. P. Gardiner. 2001. Floristic Quality Assessment with Wetland Categories and Examples of Computer Applications for the State of Michigan. Revised, 2nd edition. MDNR.
MN	Milburn, S. A., M. Bourdaghs, and J. J. Husveth. Floristic Quality Assessment for Minnesota Wetlands. Minnesota Pollution Control Agency, St. Paul, Minn.
MS	Herman, B. D., J. D. Madsen, and G. N. Ervin. 2006. Development of Coefficients of Conservatism for Wetland Vascular Flora of North and Central Mississippi. GeoResources Institute Report 4001.
	Gianopulos, K. 2014. Coefficient of Conservatism Database Development for Wetland Plants in the Southeast United States. North Carolina Dept. of Environment and Natural Resources, Division of Water Resources. Wetlands Branch. Report to the EPA, Region 4.
MO	Ladd, D. M. 1993. Coefficients of Conservatism for Missouri vascular flora. The Nature Conservancy, St. Louis, MO. 53 p.
MT	Jones, W. M. 2005. A vegetation index of biotic integrity for small-order streams in southwestern Montana and a Floristic Quality Assessment for western Montana wetlands. Report to the Montana Department of Environmental Quality and US Environmental Protection Agency, Montana Natural Heritage Program.
NE	Rolfsmeier, S. and G. Steinauer. 2003. Vascular Plants of Nebraska (Version I -July 2003). Nebraska Game and Parks Commission, Lincoln, NE 57 pp.
NV	*No State or regional CC list available.*

State	Source of C-values used in National Floristic Quality Database
NH	New England Interstate Water Pollution Control Commission. 2011. Coefficients of Conservatism for the Vascular Flora of New York and New England (unpublished). http://www.neiwpcc.org/nebawwg/necocscores.asp.
NJ	Kelly, L., K. Anderson, K. S. Walz, and D. B. Snyder. 2013. New Jersey Floristic Quality Assessment: Coefficients of Conservatism for Vascular Taxa. New Jersey Department of Environmental Protection, State Forestry Services, Office of Natural Lands Management, Natural Heritage Program, Trenton, NJ.
NM	*No State or regional CC list available.*
NY	New England Interstate Water Pollution Control Commission. 2011. Coefficients of Conservatism for the Vascular Flora of New York and New England (unpublished). http://www.neiwpcc.org/nebawwg/necocscores.asp.
NC	Gianopulos, K. 2014. Coefficient of Conservatism Database Development for Wetland Plants in the Southeast United States. North Carolina Dept. of Environment and Natural Resources, Division of Water Resources. Wetlands Branch. Report to the EPA, Region 4.
ND	The Northern Great Plains Floristic Quality Assessment Panel. 2001, Coefficients of conservatism for the vascular flora of the Dakotas and adjacent grasslands: US Geological Survey, Biological Resources Division, Information and Technology Report USGS/ BRD/ITR—2001-0001, 32 p.
OH	Andreas, B. K., J. J. Mack, and J. S. McCormac. 2004. Floristic Quality Assessment Index (FQAI) for vascular plants and mosses for the State of Ohio. Ohio Environmental Protection Agency, Division of Surface Water, Wetland Ecology Group, Columbus, OH, 219 p.
OK	Ewing, A. K. and B. Hoagland. 2012. Development of Floristic Quality Index Approaches for Wetland Plant Communities in Oklahoma. USEPA Final Report, FY 2010, 104(b)(3), CD-00F074, Project 2.
OR	Magee, T.K. and M. A. Bollman. *Unpublished*. Coefficients of Conservatism for 538 species observed in riparian areas associated with randomly selected 1-km long stream reaches including 36 sites distributed across the John Day River Basin (eastern Oregon) and 4 sites in the Oregon Cascade Range.
PA	Chamberlain, S. J. and H. M. Ingram. 2012. Developing coefficients of conservatism to advance floristic quality assessment in the Mid-Atlantic region. Journal of the Torrey Botanical Society 139: 416-427.
RI	New England Interstate Water Pollution Control Commission. 2011. Coefficients of Conservatism for the Vascular Flora of New York and New England (unpublished). http://www.neiwpcc.org/nebawwg/necocscores.asp.
SC	Gianopulos, K. 2014. Coefficient of Conservatism Database Development for Wetland Plants in the Southeast United States. North Carolina Dept. of Environment and Natural Resources, Division of Water Resources. Wetlands Branch. Report to the EPA, Region 4.
SD	The Northern Great Plains Floristic Quality Assessment Panel. 2001. Coefficients of conservatism for the vascular flora of the Dakotas and adjacent grasslands: US Geological Survey, Biological Resources Division, Information and Technology Report USGS/ BRD/ITR—2001-0001, 32 p.
TN	Willis, K. and L. Estes. 2013. Floristic Quality Assessment for Tennessee Vascular Plants, and Application to Barrens Environments. Manuscript in Preparation.
	Gianopulos, K. 2014. Coefficient of Conservatism Database Development for Wetland Plants in the Southeast United States. North Carolina Dept. of Environment and Natural Resources, Division of Water Resources. Wetlands Branch. Report to the EPA, Region 4.
TX	*No State or regional CC list available.*
UT	*No State or regional CC list available.*

State	Source of C-values used in National Floristic Quality Database
VT	New England Interstate Water Pollution Control Commission. 2011. Coefficients of Conservatism for the Vascular Flora of New York and New England (unpublished). http://www.neiwpcc.org/nebawwg/necocscores.asp.
VA	Virginia Department of Environmental Quality. Office of Wetlands & Water Protection. 2005. Determining Coefficient of Conservatism Values (C-Values) for Vascular Plants Frequently Encountered in Tidal and Nontidal Wetlands in Virginia
WA	Rocchio, F. J. 2013. Western Washington Floristic Quality Assessment. Natural Heritage Program Report Number 2013-03. Natural Heritage Program, Washington Department of Natural Resources. Olympia, Washington. http://www1.dnr.wa.gov/nhp/refdesk/communities/fqa/fqa_report.pdf
WV	Rentch, J. S. and J. T. Anderson. 2006. A floristic quality index for West Virginia wetland and riparian plant communities. West Virginia Agricultural and Forestry Experiment Station Bulletin. Bulletin 2967. 67pp
WI	Bernthal, T. W. 2003. Development of a Floristic Quality Assessment methodology for Wisconsin. Report to the USEPA (Region V). Wisconsin Department of Natural Resources, Madison, WI. Note the appendix containing the C values is listed in a separate website.
WY	*No State or regional CC list available.*

Chapter 6: Candidate Vegetation Metrics of Condition or Stress

6.1 Background

Potential vegetation indicators of ecological condition or stress in wetlands were identified during the planning effort for NWCA. The indicator selection process included extensive literature review, several workshops involving many wetland experts who provided recommendations of indicators based on evaluations of utility and cost-effectiveness, and a final workshop including states, tribes, and other NWCA partners to allow review of and consensus on selection of Metric Groups to be evaluated in the NWCA. Several major Vegetation Metric Groups (**Table 6-1**) were recognized as ecologically important and/or commonly used as indicators in wetland assessments.

The NWCA Vegetation Field Protocol (see **Section 5.3**) was designed to collect data to inform the development of candidate metrics within these Metric Groups. Validated vegetation field data (see **Sections 5.3.2 and 5.5**), along with species trait information, (see **Sections 5.6 through 5.9**) were used to develop candidate metrics.

In this chapter, we focus on development and evaluation of candidate vegetation metrics that describe wetland ecological condition or stress. Both metric evaluation (this chapter) and the development of the NWCA VMMI (**Chapter 7**) require 1) accounting for natural, regional, and wetland type variability, and 2) the use of calibration and validation data. The NWCA divided the data from sampled sites into two groups, one data set for calibration of metrics and potential VMMI(s) and one for validation of results. The first application of accounting for variability and first use of calibration and validation data occurs here, so both topics are discussed in subsections this chapter and we refer back to them, as needed, from **Chapter 7 "Wetland Condition – Vegetation Multimetric Index"**. All analyses for metric development, calculation, and evaluation were conducted using R Statistical Software, version 3.1.1 (R Core Team 2014).

6.2 Developing and Calculating Candidate Metrics

Each Metric Group listed in **Table 6-1** is comprised of a variety of major metric types, and for each metric type, several-to-many specific candidate metrics for describing ecological condition or stress were calculated. Most of the metric types include versions of metrics that incorporate all species, only native species, or only nonnative species. Vegetation metrics based on all species or on native species only were considered potential descriptors of wetland condition (n = 405). Metrics based on only nonnative species were viewed as indicators of wetland stress (n = 126). For the NWCA, nonnative plant species were defined as both alien and cryptogenic species (see **Section 5.8** and **Chapter 8**, **Section 8.5**). Candidate condition metrics were used in developing the Vegetation Multimetric Index (VMMI, see Chapter 7), whereas, candidate vegetation stressors were used in the development of the Nonnative Plant Stressor Indicator (NPSI) (see **Chapter 8**, **Section 8.5**).

Numerous metrics were developed and evaluated because the NWCA was the first attempt to develop vegetation indices reflecting ecological condition or stress at the scale of the conterminous US. The NWCA candidate metric set included metrics that were likely to have broad applicability across regions and wetland types, as well as, metrics that were expected to have more restricted utility for specific wetland types. The 531 candidate metrics developed and calculated for the NWCA are described in **Section 6.8**, **Appendix D**, which lists: names and short descriptions of the metrics, how each was calculated, the field data and species trait groups on which each metric is based, and whether the metric is intended to describe ecological condition or stress.

Table 6-1. Metric Groups and component Metric Types for characterizing vegetation condition.

Metric Groups	**Major Metric Types for each Indicator/Metric Group** *(Most types include versions of metrics based on all, native, or nonnative species)*
Taxa Composition	Richness, diversity, frequency, cover, importance of vascular plant species, genera, families, etc.
Floristic Quality	Mean Coefficient of Conservatism, Floristic Quality Assessment Index (presence based and frequency and cover weighted versions)
Tolerance and Sensitivity to Disturbance	Richness and abundance of sensitive, insensitive, tolerant, highly tolerant species
Hydrophytic Status	Richness and abundance by Wetland Indicator Status; Wetland Indices
Life History	Richness and abundance by growth habit type, duration/longevity category, vascular plant category (e.g., ferns, dicots, etc.)
Vegetation Structure	Frequency, cover, importance, diversity, by structural (height) vegetation groups
Nonvascular	Frequency, cover, importance for ground or arboreal bryophytes or lichens, algae
Ground Surface Attributes	Frequency, cover, importance, depth, types of water, litter, bare ground
Woody Debris and Snags	Frequency, cover, importance for woody debris, counts for snags
Trees	Richness, counts, or frequency, cover or importance by height or diameter classes

Development of each metric necessitated specification of required validated field data and trait information, the data tables within the NWCA database where relevant data were located, and a general formula for metric calculation. Autecological traits for each vascular plant and tree species were merged with cover data based on geographic region where necessary, resulting in site-specific traits associated with cover information. This information was used to develop R code to calculate each metric.

The accuracy of metric calculations was checked in several ways. First, five NWCA sampled sites representing highly divergent species richness, species composition, and wetland types were selected for checking accuracy of the R code computations, and to ensure that the R code was calculating the metrics as intended. For these five sites, formulas for calculating the metrics were developed in Excel and results were compared to the values for the metrics resulting from the R-code. In addition, all metrics for these five sites were recalculated by hand to verify that they reflected the concepts intended by the Vegetation Analysis Team. Any discrepancies observed were resolved in the R code.

Next, code was developed independently in SAS (v.9.2, SAS Institute Inc., Cary, NC) to calculate all vegetation metrics for all sampled sites. The results of the SAS-based calculations were compared to the results obtained from the R Code as a quality assurance check on the accuracy of computations. Comparison of both sets of code showed no differences in any calculated values. Following completion of these quality assurance procedures, the resulting 531 candidate metrics, calculated for all sampled sites, were compiled in the vegetation metric data set that was used in analyses to assess wetland condition or stress based on vegetation properties.

6.3 Accounting for Regional and Wetland Type Differences

Ecoregional variation in species composition, environmental conditions, and human-caused disturbance may be great at the scale of the conterminous United States. In addition, wetland type interacts with these sources of variability. All these sources of variation have implications for the definition of least disturbed or reference sites. In addition, this variation can influence or obscure the response of candidate metrics to human-caused disturbance. To account for physical and biotic diversity, finer scales (sub-national) or modeling approaches are often needed to facilitate development of effective VMMI(s) and to define thresholds for good, fair, and poor classes of ecological condition (Hawkins et al. 2010; Pont et al. 2009; Stoddard et al. 2008; USEPA 2006).

For the NWCA, we employed a series of site groupings to account for this variation and inform candidate metric evaluation and VMMI development:

- All wetlands – National Scale
- 4 Aggregated Ecoregions
- 4 Aggregated Wetland Types
- 10 Aggregated Ecoregion *x* Aggregated Wetland Type Groups (Reporting Groups)

Rationale for, and a description of, these Site Groups are provided in **Chapter 4**, along with the procedures defining least (reference) and most disturbed sites.

All 1138 sites (probability and not-probability sites) sampled in in the 2011 NWCA (see **Chapter 4**, **Table 4-9**) were used in candidate metric evaluation and for developing the NWCA VMMI. The distribution of the 1138 sites (total number of sites and the numbers of sampled sites identified as least, intermediate, and most disturbed) for each of three major NWCA Site Groups are listed in **Table 6-2** through **Table 6-4**. In **Table 6-4**, in addition to numbers of sampled sites for the 10 NWCA Reporting Groups, the total sample sizes across the conterminous US are provided, along with the number of Revisit Sites that were sampled, once during the index visit (primary sampling event, Visit 1) and again during the sampling season (Visit 2) to quantify within-year sampling variability.

Table 6-2. Distribution of 1138 NWCA sampled sites (probability and not-probability) by 2011 NWCA Aggregated Ecoregions. n = numbers of sites.

Code	Aggregated Ecoregions (NWCA_ECO4)	n Total	n Least Disturbed	n Intermediate Disturbance	n Most Disturbed
CPL	Coastal Plains	567	167	252	148
EMU	Eastern Mtns & Upper Midwest	214	39	116	59
IPL	Interior Plains	190	38	96	56
W	West	167	33	65	69

Table 6-3. Distribution of 1138 NWCA sampled sites (probability and not-probability) by NWCA Aggregated Wetland Types. n = numbers of sites. Code PRL is pronounced 'pearl'.

Code	Aggregated Wetland Types (NWCA_WET_GRP)	n Total	n Least Disturbed	n Intermediate Disturbance	n Most Disturbed
EH	Estuarine Herbaceous (emergent)	272	100	90	82
EW	Estuarine Woody (shrub or forest)	73	16	38	19
PRLH	Palustrine, Riverine and Lacustrine Herbaceous (emergent, ponds, previously farmed)	358	75	169	114
PRLW	Palustrine, Riverine and Lacustrine Woody (shrub or forest)	435	86	232	117

Table 6-4. Distribution of 1138 NWCA of sampled sites (probability and not-probability) and 96 revisited sites across the conterminous United States and by NWCA Reporting Groups. n = numbers of sites.

Code	Reporting Groups (Ecoregion by Wetland Type, ECO_X_WETGRP)	n Total	n Least Disturbed	n Intermediate Disturbance	n Most Disturbed	n Revisit Sites
NATIONAL	***Conterminous US***	***1138***	***277***	***529***	***332***	***96***
ALL-EH*	All - Estuarine Herbaceous	272	100	90	82	18
ALL-EW*	All - Estuarine Woody	73	16	38	19	3
CPL-PRLH	Coastal Plain - Palustrine, Riverine, and Lacustrine Herbaceous	72	16	36	20	3
CPL-PRLW	Coastal Plain - Palustrine, Riverine, and Lacustrine Woody	189	37	97	55	11
EMU-PRLH	Eastern Mountains & Upper Midwest - Palustrine, Riverine, and Lacustrine Herbaceous	73	16	33	24	10
EMU-PRLW	Eastern Mountains & Upper Midwest - Palustrine, Riverine, and Lacustrine Woody	127	21	79	27	15
IPL-PRLH	Interior Plains - Palustrine, Riverine, and Lacustrine Herbaceous	138	26	70	42	16
IPL-PRLW	Interior Plains - Palustrine, Riverine, and Lacustrine Woody	52	12	26	14	3
W-PRLH	West - Palustrine, Riverine, and Lacustrine Herbaceous	75	17	30	28	9
W-PRLW	West - Palustrine, Riverine, and Lacustrine Woody	67	16	30	21	8

*The Estuarine Reporting Groups span all coastal areas of the conterminous United States

6.4 Calibration and Validation Data

The NWCA marks the first use of vegetation in a NARS assessment across the conterminous United States, and the first time a wetland VMMI has been developed at this scale. The sampled sites for the 2011 NWCA spanned wide geographic and ecological diversity, as well as many wetland types. For these reasons, a large number of candidate vegetation metrics of condition (n=405) were evaluated for potential effectiveness and possible inclusion in national or reporting group VMMI(s). In addition, 126 metrics based on nonnative plant taxa were evaluated for consideration for use in the Nonnative Plant Stressor Indicator (NPSI).

The NWCA VMMI development approach (**Chapter 7**) examines many potential VMMI versions; evaluating 1) numerous VMMIs constructed from randomly selected sets of 4, 6, 8, or 10 metrics, or 2) all possible VMMI combinations based on a particular number of metrics (Van Sickle 2010). The many permutations of potential VMMIs could result in selection of a VMMI well fit to the 2011 NWCA data, but which might not reflect conditions from future NWCA Surveys or other wetland data sets. Thus, to help ensure that the final VMMI would be widely applicable and not over-fitted to specific data collected in 2011, we divided the vegetation data into validation (20% of sampled sites) and calibration (80% of sampled sites) data sets **Table 6-5**.

The 20% of sampled sites included in the validation data were randomly selected from least, intermediate, and most disturbed categories to encompass the entire range of the disturbance gradient observed in the NWCA. The random selection of the validation sites was also stratified by All Estuarine (EH + EW), PRLH, and PRLW wetlands to span the range of Aggregated Wetland Types. These validation data were reserved to evaluate the consistency and robustness of each potential VMMI.

The 80% of sampled sites comprising the calibration data were used to examine the efficacy of <u>each</u> candidate metric across all wetlands (national scale) and across wetlands within each of three wetland type groups (see **Section 6.5**). Calibration data were also used to score condition metrics on a 0-10 continuous scale within each NWCA Site Group for which a potential VMMI was developed (see **Section 7.2**). The resulting metric scoring was applied to the corresponding validation data. A robust potential VMMI developed using this metric scoring should similarly distinguish least from most disturbed for both the calibration and validation data (see **Section 7.3**).

Table 6-5. Distribution of sites in calibration and validation data sets for all sites, by disturbance type, and by Aggregated Wetland Type. Total n = 1138.

Site Type	Calibration Data	Validation Data
All	n = 911	n =227
Disturbance Class		
Least Disturbed (Reference)	n = 222	n = 55
Intermediately Disturbed	n = 423	n = 106
Most Disturbed	n = 266	n = 66
Aggregated Wetland Type		
E – Estuarine	n = 276	n = 69
PRLH – Palustrine, riverine, lacustrine herbaceous	n = 286	n = 72
PRLW – Palustrine, riverine, lacustrine woody	n = 349	n = 86

6.5 Evaluating Candidate Vegetation Metrics

The performance of NWCA candidate vegetation metrics describing ecological condition or stress (**Section 6.8**, **Appendix D**) was evaluated for potential utility in the VMMI(s) or the NPSI using the calibration data set (see **Section 6.4**). A series of screening criteria have commonly been employed by NARS for evaluating metrics considered in index development (Stoddard et al. 2008; Pont et al. 2009). The NWCA metric screening approach was adapted and expanded from these standard methods and applied to both candidate condition and stress metrics. An overview of the metric criteria included in the screening approach is listed below.

Metric Screening Criteria:

- Range – Sufficient range to permit signal detection
  - *Total range, skewness, % values identical*
- Repeatability – Among site variability (signal) > sampling variability (noise)
  - *Signal:Noise > 4*
- Responsiveness – Distinguish least (reference) from most disturbed sites
  - *Kruskal-Wallis test* ($p \leq 0.05$)
  - *Ranking of box-plot separation of least and most disturbed sites*
- Redundancy – Metrics included in a MMI should not be strongly correlated
  - *Considered when assembling the VMMI* ($r \leq |0.75|$)

These screening criteria were applied across all sites nationally and for three wetland type Site Groups. To be retained for further consideration each metric had to pass all screening criteria for at least one of the Site Groups:

- All Wetlands - Conterminous US
- All Estuarine Wetlands (EH + EW)
- Palustrine, Riverine, and Lacustrine Herbaceous Wetlands (PRLH)
- Palustrine, Riverine, and Lacustrine Woody Wetlands (PRLW)

For a subset of plant stressor metrics, the responsiveness criterion was given less weight compared to the range and repeatability criteria in evaluating metric utility. One of the criteria used in defining least disturbed (reference) sites was based on a metric describing relative alien cover (**Chapter 4**). Relative alien cover was also incorporated in some potential stressor metrics, so for these particular metrics, responsiveness was given limited consideration to avoid circularity.

Prior to beginning metric screening, we examined histograms of the distributions of values for the 531 vegetation metrics. Most were strongly non-normal; consequently, nonparametric statistical (e.g., Kruskal-Wallis test) approaches were used in the screening analyses. Specific tests or evaluation criteria were developed for each screening test and are detailed under the subheadings below. R code was written to implement the screening tests, and results for all metrics were exported from R into a multi-page Excel Workbook for review.

6.5.1 *Range Tests*

Metrics with limited range, too many zero values, or highly skewed distributions have been shown to generally be poor indicators of ecological condition. We used two tests to define sufficient (PASS), marginal (PASS-), and insufficient (FAIL) range for metric values.

- **Test 1** – Identifies metrics with large proportion of 0 values or highly skewed distributions:
    - *If the 75th percentile = 0, i.e., more than 75% of values are zero, then FAIL*
    - *If the 75th percentile = the minimum OR the 25th percentile = max (indicating 75% of values identical), then FAIL* (ensures that a majority of values are not the same as the minimum or maximum to help eliminate variables that are highly skewed and mostly a single non-zero value*;*
    - *If the median=0, then PASS-*

- **Test 2** – Identifies metrics with very narrow ranges
    - *If the metric is a percent variable and (max-25th percentile) < 15%, then FAIL*
    - *If the metric is not a percent variable and (max-25th) < (max/3), then FAIL*

If either Test 1 or 2 resulted in a FAIL, the final assignment for the metric was FAIL. If the first two screens in Test 1 resulted in a PASS, but the third screen a PASS-, the result was PASS-. To pass the range screen, each metric had to receive a PASS or PASS-.

6.5.2 *Repeatability*

Useful metrics tend to have high repeatability, that is among site variability will be greater than sampling variability based on repeat sampling at a subset of sites (see **Table 6-3**, revisit sites). To quantify repeatability, NARS uses Signal:Noise (S:N) or the ratio of variance associated with sampling site (signal) to the variance associated with repeated visits to the same site (noise) (Kaufmann et al. 1999). All sites are included in the signal, whereas only revisit sites contribute to the noise component. Metrics with high S:N are more likely to show consistent responses to human caused disturbance, and S:N values ≤ 1 indicate that sampling a site twice yields as much or more metric variability as sampling two different sites (Stoddard et al. 2008).

In other NARS, S:N thresholds for retention of metrics have been set to reflect the variability in the assemblages being sampled, e.g., S:N ≥ 4 or 5 for fish metrics, 2 for macroinvertebrate metrics (Stoddard et al. 2008). In the NWCA, because we had such a large number of metrics to evaluate, we set an initial criterion of S:N ≥ 4. In practice, however, the observed S:N values for the vegetation metrics were much higher, so we ultimately set the metric retention criterion to S:N ≥ 10, or ≥ 5 if metric type was as yet unrepresented in the suite of metrics passing all selection criteria. For the NWCA, S:N for individual metrics was calculated using the R package “lme4” (version 1.1-7, Bates et al. 2014). Each metric was used as a response variable with SITE_ID (a site identifier) as the main factor in a random effects model. Then the variance components from the resulting model were used to calculate S:N.

6.5.3 *Responsiveness*

The most fundamental test of the efficacy of a candidate metric is its capacity to discriminate degraded from relatively undisturbed ecosystems. Responsive candidate metrics effectively distinguish least disturbed (reference) from most disturbed sites (Stoddard et al. 2008). In the NWCA, the ability to differentiate least from most disturbed sites was evaluated based on p-values and Chi-values from a Kruskal-Wallis test (large sample approximation). The assessment of the discriminatory capability of individual metrics was also supported by ranking the separation of least and most disturbed sites based on boxplot comparisons, where the degree of overlap of medians and interquartile ranges (IQRs) between least and most disturbed sites provides a signal of the metric responsiveness (Klemm et al. 2002).

R code was developed to automate a process to simulate comparison of boxplots for least and most disturbed sites, for each vegetation metric, and to rank the separation levels. Using the approach developed by Barbour et al. (1996) and outlined in Klemm et al. (2002), the medians and IQRs of the least and most disturbed sites were compared, and metrics were scored as follows:

- Score of 0 (lowest discriminatory power) – Complete overlap of each group's IQRs with the median of the other group

- Score of 1 – Only one median was overlapping with the IQRs of the other group

- Score of 2 – Neither median overlapped with the IQR of the other group, but the IQRs overlapped

- Score of 3 (highest discriminatory power) – IQRs did not overlap.

Metric responsiveness was evaluated using three acceptance thresholds:

1) Kruskal-Wallis $p \leq 0.05$

2) Chi-squared value from Kruskal-Wallis test ≥10, or ≥5 if metric type was as yet unrepresented in the suite of metrics passing all selection criteria

3) A boxplot separation score of 1, 2, or 3, unless metric type was unrepresented then a 0 value was permitted.

Among metrics passing the responsiveness screen, the Kruskal-Wallis p-values were often much lower and Chi-squared values were often much higher than acceptance thresholds. The boxplot separation scores for passing metrics were ranged from 1 to 3, with 2 being the most common value.

6.5.4 *Redundancy*

It is generally agreed that metrics included in a MMI should not be strongly correlated, and $r \leq |0.75|$ is often a cut off point for metrics included in the same MMI (e.g., Stoddard et al. 2008; Pont et al 2009; Van Sickle 2010). Redundancy screening was primarily handled during the process of VMMI development; metrics were screened to ensure that none of the metrics included in a particular candidate VMMI had correlations greater than this threshold (see **Section 7.2**).

In addition, during metric screening, a subset of ~50 metrics that passed the range, repeatability, and responsiveness tests, but which conveyed very similar information to other metrics were dropped, particularly if they were not strong performers. This typically included metrics that were very similar (absolute versus relative cover for trait based metrics) or which contained nested information, e.g., stressor metrics, such as, introduced versus alien (introduced + adventive) species. In such cases, the metric which performed best on screening tests was selected. Where screening results were similar, the metric that was most ecologically meaningful or easiest to collect or calculate was selected.

6.6 Metric Screening Results

Candidate condition and stress metrics, based on vegetation, that passed all screening tests for at least one of the evaluation Site Groups (all wetlands, estuarine wetlands (EH + ES), PLRH wetlands, or PRLW wetlands) were retained for consideration in further analyses. Condition metrics (**Table 6-6**) were used in VMMI development (see **Section 7.2**). Stress metrics (**Table 6-7**) were considered as potential components of the Nonnative Plant Stressor Indicator (see **Chapter 8, Section 8.5**).

Table 6-6. List of vegetation condition metrics that passed all screening tests described in **Section 6.5** for at least one evaluation Site Group. For metric descriptions see **Section 6.8, Appendix D**.

Vegetation Condition Metrics that Passed Evaluation Screens		
All Native Species	***Life History***	***Other***
TOTN_NATSPP	PCTN_OBL	N_PEAT_MOSS_DOM
PCTN_NATSPP	PCTN_FACW	XCOV_BRYOPHYTES
XRCOV_NATSPP	PCTN_FAC	IMP_LICHENS
RFREQ_NATSPP	WETIND_COV_ALL	XCOV_BAREGD
RIMP_NATSPP	PCTN_GRAMINOID_NAT	XDETPH_LITTER
XBCDIST_NATSPP	XRCOV_GRAMINOID_NAT	TOTN_SNAGS
Floristic Quality	PCTN_MONOCOTS_NAT	
XC_NAT	XRCOV_MONOCOTS_NAT	
XC_ALL	PCTN_HERB_NAT	
XC_COV_NAT	XRCOV_HERB_NAT	
XC_COV_ALL	N_VINE	
FQAI_NAT	N_SHRUB_COMB_NAT	
FQAI_ALL	PCTN_SHRUB_COMB_NAT	
FQAI_COV_NAT	XRCOV_SHRUB_COMB_NAT	
FQAI_COV_ALL	N_TREE_UPPER	
Sensitivity or Tolerance	IMP_TREE_UPPER	
N_SEN	PCTN_GYMNOSPERM	
N_TOL	PCTN_ANNUAL	
N_HTOL	PCTN_PERENNIAL_NAT	
PCTN_SEN		
PCTN_TOL		
XRCOV_SEN		
XRCOV_TOL		
XRCOV_HTOL		

Table 6-7. List of vegetation stress metrics that passed all screening tests described in **Section 6.5** for at least one evaluation Site Group. For metric descriptions see **Section 6.8, Appendix D**.

Vegetation Stress Metrics that Passed Evaluation Screens	
All Nonnative Species	***Nonnative Species by Life History Groups***
TOTN_ALIENSPP	XRCOV_OBLFACW_AC
XN_ALIENSPP	XRCOV_FORB_AC
PCTN_ALIENSPP	N_HERB_AC
RFREQ_ALIENSPP	PCTN_HERB_AC
XABCOV_ALIENSPP	XRCOV_HERB_AC
RIMP_ALIENSPP	N_GRAMINOID_AC
TOTN_AC	PCTN_GRAMINOID_AC
XN_AC	XRCOV_OBLFACW_AC
PCTN_AC	N_MONOCOTS_AC
RFREQ_AC	PCTN_MONOCOTS_AC
XABCOV_AC	XRCOV_MONOCOTS_AC
XRCOV_AC	N_DICOTS_AC
RIMP_AC	PCTN_DICOTS_AC
TOTN_AC	XRCOV_DICOTS_ALIEN
XN_AC	XRCOV_DICOTS_AC
PCTN_AC	PCTN_PERENNIAL_AC
RFREQ_AC	XRCOV_PERENNIAL_AC
XABCOV_AC	
XRCOV_AC	
RIMP_AC	

6.7 Literature Cited

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6.8 Appendix D: NWCA Candidate Vegetation Metrics Evaluated in 2011

READ THIS: Key Information for Reading and Using This Appendix

- ***Important:*** *This Appendix is intended* ***only as a descriptive overview*** *of the NWCA Candidate Vegetation Metrics. Exact methods/formulas for calculations and specific field data and trait information used for each metric were defined in the Vegetation Metric R Code.*

- Unless otherwise indicated, vegetation metrics are summarized to site level. Metrics are calculated based on data from five 100-m^2 plots in the Assessment Area (AA) for the site (or if fewer than 5 plots were sampled, then the total number plots sampled). In the metric descriptions or formulas provided in this appendix, the phrase 'five 100-m^2 plots' can be assumed to mean the 5 plots in the AA or the total number of plots sampled if less than 5. Rarely fewer than 5 vegetation plots were sampled at the AA.

- The term '*Species*' as typically used in this appendix refers to taxonomic species or lowest identifiable taxonomic unit (e.g., variety, genus, family, growth habit).

- **BLACK BANNER** with column headings is repeated at the top of each page.

- **GRAY BANNER,** heading each *major group of metrics*, lists the NWCA Field Data Form from which the validated field data that is used in metrics originated.

- **COLORED BANNERS**, under each major metric group, provide section and subsection headings for *sets of metrics that describe related ecological components*.

- **METRIC NAME column** corresponds to the *metric name* in the NWCA vegetation metrics data set.

- **DESCRIPTION column** provides narrative description of each metric.

- **CALCULATION/TRAIT INFORMATION column** provides:
  - ***In white metric rows:***
    - A general formula for calculation of the metric, if not evident in text in the DESCRIPTION column, is provided. PARAMETER NAMES representing raw data that are included in calculations are highlighted in BLUE and are defined in **Section 5.12, Appendix B**.
    - Some calculated metrics listed in the METRIC NAME column are, in turn, used as components of other calculated metrics.
    - Some calculated metrics use species trait information to aggregate species level data. Where traits are used, trait names are indicated in the calculation column using GREEN font.
  - ***In colored banner rows defining metric sets*** – General categories of species trait information used in calculating a particular series of metrics are listed, if applicable. Codes for specific traits are indicated in GREEN font. ***For metrics that use species traits, trait designations are applied as follows:***
    - Growth Habit, Duration, and Taxonomic Category are applied by species (see **Section 5.6**)
    - Wetland Indicator Status is applied to taxa-region pairs based on species values for the National Wetland Plant List Regions (see **Section 5.7**).
    - Native status designations are applied to taxa-site pairs based on state-level native status for each species (see **Section 5.8**).
    - Coefficients of Conservatism (CCs, aka C-values) are applied to taxa-site pairs based on state specific C-values for each species (see **Section 5.9**).

- **METRIC TYPE column** indicates whether the candidate metric describes ecological condition or stress.

- Metrics of the ***National Vegetation Multimetric Index (VMM)*** are highlighted in **blue bold font**

- Metrics included in the ***Nonnative Plant Stressor Indicator (NPSI)*** are highlighted in **red bold font**

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
SECTIONS 1 - 5	**Metrics based on field data: FORM V-2 – NWCA VASCULAR SPECIES PRESENCE AND COVER**		
SECTION 1	**TAXA COMPOSITION (RICHNESS, FREQUENCY, COVER, DIVERSITY)**		
Section 1.1	**All Species/Taxonomic Groups**		
TOTN_SPP	Richness - Total number of unique species across all 100-m^2 plots	Count unique species across all plots	C
XN_SPP	Mean number of species across all 100-m^2 plots		C
MEDN_SPP	Median number of species across all 100-m^2 plots		C
SDN_SPP	Standard deviation in number of species across all 100-m^2 plots		C
TOTN_GEN	Total number of unique genera across all 100-m^2 plots	Count unique genera across all plots	C
XN_GEN	Mean number of unique genera across all 100-m^2 plots		C
MED_NGEN	Median number of genera across all 100-m^2 plots		C
SDN_GEN	Standard deviation in number of genera across 100-m^2 plots		C
TOTN_FAM	Total number of families across 100-m^2 plots	Count unique families observed across all plots	C
XN_FAM	Mean number of families across 100-m^2 plots		C
MEDN_FAM	Median number of families across 100-m^2 plots		C
SDN_FAM	Standard deviation in number of families across 100-m^2 plots		C
XTOTABCOV (summary data used in calculation of other metrics)	Mean total absolute cover summed across all species across 100-m^2 plots	Σ COVER of all individual taxa across 5 plots/5 plots	
H_ALL	Shannon-Wiener Diversity Index - All species *s* = number of species observed, *i* = species *i, p* = proportion of individuals (relative cover) belonging to species *i*	$H' = -\sum_{i}^{s} p_i \ln p_i$	C
J_ALL	Evenness (Pielou) - All species *S* = number of species observed	$J = \frac{H'}{\ln S}$	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
D_ALL	Simpson Diversity Index - All species *s* = number of species observed, *i* = species *i*, *p* = proportion of individuals (relative cover) belonging to species *i*	$D = 1 - \sum_{i}^{s} p_i^2$	C
XBCDIST_SPP	Within Assessment Area dissimilarity based on species composition = Mean of between-plot Bray-Cutis (BC) Distance (Dissimilarity) based on all species.	Calculate between-plot Bray Curtis Distance for all plot pairs based on species and plot level cover values. Calculate mean of these values to get mean within AA distance: $BC_{ih} = 1 \frac{2\sum_{j=1}^{p} MIN(a_{ij}, a_{hj})}{\sum_{j=1}^{p} a_{ij} + \sum_{j=1}^{p} a_{hj}}$	C
SECTIONS 1.2 - 1.3	**NATIVE STATUS**	**Trait Information = Native Status (see Table 5-4)**	
Section 1.2	**Native (NAT) Species/Taxonomic Groups**		
TOTN_NATSPP	Native Richness: Total number of unique native species across all 100-m^2 plots	Count unique native (NAT) species across all plots	C
XN_NATSPP	Mean number of native species across 100-m^2 plots		C
MEDN_NATSPP	Median number of native species across 100-m^2 plots		C
SDN_NATSPP	Standard deviation in number of native species across 100-m^2 plots		C
PCTN_NATSPP	Percent richness of native species observed across 100-m^2 plots	(TOTN_NATSPP/TOTN_SPP) x 100	C
RFREQ_NATSPP	Relative frequency of occurrence for native species as a percent of total frequency (sum of all species)	∑ Frequencies of all (NAT species/∑ Frequencies of all species) x 100; Frequency for individual species = % of 100-m^2 plots in which it occurs.	C
XABCOV_ NATSPP	Mean total absolute cover of native species across 100-m^2 plots	∑ COVER of all individual native (NAT) taxa across 5 plots/5 plots	C
XRCOV_NATSPP	Mean relative cover of native species across 100-m^2 plots as a percentage of total cover	(XABCOV_NATSPP/XTOTABCOV) x 100	C
RIMP_NATSPP	**Mean relative importance of all native species**	**(RFREQ_NATSPP + XRCOV_NATSPP)/2**	**C, Used in VMMI**
H_NAT	Shannon-Wiener Diversity Index – Native species only	See H_ALL	C
J_NAT	Evenness (Pielou) – Native species only	See J_ALL	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
D_NAT	Simpson Diversity Index – Native species only	See D_NAT	C
XBCDIST_ NATSPP	Within AA dissimilarity based on native species only composition = Mean of between plot Bray-Cutis Distance (Dissimilarity) based on native species only	See XBCDIST_SPP	C
Section 1.3	**Introduced (INTR), Adventive (ADV), ALIEN (INTR + ADV), Cryptogenic (CRYP)**	**Trait Information = Native Status (see Table 5-4)**	
TOTN_INTRSPP	Introduced Richness: Total number of unique introduced species across all 100-m^2 plots	Count unique introduced (INTR) species across all plots	S
XN_INTRSPP	Mean number of introduced species across 100-m^2 plots		S
MEDN_INTRSPP	Median number of introduced species across 100-m^2 plots		S
SDN_INTRSPP	Standard deviation in number of introduced species across 100-m^2 plots		S
PCTN_INTRSPP	Percent richness introduced species observed across 100-m^2 plots	(TOTN_INTRSPP/TOTN_SPP) x 100	S
RFREQ_INTRSPP	Relative frequency of occurrence for introduced species as a percent of total frequency (sum of all species)	(∑ Frequencies of all introduced (INTR) species/∑ Frequencies of all species) x 100; Frequency for individual species = % of 100-m^2 plots in which it occurs.	S
XABCOV_ INTRSPP	Mean total absolute cover of all introduced species across 100-m^2 plots	Σ COVER of all individual INTR taxa across 5 plots/5 plots	S
XRCOV_INTRSPP	Mean relative cover of all INTR species across 100-m^2 plots as a percentage of total cover	(XABCOV_INTRSPP/XTOTABCOV) x 100	S
RIMP_INTRSPP	Mean relative importance of all introduced species	(RFREQ_INTRSPP + XRCOV_INTRSPP)/2	S
TOTN_ADVSPP	Adventive Richness: Total number of adventive species across 100-m^2 plots	Count unique adventive (ADV) species across all plots	S
XN_ADVSPP	Mean number of adventive species across 100-m^2 plots		S
MEDN_ADVSPP	Median number of adventive species across 100-m^2 plots		S
SDN_ADVSPP	Standard deviation in number of adventive species across 100-m^2 plots		S
PCTN_ADVSPP	Percent richness adventive species observed across all 100-m^2 plots	(TOTN_ADVSPP/TOTN_SPP) x 100	S

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
RFREQ_ADVSPP	Relative frequency of adventive species occurrence across 100-m^2 plots	(∑ Frequencies of all adventive (ADV) species/∑ Frequencies of all species) x 100; Frequency for individual species = % of 100-m^2 plots in which it occurs.	S
XABCOV_ ADVSPP	Mean total absolute cover of all ADV species across 100-m^2 plots	Σ COVER of all individual ADV taxa across 5 plots/5 plots	S
XRCOV_ADVSPP	Mean relative cover of all ADV species or lowest taxonomic unit across 100-m^2 plots as a percentage of total cover	(XABCOV_ADVSPP/XTOTABCOV) x 100	S
RIMP_ADVSPP	Mean relative importance of all adventive species	(RFREQ_ADVSPP + XRCOV_ADVSPP)/2	S
TOTN_ALIENSPP	Alien Richness: Total number of unique alien (INTR + ADV) species across 100-m^2 plots	TOTN_ADVSPP + TOTN_INTRSPP	S
XN_ALIENSPP	Mean number of alien (INTR + ADV) species across 100-m^2 plots		S
MEDN_ALIENSPP	Median number of alien (INTR + ADV) species across 100-m^2 plots		S
SDN_ALIENSPP	Standard deviation in number of alien (INTR + ADV) species		S
PCTN_ALIENSPP	Percent richness alien species across 100-m^2 plots	(TOTN_ALIENSPP/TOTN_SPP) x 100	S
RFREQ_ ALIENSPP	Relative frequency of alien (INTR + ADV) species occurrence across 100-m^2 plots	(∑ Frequencies of all ALIEN species/∑ Frequencies of all species) x 100; Frequency for individual species = % of 100-m^2 plots in which it occurs.	S
XABCOV_ ALIENSPP	Mean total absolute cover of ALIEN (INTR + ADV) species across 100-m^2 plots	Σ COVER of all individual ALIEN taxa across 5 plots/5 plots	S
XRCOV_ ALIENSPP	Mean relative cover of all ALIEN (INTR + ADV) species across 100-m^2 plots as a percentage of total cover	(XABCOV_ALIENSPP/XTOTABCOV) x 100	S
RIMP_ALIENSPP	Mean relative importance of all ALIEN (INTR + ADV) species	(RFREQ_ALIENSPP + XRCOV_ALIENSPP)/2	S
H_ALIEN	Shannon-Wiener Diversity Index	See H_ALL	S
J_ALIEN	Evenness (Pielou)	See J_ALL	S
D_ALIEN	Simpson Diversity Index	See D_NAT	S
TOTN_CRYPSPP	Cryptogenic Richness: Total number of unique cryptogenic species across 100-m^2 plots	Count unique cryptogenic (CRYP) species across all plots	S
XN_CRYPSPP	Mean number of cryptogenic species across 100-m^2 plots		S
MEDN_CRYPSPP	Median number of cryptogenic species across 100-m^2 plots		S

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
SDN_CRYPSPP	Standard deviation in number of cryptogenic species across 100-m^2 plots		S
PCTN_CRYPSPP	Percent richness cryptogenic species across 100-m^2 plots	(TOTN_CRYPSPP/TOTN_SPP) x 100	S
RFREQ_CRYPSPP	Relative frequency of cryptogenic species occurrence across 100-m^2 plots	(∑ Frequencies of all cryptogenic (CRYP) species/∑ Frequencies of all species) x 100; Frequency for individual species = % of 100-m^2 plots in which it occurs.	S
XABCOV_ CRYPSPP	Mean total absolute cover of all CRYP species across 100-m^2 plots	∑ COVER of all CRYP taxa across 5 plots/5 plots	S
XRCOV_CRYPSPP	Mean relative cover of all CRYP species across 100-m^2 plots as a percentage of total cover	(XABCOV_CRYPSPP/XTOTABCOV) x 100	S
RIMP_CRYPSPP	Mean relative importance of all CRYP species	(RFREQ_CRYPSPP + XRCOV_CRYPSPP)/2	S
TOTN_AC	**AC Richness: Total number of unique alien and cryptogenic species across 100-m^2 plots**	**TOTN_CRYPSPP + TOTN_ALIENSPP**	**S, Used in NPSI**
XN_AC	Mean number of AC (ALIEN + CRYP) species across 100-m^2 plots		S
MEDN_AC	Median number of AC (ALIEN + CRYP) species across 100-m^2 plots		S
SDN_AC	Standard deviation number of AC (ALIEN + CRYP) species across 100-m^2 plots		S
PCTN_AC	Percent Richness AC species (ALIEN + CRYP) across 100-m^2 plots	(TOTN_CRYPSPP + TOTN-ALIENSPP/TOTN_SPP) x 100	S
RFREQ_AC	**Relative frequency of alien and cryptogenic species occurrence in flora based on five 100-m^2 plots**	**(∑ Frequencies of all ALIEN + CRYP species/∑ Frequencies of all species) x 100; Frequency for individual species = % of 100-m^2 plots in which it occurs.**	**S, Used in NPSI**
XABCOV_AC	Mean total absolute cover of all AC (ALIEN + CRYP) species across 100-m^2 plots	∑ COVER of all ALIEN + CRYP taxa across 5 plots/5 plots	S
XRCOV_AC	**Mean relative cover of all AC (ALIEN + CRYP) species across 100-m^2 plots as a percentage of total cover**	**(XABCOV_AC/XTOTABCOV) x 100**	**S, Used in NPSI**
RIMP_AC	Mean relative importance of all AC (ALIEN + CRYP) species	(RFREQ_AC + XRCOV_AC)/2	S
H_AC	Shannon-Weiner Diversity Index	See H_ALL	S
J_AC	Evenness (Pielou)	See J_ALL	S
D_AC	Simpson Diversity Index	See D_NAT	S

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
Section 2	**FLORISTIC QUALITY**	**Trait Information = Coefficients of Conservatism (see Section 5.9); Native Status (see Table 5-4)**	
Equation 1	**General formula for Mean C** CC_{ij} – coefficient of conservatism for each unique species *i* at site *j*, N = number of species at site *j*	$\overline{C} = \left(\sum cc_{ij}\right) / N_j$	
Equation 2	**General formula for FQAI** CC_{ij} – coefficient of conservatism for each unique species *i* at site *j*, N = number of species at site *j*	$FQAI = \sum CC_{ij} / \sqrt{N_j}$	
Equation 3	**For weighted Mean C or FQAI** Replace CC_{ij} with wCC_{ij}, where p_{ij} = relative frequency or relative cover	$wCCij = p_{ij} CC_{ij}$	
XC_NAT	Mean Coefficient of Conservatism with native species only	Equation 1	C
XC_ALL	Mean Coefficient of Conservatism with all species	Equation 1	C
XC_FREQ_NAT	Relative frequency-weighted Mean Coefficient of Conservatism with native species only	Equation 1, Equation 3	C
XC_FREQ_All	Relative frequency-weighted Mean Coefficient of Conservatism with all species only	Equation 1, Equation 3	C
XC_COV_NAT	Relative cover-weighted Mean Coefficient of Conservatism with native species only	Equation 1, Equation 3	C
XC_COV_All	Relative cover-weighted Mean Coefficient of Conservatism with all species	Equation 1, Equation 3	C
FQAI_NAT	Floristic Quality Index with native species only	Equation 2	C
FQAI_ALL	**Floristic Quality Index with all species**	**Equation 2**	**C, Used in VMMI**
FQAI_FREQ_NAT	Proportional frequency-weighted Floristic Quality Assessment Index with native species only	Equation 2, Equation 3	C
FQAI_FREQ_ALL	Proportional frequency-weighted Floristic Quality Assessment Index with all species only	Equation 2, Equation 3	C
FQAI_COV_NAT	Proportional cover-weighted Floristic Quality Assessment Index with native species only	Equation 2, Equation 3	C
FQAI_COV_ALL	Proportional cover-weighted Floristic Quality Assessment Index with all species	Equation 2, Equation 3	C

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Section 3	**STRESS TOLERANCE/SENSITIVITY**	**Trait Information = Coefficients of Conservatism (Section 5.9)**	
N_HSEN	Number (Richness) Highly Sensitive Species; C-value >= 9	Count unique species that meet criterion across 100-m^2 plots	C
N_SEN	Number (Richness) Sensitive Species; C -value >= 7	Count unique species that meet criterion across 100-m^2 plots	C
N_ISEN	Number (Richness) Intermediate Sensitivity Species; C-value = 5 to 6	Count unique species that meet criterion across 100-m^2 plots	C
N_TOL	**Number (Richness) Tolerant Species; C -value <= 4**	**Count unique species that meet criterion across 100-m^2 plots**	**C**
N_HTOL	Number (Richness) Highly Tolerant Species; C-value <= 2	Count unique species that meet criterion across 100-m^2 plots	C
PCTN_HSEN	Percent Richness Highly Sensitive Species; C-value >= 9	(N_HSEN/TOTN_SPP) x 100	C
PCTN_SEN	Percent Richness Sensitive Species; C-value >= 7	(N_SEN/TOTN_SPP) x 100	C
PCTN_ISEN	Percent Richness Intermediate Sensitivity Species; C-value = 5 to 6	(N_ISEN/TOTN_SPP) x 100	C
PCTN_TOL	Percent Richness Tolerant Species; C-value <= 4	(N_TOL/TOTN_SPP) x 100	C
PCTN_HTOL	Percent Richness Highly Tolerant Species; C-value <= 2	(N_HTOL/TOTN_SPP) x 100	C
XABCOV_HSEN	Absolute Mean Cover Highly Sensitive Species; C-value >= 9	Σ COVER of species with C-value >= 9 across 5 plots/5 plots	C
XABCOV_SEN	Absolute Mean Cover Sensitive Species; C-value >= 7	Σ COVER of species with C-value >= 7 across 5 plots/5 plots	C
XABCOV_ISEN	Absolute Mean Cover Intermediate Sensitivity Species; C-value= 5 to 6	Σ COVER of species with C-value = 5 or 6 across 5 plots/5 plots	C
XABCOV_TOL	Absolute Mean Cover Tolerant Species; C-value <= 4	Σ COVER of species with C-value <= 4 across 5 plots/5 plots	C
XABCOV_HTOL	Absolute Mean Cover Highly Tolerant Species; C-value <= 2	Σ COVER of species with C-value <= 2 across 5 plots/5 plots	C
XRCOV_HSEN	Relative Mean Cover Highly Sensitive Species; C >= 9	(XABCOV_HSEN/XTOTABCOV) x 100	C
XRCOV_SEN	Relative Mean Cover Sensitive Species; C-value >= 7	(XABCOV_SEN/XTOTABCOV) x 100	C
XRCOV_ISEN	Relative Mean Cover Intermediate Sensitivity Species; C-value = 5 to 6	(XABCOV_ISEN/XTOTABCOV) x 100	C
XRCOV_TOL	Relative Mean Cover Tolerant Species; C-value <= 4	(XABCOV_TOL/XTOTABCOV) x 100	C
XRCOV_HTOL	Relative Mean Cover Highly Tolerant Species; C-value <= 2	(XABCOV_HTOL/XTOTABCOV) x 100	C

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SECTION 4	**HYDROPHYTIC STATUS** Obligate (OBL), Facultative Wetland (FACW), Facultative (FAC), Facultative Upland (FACU), Upland (UPL + Not Listed (NL))	**Trait Information =** Wetland Indicator Status (WIS) from National Wetland Plant List (Table 5-3); Native Status (Table 5-4)	
N_OBL	Richness (number) of Obligate species	Count unique OBL species across 100-m^2 plots	C
N_FACW	Richness (number) of Facultative Wetland species	Count unique FACW species across 100-m^2 plots	C
N_FAC	Richness (number) of Facultative species	Count unique FACU species across 100-m^2 plots	C
N_FACU	Richness (number) of Facultative Upland species	Count unique FAC species across 100-m^2 plots	C
N_UPL	Richness (number) of UPL species = UPL	Count unique UPL species across 100-m^2 plots	C
PCTN_OBL	Percent richness of Obligate species	(N_OBL/TOTN_SPP) x 100	C
PCTN_FACW	Percent richness of Facultative Wetland species	(N_FACW/TOTN_SPP) x 100	C
PCTN_FAC	Percent richness of Facultative species	(N_FAC/TOTN_SPP) x 100	C
PCTN_FACU	Percent richness of Facultative Upland species	(N_FACU/TOTN_SPP) x 100	C
PCTN_UPL	Percent richness of UPL (= UPL + NL) species	(N_UPL/TOTN_SPP) x 100	C
XABCOV_OBL	Mean Absolute Cover of Obligate species	Σ COVER of OBL species across 5 plots/5 plots	C
XABCOV_FACW	Mean Absolute Cover of Facultative Wetland species	Σ COVER of FACW species across 5 plots/5 plots	C
XABCOV_FAC	Mean Absolute Cover of Facultative species	Σ COVER of FAC species across 5 plots/5 plots	C
XABCOV_FACU	Mean Absolute Cover of Facultative Upland species	Σ COVER of FACU species across 5 plots/5 plots	C
XABCOV_UPL	Mean Absolute Cover of UPL species	Σ COVER of UPL species across 5 plots/5 plots	C
XRCOV_OBL	Mean Relative Cover of Obligate species	(XABCOV_OBL/XTOTABCOV) x 100	C
XRCOV_FACW	Mean Relative Cover of Facultative Wetland species	(XABCOV_FACW/XTOTABCOV) x 100	C
XRCOV_FAC	Mean Relative Cover of Facultative species	(XABCOV_FAC/XTOTABCOV) x 100	C
XRCOV_FACU	Mean Relative Cover of Facultative Upland species	(XABCOV_FACU/XTOTABCOV) x 100	C
XRCOV_UPL	Mean Relative Cover of UPL (= UPL + NL) species	(XABCOV_UPL/XTOTABCOV) x 100	C

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WETIND_COV	Wetland Index, Cover Weighted - all species I_{ij} = Importance Value = Mean absolute cover species *i* in site *j*. E_i = Ecological score for species based on WIS (OBL = 1, FACW = 2, FAC = 3, FACU = 4, UPL = 5)	$WI = \sum_{i=1}^{p} I_{ij} E_i \Big/ \sum_{i=1}^{p} I_{ij}$	C
WETIND_FREQ	Wetland Index, Frequency Weighted - all species I_{ij} = Importance Value = Frequency for species *i* in site *j*. E_i = Ecological score for species based on WIS (OBL = 1, FACW = 2, FAC = 3, FACU = 4, UPL = 5)	$WI = \sum_{i=1}^{p} I_{ij} E_i \Big/ \sum_{i=1}^{p} I_{ij}$	C
WETIND_ COV_NAT	Wetland Index, Cover Weighted - native species only I_{ij} = Importance Value = Mean absolute cover for species *i* in site *j*. E_i = Ecological score for species based on WIS (OBL = 1, FACW = 2, FAC = 3, FACU = 4, UPL = 5)	$WI = \sum_{i=1}^{p} I_{ij} E_i \Big/ \sum_{i=1}^{p} I_{ij}$	C
WETIND_ FREQ_NAT	Wetland Index, Frequency Weighted - native species only I_{ij} = Importance Value = Frequency for species *i* in site *j*. E_i = Ecological score for species based on WIS (OBL = 1, FACW = 2, FAC = 3, FACU = 4, UPL = 5)	$WI = \sum_{i=1}^{p} I_{ij} E_i \Big/ \sum_{i=1}^{p} I_{ij}$	C
N_OBLFACW_AC	Number of Alien + Cryptogenic Obligate and facultative wetland species	Count unique ALIEN and CRYP OBL and FACW species across 100-m^2 plots	S
XABCOV_ OBLFACW_AC	Mean Absolute Cover of Alien + Cryptogenic Obligate and Facultative Wetland species	Σ COVER of ALIEN and CRYP OBL and FACW species across 5 plots/5 plots	S
XRCOV_ OBLFACW_AC	Mean Relative Cover of Alien + Cryptogenic Obligate and Facultative Wetland species	(XABCOV_OBLFACW_AC/ XTOTABCOV) x 100	S

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SECTION 5	**LIFE HISTORY**		
SECTION 5.1	***GROWTH HABIT***	**Trait Information = Growth Habit (Table 5-1); Native Status (Table 5-4)**	
N_GRAMINOID	Graminoid richness	Count unique GRAMINOID species across 100-m^2 plots	C
N_GRAMINOID_ NAT	Native Graminoid richness	Count unique native (NAT) GRAMINOID species across 100-m^2 plots	C
N_GRAMINOID_ AC	Alien and cryptogenic Graminoid richness	Count unique ALIEN and CRYP GRAMINOID species across 100-m^2 plots	S
N_FORB	Forb richness	Count unique FORB species across 100-m^2 plots	C
N_FORB_NAT	Native Forb richness	Count unique native(NAT) FORB species across 100-m^2 plots	C
N_FORB_AC	Alien and cryptogenic Forb richness	Count unique ALIEN and CRYP FORB species across 100-m^2 plots	S
N_HERB	Herbaceous plant (FORB + GRAMINOID) species richness	N_FORB + N_GRAMINOID	C
N_HERB_NAT	Native Herbaceous species richness	N_FORB_NAT + N_GRAMINOID_NAT	C
N_HERB_AC	Alien and cryptogenic Herbaceous richness	N_FORB_AC + N_GRAMINOID_AC	S
N_SSHRUB_ FORB	Subshrub-forb richness	Count unique SUBSHRUB-FORB species across 100-m^2 plots	C
N_SSHRUB_ SHRUB	Subshrub-shrub richness	Count unique SUBSHRUB-SHRUB species across 100-m^2 plots	C
N_SHRUB	Shrub richness	Count unique SHRUB species across 100-m^2 plots	C
N_SHRUB_ COMB	Combined Shrub growth habits richness	N_SHRUB + N_SSHRUB_SHRUB + N_SSHRUB-FORB	C
N_SHRUB_ COMB_NAT	Native richness of Combined Shrub growth habits richness	Count unique native (NAT) SHRUB_COMB species across 100-m^2 plots	C
N_SHRUB_ COMB_AC	Alien and cryptogenic richness for Combined Shrub growth habits	Count unique ALIEN and CRYP SHRUB_COMB species across 100-m^2 plots	S
N_TREE_SHRUB	Tree-Shrub richness	Count unique TREE-SHRUB species across 100-m^2 plots	C
N_TREE	Tree richness	Count unique TREE species across 100-m^2 plots	C
N_TREE_COMB	Combined Tree and Tree-Shrub richness	N_TREE_SHRUB + N_TREE	C
N_TREE_ COMB_NAT	Combined Tree and Tree-Shrub richness	Count unique native (NAT) TREE_COMB species across 100-m^2 plots	C

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N_TREE_ COMB_AC	Combined Tree and Tree-Shrub richness	Count unique ALIEN and CRYP TREE_COMB species across 100-m^2 plots	S
N_VINE	Vine richness	Count unique VINE species across 100-m^2 plots	C
N_VINE_NAT	Vine richness	Count unique native (NAT) VINE species across 100-m^2 plots	C
N_VINE_AC	Vine richness	Count unique ALIEN and CRYP VINE species across 100-m^2 plots	S
N_VINE_SHRUB	Vine-Shrub richness	Count unique a VINE-SHRUB species across 100-m^2 plots	C
N_VINE_ SHRUB_NAT	Native Vine-Shrub richness	Count unique native (NAT) VINE-SHRUB species across 100-m^2 plots	C
N_VINE_ SHRUB_AC	Alien and cryptogenic Vine-Shrub richness	Count unique ALIEN and CRYP VINE-SHRUB species across 100-m^2 plots	S
PCTN_ GRAMINOID	Graminoid percent richness	(N_GRAMINOID/TOTN_SPP) x 100	C
PCTN_ GRAMINOID_NAT	Native Graminoid percent richness	(N_GRAMINOID_NAT/ TOTN_SPP) x 100	C
PCTN_ GRAMINOID_AC	Graminoid percent richness	(N_GRAMINOID_AC/TOTN_SPP) x 100	S
PCTN_FORB	Forb percent richness	(N_FORB/TOTN_SPP) x 100	C
PCTN_FORB_ NAT	Native Forb percent richness	(N_FORB_NAT/TOTN_SPP) x 100	C
PCTN_FORB_AC	Alien and cryptogenic Forb percent richness	(N_FORB_AC/TOTN_SPP) x 100	S
PCTN_HERB	Percent Herbaceous (FORB + GRAMINOID) richness	(N_HERB/TOTN_SPP) x 100	C
PCTN_HERB_ NAT	Percent native Herbaceous richness	(N_HERB_NAT/TOTN_SPP) x 100	C
PCTN_HERB_ AC	Percent alien and cryptogenic Herbaceous richness	(N_HERB_AC/TOTN_SPP) x 100	S
PCTN_SSHRUB_ FORB	Subshrub-Forb percent richness	(N_SSHRUB_FORB/TOTN_SPP) x 100	C
PCTN_SSHRUB_ SHRUB	Subshrub-Shrub percent richness	(N_SSHRUB/TOTN_SPP) x 100	C
PCTN_SHRUB	Shrub percent richness	(N_SHRUB/TOTN_SPP) x 100	C
PCTN_SHRUB_ COMB	Combined Shrub richness	(N_SHRUB_COMB/TOTN_SPP) x 100	C
PCTN_SHRUB_ COMB_NAT	Percent native richness of Combined Shrub growth habits	(N_SHRUB_COMB_NAT/TOTN_SPP) x 100	C
PCTN_SHRUB_ COMB_AC	Percent alien and cryptogenic richness for Combined Shrub growth habits	(N_SHRUB_COMB_AC/TOTN_SPP) x 100	S

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PCTN_TREE_ SHRUB	Tree-Shrub percent richness	(N_TREE_SHRUB/TOTN_SPP) x 100	C
PCTN_TREE	Tree percent richness	(N_TREE/TOTN_SPP) x 100	C
PCTN_TREE_ COMB	Combined Tree and Tree-Shrub percent richness	(N_TREE_COMB/TOTN_SPP) x 100	C
PCTN_TREE_ COMB_NAT	Combined Tree and Tree-Shrub percent richness	(N_TREE_COMB_NAT/TOTN_SPP) x 100	C
PCTN_TREE_ COMB_AC	Combined Tree and Tree-Shrub percent richness	(N_TREE_COMB_AC/TOTN_SPP) x 100	S
PCTN_VINE	Vine percent richness	(N_VINE/TOTN_SPP) x 100	C
PCTN_VINE_NAT	Native Vine percent richness	(N_VINE_NAT/TOTN_SPP) x 100	C
PCTN_VINE_AC	Alien and cryptogenic Vine percent richness	(N_VINE_AC/TOTN_SPP) x 100	S
PCTN_VINE_ SHRUB	Vine-Shrub percent richness	(N_VINE_SHRUB/TOTN_SPP) x 100	C
PCTN_VINE_ SHRUB_NAT	Native Vine-Shrub percent richness	(N_VINE_SHRUB_NAT/TOTN_SPP) x 100	C
PCTN_VINE_ SHRUB_AC	Alien and Cryptogenic Vine-Shrub percent richness	(N_VINE_SHRUB_AC/TOTN_SPP) x 100	S
XABCOV_ GRAMINOID	Mean absolute Graminoid cover	Σ COVER of GRAMINOID species across 5 plots/5 plots	C
XABCOV_ GRAMINOID_NAT	Mean absolute native Graminoid cover	Σ COVER of GRAMINOID NAT species across 5 plots/5 plots	C
XABCOV_ GRAMINOID_AC	Mean absolute alien and cryptogenic Graminoid cover	Σ COVER of GRAMINOID ALIEN and CRYP species across 5 plots/5 plots	S
XABCOV_FORB	Mean absolute FORB cover	Σ COVER of FORB species across 5 plots/5 plots	C
XABCOV_FORB_ NAT	Mean absolute native FORB cover	Σ COVER of NAT FORB species across 5 plots/5 plots	C
XABCOV_FORB_ AC	Mean absolute alien and cryptogenic FORB cover	Σ COVER of ALIEN and CRYP FORB species across 5 plots/5 plots	S
XABCOV_HERB	Mean absolute Herbaceous species cover (FORB + GRAMINOID)	XABCOV_FORB + XABCOV_GRAMINOID	C
XABCOV_HERB_ NAT	Mean absolute native Herbaceous cover	XABCOV_FORB_NAT + XABCOV_GRAMINOID_NAT	C
XABCOV_HERB_ AC	Mean relative Herbaceous alien and cryptogenic cover	XABCOV_FORB_AC + XABCOV_GRAMINOID_AC	S
XABCOV_ SSHRUB_FORB	Mean absolute Subshrub-Forb cover	Σ COVER of SUBSHRUB-FORB species across 5 plots/5 plots	C
XABCOV_ SSHRUB_SHRUB	Mean absolute Subshrub-Shrub cover	Σ COVER SUBSHRUB-SHRUB species across 5 plots/5 plots	C
XABCOV_SHRUB	Mean absolute Shrub cover	Σ COVER of SHRUB species across 5 plots/5 plots	C
XABCOV_ SHRUB_COMB	Combined Shrub growth habits absolute cover	Σ COVER of SHRUB_COMB species across 5 plots/5 plots	C

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XABCOV_SHRUB_COMB_NAT	Mean absolute native Combined Shrub growth habits cover	Σ COVER of NAT SHRUB-COMB species across 5 plots/5 plots	C
XABCOV_SHRUB_COMB_AC	Mean absolute alien and cryptogenic Combined Shrub growth habits cover	Σ COVER of ALIEN and CRYP SHRUB_COMB species across 5 plots/5 plots	S
XABCOV_TREE_SHRUB	Mean absolute Tree-Shrub cover	Σ COVER of TREE-SHRUB species across 5 plots/5 plots	C
XABCOV_TREE	Mean absolute Tree cover	Σ COVER of TREE species across 5 plots/5 plots	C
XABCOV_TREE_COMB	Combined Tree and Tree-Shrub absolute cover	Σ COVER of TREE_COMB species across 5 plots/5 plots	C
XABCOV_TREE_COMB_NAT	Combined native Tree and Tree-Shrub absolute cover	Σ COVER of NAT TREE_COMB species across 5 plots/5 plots	C
XABCOV_TREE_COMB_AC	Combined alien and cryptogenic Tree and Tree-Shrub absolute cover	Σ COVER of ALIEN and CRYP TREE_COMB species across 5 plots/5 plots	S
XABCOV_VINE	Mean absolute Vine cover	Σ COVER of VINE species across 5 plots/5 plots	C
XABCOV_VINE_NAT	Mean native absolute Vine cover	Σ COVER of NAT VINE species across 5 plots/5 plots	C
XABCOV_VINE_AC	Mean alien and cryptogenic absolute Vine cover	Σ COVER of ALIEN and CRYP VINE species across 5 plots/5 plots	S
XABCOV_VINE_SHRUB	Mean absolute Vine-Shrub cover	Σ COVER of VINE-SHRUB species across 5 plots/5 plots	C
XABCOV_VINE_SHRUB_NAT	Mean absolute native Vine-Shrub cover	Σ COVER of NAT VINE-SHRUB species across 5 plots/5 plots	C
XABCOV_VINE_SHRUB_AC	Mean absolute alien and cryptogenic Vine-Shrub cover	Σ COVER of ALIEN and CRYP VINE-SHRUB species across 5 plots/5 plots	S
XRCOV_GRAMINOID	Mean relative Graminoid cover	(XABCOV_GRAMINOID/XTOTABCOV) x 100	C
XRCOV_GRAMINOID_NAT	Mean relative native Graminoid cover	(XABCOV_GRAMINOID_NAT/XTOTABCOV) x 100	C
XRCOV_GRAMINOID_AC	Mean relative alien and cryptogenic Graminoid cover	(XABCOV_GRAMINOID_AC/XTOTABCOV) x 100	S
XRCOV_FORB	Mean relative Forb cover	(XABCOV_FORB/XTOTABCOV) x 100	C
XRCOV_FORB_NAT	Mean relative native Forb cover	(XABCOV_FORB_NAT/XTOTABCOV) x 100	C
XRCOV_FORB_AC	Mean relative alien and cryptogenic Forb cover	(XABCOV_FORB_AC/XTOTABCOV) x 100	C
XRCOV_HERB	Mean relative Herbaceous (FORB + GRAMINOID) cover	(XABCOV_HERB/XTOTABCOV) x 100	C
XRCOV_HERB_NAT	Mean relative native Herbaceous cover	(XABCOV_HERB_NAT/XTOTABCOV) x 100	C
XRCOV_HERB_AC	Mean relative alien and cryptogenic Herbaceous cover	(XABCOV_HERB_AC/XTOTABCOV) x 100	S

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XRCOV_SSHRUB_FORB	Mean relative Subshrub-Forb cover	(XABCOV_SSHRUB_FORB/ XTOTABCOV) x 100	C
XRCOV_SSHRUB_SHRUB	Mean relative Subshrub-Shrub cover	(XABCOV_SSHRUB_SHRUB/ XTOTABCOV) x 100	C
XRCOV_SHRUB	Mean relative Shrub cover	(XABCOV_SHRUB/XTOTABCOV) x 100	C
XRCOV_SHRUB_COMB	Mean relative Combined Shrub growth habits cover	(XABCOV_SHRUB_COMB/ XTOTABCOV) x 100	C
XRCOV_SHRUB_COMB_NAT	Mean relative native Combined Shrub growth habits cover	(XABCOV_SHRUB_COMB_NAT/ XTOTABCOV) x 100	C
XRCOV_SHRUB_COMB_AC	Mean relative alien and cryptogenic Combined Shrub growth habits cover	(XABCOV_SHRUB_COMB_AC/ XTOTABCOV) x 100	S
XRCOV_TREE_SHRUB	Mean relative Tree-Shrub cover	(XABCOV_TREE_SHRUB/ XTOTABCOV) x 100	C
XRCOV_TREE	Mean relative Tree cover	(XABCOV_TREE/XTOTABCOV) x 100	C
XRCOV_TREE_COMB	Mean relative Combined Tree and Tree-Shrub cover	(XABCOV_TREE_COMB/ XTOTABCOV) x 100	C
XRCOV_TREE_COMB_NAT	Mean relative Combined Tree and Tree-Shrub cover	(XABCOV_TREE_COMB_NAT/ XTOTABCOV) x 100	C
XBCOV_TREE_COMB_AC	Mean relative Combined Tree and Tree-Shrub cover	(XABCOV_TREE_COMB_AC/ XTOTABCOV) x 100	S
XRCOV_VINE	Mean relative Vine cover	(XABCOV_VINE/XTOTABCOV) x 100	C
XABCOV_VINE_NAT	Mean native relative Vine cover	(XABCOV_VINE_NAT/XTOTABCOV) x 100	C
XABCOV_VINE_AC	Mean alien and cryptogenic relative Vine cover	(XABCOV_VINE_AC/XTOTABCOV) x 100	S
XRCOV_VINE_SHRUB	Mean relative Vine-Shrub cover	(XABCOV_VINE_SHRUB/ XTOTABCOV) x 100	C
XRCOV_VINE_SHRUB_NAT	Mean native relative Vine-Shrub cover	(XABCOV_VINE_SHRUB_NAT/ XTOTABCOV) x 100	C
XRCOV_VINE_SHRUB_AC	Mean alien and cryptogenic relative Vine-Shrub cover	(XABCOV_VINE_SHRUB_AC/ XTOTABCOV) x 100	S
Section 5.2	***DURATION***	**Trait Information = Duration (Table 5-2); Native Status (Table 5-4)**	
N_ANNUAL	Annual species richness	Count unique ANNUAL species across 100-m^2 plots	C
N_ANNUAL_NAT	Native Annual richness	Count unique NAT ANNUAL species across 100-m^2 plots	C
N_ANNUAL_AC	Alien and cryptogenic Annual richness	Count unique ALIEN and CRYP ANNUAL species across 100-m^2 plots	S

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
N_ANN_BIEN	Annual-Biennial richness	Count unique ANN_BIEN species across 100-m^2 plots	C
N_ANN_BIEN_NAT	Native Annual-Biennial richness	Count unique NAT ANN_BIEN species across 100-m^2 plots	C
N_ANN_BIEN_AC	Alien and cryptogenic Annual-Biennial richness	Count unique ALIEN and CRYP ANN_BIEN species across 100-m^2 plots	S
N_ANN_PEREN	Annual-Perennial richness	Count unique ANN_PEREN species across 100-m^2 plots	C
N_ANN_PEREN_NAT	Native Annual-Perennial richness	Count unique NAT ANN_PEREN species across 100-m^2 plots	C
N_ANN_PEREN_AC	Alien and cryptogenic Annual-Perennial richness	Count unique ALIEN and CRYP ANN_PEREN species across 100-m^2 plots	S
N_PERENNIAL	Perennial richness	Count unique PERENNIAL species across 100-m^2 plots	C
N_PERENNIAL_NAT	Native Perennial richness	Count unique NAT PERENNIAL species across 100-m^2 plots	C
N_PERENNIAL_AC	Alien and cryptogenic Perennial richness	Count unique ALIEN and CRYP PERENNIAL species across 100-m^2 plots	S
PCTN_ANNUAL	Percent Annual richness	(N_ANNUAL/TOTN_SPP) x 100	C
PCTN_ANNUAL_NAT	Percent native Annual richness	(N_ANNUAL_NAT/TOTN_SPP) x 100	C
PCTN_ANNUAL_AC	Percent alien and cryptogenic Annual richness	(N_ANNUAL_AC/TOTN_SPP) x 100	S
PCTN_ANN_BIEN	Percent Annual-Biennial richness	(N_ANN_BIEN/TOTN_SPP) x 100	C
PCTN_ANN_BIEN_NAT	Percent native Annual-Biennial richness	(N_ANN_BIEN_NAT/TOTN_SPP) x 100	C
PCTN_ANN_BIEN_AC	Percent alien and cryptogenic Annual-Biennial richness	(N_ANN_BIEN_AC/TOTN_SPP) x 100	S
PCTN_ANN_PEREN	Percent Annual-Perennial richness	(N_ANN_PEREN/TOTN_SPP) x 100	C
PCTN_ANN_PEREN_NAT	Percent native Annual-Perennial richness	(N_ANN_PEREN_NAT/TOTN_SPP) x 100	C
PCTN_ANN_PEREN_AC	Percent alien and cryptogenic Annual-Perennial richness	(N_ANN_PEREN_AC/TOTN_SPP) x 100	S
PCTN_PERENNIAL	Percent Perennial richness	(N_PERENNIAL/TOTN_SPP) x 100	C
PCTN_PERENNIAL_NAT	Percent native Perennial richness	(N_PERENNIAL_NAT/TOTN_SPP) x 100	C
PCTN_PERENNIAL_AC	Percent alien and cryptogenic Perennial richness	(N_PERENNIAL_AC/TOTN_SPP) x 100	S
XABCOV_ANNUAL	Mean absolute Annual cover	Σ COVER of ANNUAL species across 5 plots/5 plots	C
XABCOV_ANNUAL_NAT	Mean absolute native Annual cover	Σ COVER of NAT ANNUAL species across 5 plots/5 plots	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
XABCOV_ ANNUAL_AC	Mean absolute alien and cryptogenic Annual cover	Σ COVER of ALIEN and CRYP ANNUAL species across 5 plots/5 plots	S
XABCOV_ANN_ BIEN	Mean absolute Annual-Biennial cover	Σ COVER of ANN_BIEN species across 5 plots/5 plots	C
XABCOV_ANN_ BIEN_NAT	Mean absolute native Annual-Biennial cover	Σ COVER of NAT ANN_BIEN species across 5 plots/5 plots	C
XABCOV_ANN_ BIEN_AC	Mean absolute alien and cryptogenic Annual-Biennial cover	Σ COVER of ALIEN and CRYP ANN_BIEN species across 5 plots/5 plots	S
XABCOV_ANN_ PEREN	Mean absolute Annual-Perennial cover	Σ COVER of ANN_PEREN species across 5 plots/5 plots	C
XABCOV_ANN_ PEREN_NAT	Mean absolute native Annual-Perennial cover	Σ COVER of NAT ANN_PEREN species across 5 plots/5 plots	C
XABCOV_ANN_ PEREN_AC	Mean absolute alien and cryptogenic Annual-Perennial cover	Σ COVER of ALIEN and CRYP ANN_PEREN species across 5 plots/5 plots	S
XABCOV_ PERENNIAL	Mean absolute Perennial cover	Σ COVER of PERENNIAL species across 5 plots/5 plots	C
XABCOV_ PERENNIAL_NAT	Mean absolute native Perennial cover	Σ COVER of NAT PERENNIAL species across 5 plots/5 plots	C
XABCOV_ PERENNIAL_AC	Mean absolute alien and cryptogenic Perennial cover	Σ COVER of ALIEN and CRYP PERENNIAL species across 5 plots/5 plots	S
XRCOV_ANNUAL	Mean relative annual cover	(XABCOV_ANNUAL/XTOTABCOV) x 100	C
XRCOV_ANNUAL_ NAT	Mean relative native Annual cover	(XABCOV_ANNUAL_NAT/ XTOTABCOV) x 100	C
XRCOV_ANNUAL_ AC	Mean relative alien and cryptogenic Annual cover	(XABCOV_ANNUAL_AC/ XTOTABCOV) x 100	S
XRCOV_ANN_ BIEN	Mean relative Annual-Biennial cover	(XABCOV_ANN_BIEN/ XTOTABCOV) x 100	C
XRCOV_ANN_ BIEN_NAT	Mean relative native Annual-Biennial cover	(XABCOV_ANN_BIEN_NAT/ XTOTABCOV) x 100	C
XRCOV_ANN_ BIEN_AC	Mean relative alien and cryptogenic Annual-Biennial cover	(XABCOV_ANN_BIEN_AC/ XTOTABCOV) x 100	S
XRCOV_ANN_ PEREN	Mean relative Annual-Perennial cover	(XABCOV_ANN_PEREN/ XTOTABCOV) x 100	C
XRCOV_ANN_ PEREN_NAT	Mean relative native Annual-Perennial cover	(XABCOV_ANN_PEREN_NAT/ XTOTABCOV) x 100	C
XRCOV_ANN_ PEREN_AC	Mean relative alien and cryptogenic Annual-Perennial cover	(XABCOV_ANN_PEREN_AC/ XTOTABCOV) x 100	S
XRCOV_ PERENNIAL	Mean relative Perennial cover	(XABCOV_PERENNIAL/ XTOTABCOV) x 100	C
XRCOV_ PERENNIAL_NAT	Mean relative native Perennial cover	(XABCOV_PERENNIAL_NAT/ XTOTABCOV) x 100	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
XRCOV_ PERENNIAL_AC	Mean relative alien and cryptogenic Perennial cover	(XABCOV_PERENNIAL_AC/ XTOTABCOV) x 100	S
Section 5.3	***PLANT CATEGORY***	**Trait Information = Plant Category (See Section 5.6.3); Native Status (Table 5-4)**	
N_DICOTS	Dicot richness	Count unique DICOT species across 100-m^2 plots	C
N_DICOTS_NAT	Native Dicot richness	Count unique NAT DICOT species across 100-m^2 plots	C
N_DICOTS_ALIEN	Alien Dicot richness	Count unique ALIEN DICOT species across 100-m^2 plots	S
N_DICOTS_CRYP	Cryptogenic Dicot richness	Count unique CRYP DICOT species across 100-m^2 plots	C
N_DICOTS_AC	Alien and Cryptogenic richness	N_DICOT_ALIEN + N_DICOT_CRYP	S
N_FERNS	Fern richness	Count unique FERN species across 100-m^2 plots	C
N_FERNS_NAT	Native Fern richness	Count unique native FERN species across 100-m^2 plots	C
N_FERNS_INTR	Introduced FERN species richness	Count unique introduced FERN species across 100-m^2 plots	S
N_GYMNOSPERM	Gymnosperm richness	Count unique GYMNOSPERM species across 100-m^2 plots	C
N_LYCOPOD	Lycopod richness	Count unique LYCOPOD species across 100-m^2 plots	C
N_HORSETAIL	Horsetail richness	Count unique HORSETAIL species across 100-m^2 plots	C
N_MONOCOT	Monocot richness	Count unique MONOCOT species across 100-m^2 plots	C
N_MONOCOTS_ NAT	Native Monocot richness	Count unique NAT MONOCOT species across 100-m^2 plots	C
N_MONOCOTS_ ALIEN	Alien Monocot richness	Count unique ALIEN MONOCOT species across 100-m^2 plots	S
N_MONOCOTS_ CRYP	Cryptogenic Monocot richness	Count unique CRYP MONOCOT species across 100-m^2 plots	S
N_MONOCOTS_ AC	Alien and cryptogenic Monocot richness	N_MONOCOT_ALIEN + N_MONOCOT_CRYP	S
PCTN_DICOTS	Dicot percent richness	(N_DICOTS/TOTN_SPP) x 100	C
PCTN_DICOTS_ NAT	Native Dicot percent richness	(N_DICOTS_NAT/TOTN_SPP) x 100	C
PCTN_DICOTS_ ALIEN	Alien Dicot percent richness	(N_DICOTS_ALIEN/TOTN_SPP) x 100	S
PCTN_DICOTS_ CRYP	Cryptogenic Dicot percent richness	(N_DICOTS_CRYP/TOTN_SPP) x 100	S
PCTN_DICOT_AC	Alien and cryptogenic Dicot percent richness	(N_DICOTS_AC/TOTN_SPP) x 100	S
PCTN_FERNS	Fern percent richness	(N_FERNS/TOTN_SPP) x 100	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
PCTN_FERNS_ NAT	Native Ferns percent richness	(N_FERNS_NAT/TOTN_SPP) x 100	C
PCTN_FERNS_ INTR	Introduced Fern percent richness	(N_FERNS_INTR/TOTN_SPP) x 100	S
PCTN_ GYMNOSPERM	GYMNOSPERM Percent Richness	(N_GYNOSPERM/TOTN_SPP) x 100	C
PCTN_LYCOPOD	Lycopod percent richness	(N_LYCOPOD/TOTN_SPP) x 100	C
PCTN_HORSETAIL	Horsetail percent richness	(N_HORSETAIL/TOTN_SPP) x 100	C
PCTN_ MONOCOTS	Monocot percent richness	(N_MONOCOTS/TOTN_SPP) x 100	C
PCTN_ MONOCOTS_NAT	Native Monocot percent richness	(N_MONOCOTS_NAT/TOTN_SPP) x 100	C
PCTN_ MONOCOTS_ ALIEN	Alien Monocot percent richness	(N_MONOCOTS_ALIEN/ TOTN_SPP) x 100	S
PCTN_ MONOCOTS_ CRYP	Cryptogenic Monocot percent richness	(N_MONOCOTS_CRYP/TOTN_SPP) x 100	S
PCTN_ MONOCOTS_AC	Alien and cryptogenic monocot percent richness	(N_MONOCOTS_AC/TOTN_SPP) x 100	S
XABCOV_DICOTS	Mean absolute cover Dicots	Σ COVER of DICOT species across 5 plots/5 plots	C
XABCOV_ DICOTS_NAT	Mean absolute cover native Dicots	Σ COVER of NAT DICOT species across 5 plots/5 plots	C
XABCOV_ DICOTS_ALIEN	Mean absolute cover Alien Dicots	Σ COVER of ALIEN DICOT species across 5 plots/5 plots	S
XABCOV_ DICOTS_CRYP	Mean absolute cover cryptogenic Dicots	Σ COVER of CRYP DICOT species across 5 plots/5 plots	S
XABCOV_ DICOTS_AC	Mean absolute cover of alien and cryptogenic Dicots	XABCOV_DICOTS_ALIEN + XABCOV_DICOTS_CRYP	S
XABCOV_FERN	Mean absolute cover of Ferns	Σ COVER of FERN species across 5 plots/5 plots	C
XABCOV_FERNS_ NAT	Mean absolute cover of native Ferns	Σ COVER of native FERN species across 5 plots/5 plots	C
XABCOV_FERNS_ INTR	Mean absolute cover of introduced Ferns	Σ COVER of introduced FERN species across 5 plots/5 plots	S
XABCOV_ GYMNOSPERM	Mean absolute cover of Gymnosperms	Σ COVER of GYMNOSPERM species across 5 plots/5 plots	C
XABCOV_ LYCOPODS	Mean absolute cover of Lycopods	Σ COVER of LYCOPOD species across 5 plots/5 plots	C
XABCOV_ HORSETAIL	Mean absolute cover of Horsetails	Σ COVER of HORSETAIL species across 5 plots/5 plots	C
XABCOV_ MONOCOT	Mean absolute cover of Monocots	Σ COVER of MONOCOT species across 5 plots/5 plots	C
XABCOV_ MONOCOTS_NAT	Mean absolute cover of native Monocots	Σ COVER of NAT MONOCOT species across 5 plots/5 plots	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
XABCOV_ MONOCOTS_ ALIEN	Mean absolute cover of alien Monocots	Σ COVER of ALIEN MONOCOT species across 5 plots/5 plots	S
XABCOV_ MONOCOTS_ CRYP	Mean absolute cover of cryptogenic Monocots	Σ COVER of CRYP MONOCOT species across 5 plots/5 plots	S
XABCOV_ MONOCOTS_AC	Mean absolute cover of alien and cryptogenic Monocots	XABCOV_MONOCOTS_ALIEN + XABCOV_MONOCOTS_CRYP	S
XRCOV_DICOT	Mean relative cover Dicots	(XABCOV_DICOTS/XTOTABCOV) x 100	C
XRCOV_DICOTS_ NAT	Mean relative cover native Dicots	(XABCOV_DICOTS_NAT/ XTOTABCOV) x 100	C
XRCOV_DICOTS_ ALIEN	Mean relative cover alien Dicots	(XABCOV_DICOTS_ALIEN/ XTOTABCOV) x 100	S
XRCOV_DICOTS_ CRYP	Mean relative cover cryptogenic Dicots	(XABCOV_DICOTS_CRYP/ XTOTABCOV) x 100	S
XRCOV_DICOTS_ AC	Mean relative cover of alien and cryptogenic Dicots	(XABCOV_DICOTS_AC/ XTOTABCOV) x 100	S
XRCOV_FERN	Mean relative cover of Ferns	(XABCOV_FERNS/ XTOTABCOV) x 100	C
XRCOV_FERNS_ NAT	Mean relative cover of native Ferns	(XABCOV_FERNS_NAT/ XTOTABCOV) x 100	C
XRCOV_FERNS_ INTR	Mean relative cover of introduced Ferns	(XABCOV_FERNS_INTR/ XTOTABCOV) x 100	S
XRCOV_ GYMNOSPERM	Mean relative cover of Gymnosperms	(XABCOV_GYMNOSPERMS/ XTOTABCOV) x 100	C
XRCOV_LYCOPOD	Mean relative cover of Lycopods	(XABCOV_LYCOPODS/ XTOTABCOV) x 100	C
XRCOV_ HORSETAIL	Mean relative cover of Horsetails	(XABCOV_HORSETAILS/ XTOTABCOV) x 100	C
XRCOV_ MONOCOT	Mean relative cover of Monocots	(XABCOV_MONOCOTS/ XTOTABCOV) x 100	C
XRCOV_ MONOCOTS_NAT	**Mean relative cover of native Monocots**	**(XABCOV_MONOCOTS_NAT/ XTOTABCOV) x 100**	**C, Used in VMMI**
XRCOV_ MONOCOTS_ ALIEN	Mean relative cover of alien Monocots	(XABCOV_MONOCOTS_ALIEN/ XTOTABCOV) x 100	S
XRCOV_ MONOCOTS_ CRYP	Mean relative cover of cryptogenic Monocots	(XABCOV_MONOCOTS_CRYP/ XTOTABCOV) x 100	S
XRCOV_ MONOCOTS_AC	Mean relative cover of alien and cryptogenic Monocots	(XABCOV_MONOCOTS_AC/ XTOTABCOV) x 100	S

METRIC NAME	METRIC DESCRIPTION	CALCULATION (listed in White Metric Row), SPECIES TRAIT TYPE (if applicable, indicated in Colored Banners)	METRIC TYPE (C = condition, S = stress)
Sections 6 - 8	**METRICS BASED ON FIELD DATA FROM FORM V-3: NWCA VEGETATION TYPES (FRONT) AND NWCA GROUND SURFACE ATTRIBUTES (BACK)**		
SECTION 6	**WETLAND TYPE HETEROGENEITY BASED ON PLOT-LEVEL NWCA WETLAND TYPES (*designated as 'Predominant S & T Class' on Form V-3*)**		
N_SANDT	Number of unique NWCA Wetland Types in AA	Count number of unique NWCA Wetland Types across the 5 plots	C
DOM_SANDT	Dominant NWCA Wetland Type(s) in AA	Select dominant NWCA Wetland Types: Most frequent (greatest number of plots), or in case of ties, the two most frequent hyphenated	C
D_SANDT	Simpson's Diversity - Heterogeneity of NWCA Wetland Types in AA *s* = number of S&T classes present, *i* = class *i, p* = proportion of S&T Classes belonging to class *i*	$D = 1 - \sum_{i}^{s} p_i^2$	C
H_SANDT	Shannon-Wiener - Heterogeneity of NWCA Wetland Types in AA *s* = number of S&T classes present, *i* = class *i, p* = proportion of S&T Classes belonging to class *i*	$H' = -\sum_{i}^{s} p_i \ln p_i$	C
J_SANDT	Pielou Evenness - Heterogeneity of NWCA Wetland Types in AA *S* = number of S&T classes observed	$J = \frac{H'}{\ln S}$	C
SECTION 7	**VEGETATION STRUCTURE/TYPES**		
SECTION 7.1	***Vascular Strata***		
N_VASC_STRATA	Number of unique Vascular Vegetation Strata across AA	Count number of unique vascular vegetation strata across the 5 plots	C
XN_VASC_ STRATA	Mean number of vascular vegetation strata across plots		C
RG_VASC_ STRATA	Range in number of vascular vegetation strata found in all 100-m^2 plots	Maximum - minimum number of vegetation strata across five 100-m^2 plots	C
XTOTCOV_VASC_ STRATA	Mean total cover of all vascular strata	(Σ cover for all vascular strata across all 100-m^2 plots)/5 plots	C
FREQ_ SUBMERGED_AQ	Frequency Submerged Aquatic Vegetation	(# of 100-m^2 plots in which SUBMERGED_AQ occurs/5 plots) x 100	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
FREQ_FLOATING_AQ	Frequency Floating Aquatic Vegetation	(# of 100-m^2 plots in which FLOATING_AQ occurs/5 plots) x 100	C
FREQ_LIANAS	Frequency Lianas, vines, and vascular epiphytes	(# of 100-m^2 plots in which LIANAS occurs/5 plots) x 100	C
FREQ_VTALL_VEG	Frequency Vegetation > 30m tall	(# of 100-m^2 plots in which VTALL_VEG occurs/5 plots) x 100	C
FREQ_TALL_VEG	Frequency Vegetation > 15m to 30m tall	(# of 100-m^2 plots in which TALL_VEG occurs/5 plots) x 100	C
FREQ_HMED_VEG	Frequency Vegetation > 5m to 15m tall	(# of 100-m^2 plots in which HMED_VEG occurs/5 plots) x 100	C
FREQ_MED_VEG	Frequency Vegetation >2m to 5 tall	(# of 100-m^2 plots in which MED_VEG occurs/5 plots) x 100	C
FREQ_SMALL_VEG	Frequency Vegetation 0.5 to 2m tall	(# of 100-m^2 plots in which SMALL_VEG occurs/5 plots) x 100	C
FREQ_VSMALL_VEG	Frequency Vegetation < 0.5m tall	(# of 100-m^2 plots in which VSMALL_VEG occurs/5 plots) x 100	C
XCOV_SUBMERGED_AQ	Mean absolute cover Submerged Aquatic Vegetation	Σ cover of SUBMERGED_AQ across 5 plots/5 plots	C
XCOV_FLOATING_AQ	Mean absolute cover Floating Aquatic Vegetation	Σ cover of FLOATING_AQ across 5 plots/5 plots	C
XCOV_LIANAS	Mean absolute cover Lianas, vines, and vascular epiphytes	Σ cover of LIANAS across 5 plots/5 plots	C
XCOV_VTALL_VEG	Mean absolute cover Vegetation > 30m tall	Σ cover of VTALL_VEG across 5 plots/5 plots	C
XCOV_TALL_VEG	Mean absolute cover Vegetation > 15m to 30m tall	Σ cover of TALL_VEG across 5 plots/5 plots	C
XCOV_HMED_VEG	Mean absolute cover Vegetation > 5m to 15m tall	Σ cover of HMED_VEG across 5 plots/5 plots	C
XCOV_MED_VEG	Mean absolute cover Vegetation >2m to 5 tall	Σ cover of MED_VEG across 5 plots/5 plots	C
XCOV_SMALL_VEG	Mean absolute cover Vegetation 0.5 to 2m tall	Σ cover of SMALL_VEG across 5 plots/5 plots	C
XC0V_VSMALL_VEG	Mean absolute cover Vegetation < 0.5m tall	∑cover of VSMALL_VEG across 5 plots/5 plots	C
IMP_SUBMERGED_AQ	Importance Submerged Aquatic Vegetation	(FREQ_SUBMERGED_AQ + XCOV_SUBMERGED_AQ)/2	C
IMP_FLOATING_AQ	Importance Floating Aquatic Vegetation	(FREQ_FLOATING_AQ + XCOV_FLOATING_AQ)/2	C
IMP_LIANAS	Importance Lianas, vines, and vascular epiphytes	(FREQ_LIANAS + XCOV_LIANAS)/2	C
IMP_VTALL_VEG	Importance Vegetation > 30m tall	(FREQ_VTALL_VEG + XCOV_VTALL_VEG)/2	C
IMP_TALL_VEG	Importance Vegetation > 15m to 30m tall	(FREQ_TALL_VEG + XCOV_TALL_VEG)/2	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
IMP_HMED_VEG	Importance Vegetation > 5m to 15m tall	(FREQ_HMED_VEG + XCOV_HMED_VEG)/2	C
IMP_MED_VEG	Importance Vegetation >2m to 5 tall	(FREQ_MED_VEG + XCOV_MED_VEG)/2	C
IMP_SMALL_VEG	Importance Vegetation 0.5 to 2m tall	(FREQ_SMALL_VEG + XCOV_SMALL_VEG)/2	C
IMP_VSMALL_ VEG	Importance Vegetation < 0.5m tall	(FREQ_VSMALL_VEG + XCOV_VSMALL_VEG)/2	C
RXCOV_ SUBMERGED_AQ	Relative mean cover Submerged Aquatic Vegetation	(XCOV_SUBMERGED_AQ/ XTOTCOV_VASC_STRATA) x 100	C
RXCOV_ FLOATING_AQ	Relative mean cover Floating Aquatic Vegetation	(XCOV_FLOATING_AQ/ XTOTCOV_VASC_STRATA) x 100	C
RXCOV_LIANAS	Relative cover Lianas, Vines, and Vascular Epiphytes	(XCOV_LIANAS/ XTOTCOV_VASC_STRATA) x 100	C
RXCOV_VTALL_ VEG	Relative cover Vegetation > 30m tall	(XCOV_VTALL_VEG/ XTOTCOV_VASC_STRATA) x 100	C
RXCOV_TALL_ VEG	Relative cover Vegetation > 15m to 30m tall	(XCOV_TALL_VEG/ XTOTCOV_VASC_STRATA) x 100	C
RXCOV_HMED_ VEG	Relative cover Vegetation > 5m to 15m tall	(XCOV_HMED_VEG/ XTOTCOV_VASC_STRATA) x 100	C
RXCOV_MED_ VEG	Relative cover Vegetation >2m to 5 tall	(XCOV_MED_VEG/ XTOTCOV_VASC_STRATA) x 100	C
RXCOV_SMALL_ VEG	Relative cover Vegetation 0.5 to 2m tall	(XCOV_SMALL_VEG/ XTOTCOV_VASC_STRATA) x 100	C
RXC0V_VSMALL_ VEG	Relative cover Vegetation < 0.5m tall	(XCOV_VSMALL_/ XTOTCOV_VASC_STRATA) x 100	C
D_VASC_STRATA	Simpson's Diversity - Heterogeneity of Vertical Vascular Structure in AA based on occurrence and relative cover of all strata in all plots *s* = number of veg strata observed, *i* = veg stratum *i*, *p* = relative cover belonging to veg stratum *i*	$D = 1 - \sum_{i}^{s} p_i^2$	C
H_VASC_STRATA	Shannon-Wiener - Heterogeneity of Vertical Vascular Structure in AA based on occurrence and relative cover of all strata in all plots *s* = number of veg strata observed, *i* = veg stratum *i*, *p* = relative cover belonging to veg stratum *i*	$H' = -\sum_{i}^{s} p_i \ln p_i$	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
J_VASC_STRATA	Pielou Evenness - Heterogeneity of Vertical Vascular Structure in AA based on occurrence and relative cover of all strata in all plots *S*=number of strata observed	$J = \frac{H'}{\ln S}$	C
Section 7.2	***Non-Vascular Groups***		
N_PEAT_MOSS_ DOM	Number of plots where bryophytes are dominated by Sphagnum or other peat forming moss	Count number of plots where PEAT_MOSS = Y	C
FREQ_PEAT_ MOSS_DOM	Frequency of plots where bryophytes are dominated by Sphagnum or other peat forming moss	(N_PEAT_MOSS_DOM/5 plots) x 100	C
FREQ_ BRYOPHYTES	Frequency of bryophytes growing on ground surfaces, logs, rocks, etc.	(# of 100-m^2 plots in which BRYOPHYTES occur/5 plots) x 100	C
FREQ_LICHENS	Frequency of lichens growing on ground surfaces, logs, rocks, etc.	(# of 100-m^2 plots in which LICHENS occur/5 plots) x 100	C
FREQ_ARBOREAL	Frequency of arboreal Bryophytes and Lichens	(# of 100-m^2 plots in which ARBOREAL occur/5 plots) x 100	C
FREQ_ALGAE	Frequency of filamentous or mat forming algae	(# of 100-m^2 plots in which ALGAE occurs/5 plots) x 100	C
FREQ_ MACROALGAE	Macroalgae (freshwater species/seaweeds)	(# of 100-m^2 plots in which MACROALGAE occurs/5 plots) x 100	C
XCOV_ BRYOPHYTES	Mean absolute cover bryophytes growing on ground surfaces, logs, rocks, etc.	Σ cover of BRYOPHYTES across 5 plots/5 plots	C
XCOV_LICHENS	Mean absolute cover lichens growing on ground surfaces, logs, rocks, etc.	Σ cover of LICHENS across 5 plots/5 plots	C
XCOV_ARBOREAL	Mean absolute cover arboreal Bryophytes and Lichens	∑ cover of ARBOREAL across 5 plots/5 plots	C
XCOV_ALGAE	Mean absolute cover filamentous or mat forming algae	∑ cover of ALGAE across 5 plots/5 plots	C
XCOV_ MACROALGAE	Mean absolute cover macroalgae (freshwater species/seaweeds)	∑ cover of MACROALGAE across 5 plots/5 plots	C
IMP_ BRYOPHYTES	Bryophytes growing on ground surfaces, logs, rocks, etc.	(FREQ_BRYOPHYTES + XCOV_BRYOPHYTES)/2	C
IMP_LICHENS	Lichens growing on ground surfaces, logs, rocks, etc.	(FREQ_LICHENS + XCOV_LICHENS)/2	C
IMP_ARBOREAL	Arboreal Bryophytes and Lichens	(FREQ_ARBOREAL + XCOV_ARBOREAL)/2	C
IMP_ALGAE	Filamentous or mat forming algae	(FREQ_ALGAE + XCOV_ALGAE)/2	C
IMP_ MACROALGAE	Macroalgae (freshwater species/seaweeds)	(FREQ_MACROALGAE + XCOV_MACROALGAE)/2	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
Section 8	**Ground Surface Attributes**		
Section 8.1	***Water Cover and Depth***		
MIN_H2O_DEPTH	Minimum water depth	Lowest value for MINIMUM_DEPTH across five 100-m^2 plots	C
XH2O_DEPTH	Mean Predominant water depth in plots where water occurs	∑PREDOMINANT_DEPTH across plots where standing water occurs/number of plots where standing water occurs	C
XH2O_DEPTH_AA	Mean Predominant water depth across AA	∑PREDOMINANT_DEPTH across plots all sampled 100-m^2 plots/5 plots	C
MAX_H2O_DEPTH	Maximum water depth	Highest value for MAXIMUM_DEPTH across five 100-m^2 plots	C
FREQ_H2O	Frequency of occurrence of water across 100-m^2 plots	(# of 100-m^2 plots in which TOTAL_WATER occurs/5 plots) x 100	C
FREQ_H2O_NOVEG	Frequency of occurrence of water and no vegetation	(# of 100-m^2 plots in which WATER_NOVEG occurs/5 plots) x 100	C
FREQ_H2O_AQVEG	Frequency of occurrence of water and floating/submerged aquatic vegetation	(# of 100-m^2 plots in which WATER_AQVEG occurs/5 plots) x 100	C
FREQ_H2O_EMERGVEG	Frequency of occurrence of water and emergent and/or woody vegetation	(# of 100-m^2 plots in which WATER_EMERGVEG occurs/5 plots) x 100	C
MIN_COV_H2O	Minimum cover of water	Lowest value for TOTAL_WATER across five 100-m^2 plots	C
MAX_COV_H2O	Maximum cover of water	Highest value for TOTAL_WATER across five 100-m^2 plots	C
XCOV_H2O	Total cover of water (percent of Veg Plot area with water = a+b+c ≤ 100%)	Σ cover of TOTAL_WATER across 5 plots/5 plots	C
XCOV_H2O_NOVEG	a) % Veg Plot area with water and no vegetation	Σ cover of WATER_AQVEG across 5 plots/5 plots	C
XCOV_H2O_AQVEG	b) % Veg Plot area with water and floating/submerged aquatic vegetation	Σ cover of WATER_NOVEG across 5 plots/5 plots	C
XCOV_H2O_EMERGVEG	c) % Veg Plot area with water and emergent and/or woody vegetation	Σ cover of WATER_EMERGVEG across 5 plots/5 plots	C
IMP_H2O	Importance total cover of water (percent of Veg Plot area with water = a+b+c ≤ 100%)	(FREQ_H2O + XCOV_H2O)/2	C
IMP_H2O_NOVEG	Importance a) % Veg Plot area with water and no vegetation	(FREQ_H2O_NOVEG + COV_H2O_NOVEG)/2	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
IMP_H2O_AQVEG	Importance b) % Veg Plot area with water and floating/submerged aquatic vegetation	(FREQ_H2O_AQVEG + XCOV_H2O_AQVEG)/2	C
IMP_H2O_ EMERGVEG	Importance c) % Veg Plot area with water and emergent and/or woody vegetation	(FREQ_H2O_EMERGVEG + XCOV_H2O_EMERGVEG)/2	C
Section 8.2	***Bareground and Litter***		
N_LITTER_TYPE	Number of unique litter types observed across the five 100-m^2 plots	Count the number of unique litter types (LITTER_THATCH, LITTER_FORB, LITTER_CONIFER, LITTER_DECID, LITTER_BROADLEAF). Count each type only once.	C
XDEPTH_LITTER	Mean depth of litter across all 1-m^2 quadrats in AA	Sum LITTER_DEPTH for all 1-m^2 quadrats/total number of sampled quadrats (usually 10)	C
MEDDEPTH_ LITTER	Median depth of litter across all 1-m^2 quadrats in AA		C
FREQ_LITTER	Frequency of litter	(# of 100-m^2 plots in which TOTAL_LITTER occurs/5 plots) x 100	C
FREQ_BAREGD	Frequency of bareground	(# of 100-m^2 plots in which any one of EXPOSED_SOIL; EXPOSED_GRAVEL; EXPOSED_ROCK occurs/5 plots) x 100	C
FREQ_EXPOSED_ SOIL	Frequency exposed soil/sediment	(# of 100-m^2 plots in which EXPOSED_SOIL occurs/5 plots) x 100	C
FRQ_EXPOSED_ GRAVEL	Frequency exposed gravel/cobble (~2mm to 25cm)	(# of 100-m^2 plots in which EXPOSED_GRAVEL occurs/5 plots) x 100	C
FREQ_EXPOSED_ ROCK	Frequency exposed rock (> 25cm)	(# of 100-m^2 plots in which EXPOSED_ROCK occurs/5 plots) x 100	C
FREQ_WD_FINE	Frequency of fine woody debris (< 5cm diameter)	(# of 100-m^2 plots in which WD_FINE occurs/5 plots) x 100	C
FREQ_WD_ COARSE	Frequency of coarse woody debris (> 5cm diameter)	(# of 100-m^2 plots in which WD_COARSE occurs/5 plots) x 100	C
XCOV_LITTER	Mean Cover of litter	Σ cover of TOTAL_LITTER across 5 plots/5 plots	C
XCOV_BAREGD	Mean cover of bareground	Σ cover of EXPOSED_SOIL + EXPOSED_GRAVEL + EXPOSED_ROCK across 5 plots/5 plots	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
XCOV_EXPOSED_SOIL	Mean Cover exposed soil/sediment	Σ cover of EXPOSED_SOIL across 5 plots/5 plots	C
XCOV_EXPOSED_GRAVEL	Mean Cover exposed gravel/cobble (~2mm to 25cm)	Σ cover of EXPOSED_GRAVEL across 5 plots/5 plots	C
XCOV_EXPOSED_ROCK	c) Cover exposed rock (> 25cm)	Σ cover of EXPOSED_ROCK across 5 plots/5 plots	C
XCOV_WD_FINE	Mean Cover of fine woody debris (< 5cm diameter)	Σ cover of WD_FINE across 5 plots/5 plots	C
XCOV_WD_COARSE	Mean Cover of coarse woody debris (> 5cm diameter)	Σ cover of WD_COARSE across 5 plots/5 plots	C
IMP_LITTER	Importance of litter	(FREQ_LITTER + XCOV_LITTER)/2	C
IMP_BAREGD	Importance of bare ground	(FREQ_BAREGD + XCOV_BAREGD)/2	C
IMP_EXPOSED_SOIL	Importance exposed soil/sediment	(FREQ_EXPOSED_SOIL + XCOV_EXPOSED_SOIL)/2	C
IMP_EXPOSED_GRAVEL	Importance exposed gravel/cobble (~2mm to 25cm)	(FRQ_EXPOSED_GRAVEL + XCOV_EXPOSED_GRAVEL)/2	C
IMP_EXPOSED_ROCK	Importance exposed rock (> 25cm)	(FREQ_EXPOSED_ROCK + XCOV_EXPOSED_ROCK)/2	C
IMP_WD_FINE	Importance of fine woody debris (< 5cm diameter)	(FREQ_WD_FINE + XCOV_WD_FINE)/2	C
IMP_WD_COARSE	Importance of coarse woody debris (> 5cm diameter)	(FREQ_WD_COARSE+ XCOV_WD_COARSE)/2	C
SECTIONS 9 - 11	**METRICS BASED ON RAW DATA FROM FORM V-4: NWCA SNAG AND TREE COUNTS AND TREE COVER** Snag and tree metrics are calculated as means/100-m^2 plots to represent AA, unless specified as totals across AA (from all 5 100m^2). Snag and tree metrics were not placed on a per hectare basis because the AA and sampled plots do not necessarily represent homogenous patches and many wetlands are not forested, but may have occasional trees. Basal area was not calculated because diameters were estimated in classes.		
SECTION 9	**DEAD/SNAG COUNT METRICS - Based on data from FORM V-4 (Snag/standing dead tree section)**		
TOTN_XXTHIN_SNAG	Total Number Dead tree or snags 5 to 10 cm DBH (diameter breast height)	∑ number of XXTHIN_SNAGS across of all 100-m^2 plots	C
TOTN_XTHIN_SNAG	Total number of dead trees or snags 11 to 25cm DBH	∑ number of XTHIN_SNAGS across of all 100-m^2 plots	C
TOTN_THIN_SNAG	Total number of dead trees or snags 26 to 50cm DBH	∑ number of THIN_SNAGS across of all 100-m^2 plots	C
TOTN_JR_SNAG	Total number of dead trees or snags 51 to 75cm DBH	∑ number of JR_SNAGS across of all 100-m^2 plots	C
TOTN_THICK_SNAG	Total number of dead trees or snags 76 to 100cm DBH	∑ number of THICK_SNAGS across of all 100-m^2 plots	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
TOTN_XTHICK_ SNAG	Total number of dead trees or snags 101 to 200 cm DBH	∑ number of XTHICK_SNAGS across of all 100-m^2 plots	C
TOTN_SNAGS	Total number of dead trees and snags	∑ number of all dead trees and snags across all DBH classes	C
XN_XXTHIN_ SNAG	Mean Number Dead tree or snags 5 to 10 cm DBH (diameter breast height)	∑ number of XXTHIN_SNAG/5 plots	C
XN_XTHIN_SNAG	Mean number of dead trees or snags 11 to 25cm DBH	∑ number of XTHIN_SNAG/5 plots	C
XN_THIN_SNAG	Mean number of dead trees or snags 26 to 50cm DBH	∑ number of THIN_SNAG/5 plots	C
XN_JR_SNAG	Mean number of dead trees or snags 51 to 75cm DBH	∑ number of JR_SNAG/5 plots	C
XN_THICK_SNAG	Mean number of dead trees or snags 76 to 100cm DBH	∑ number of THICK_SNAG/5 plots	C
XN_XTHICK_ SNAG	Mean number of dead trees or snags 101 to 200 cm DBH	∑ number of XTHICK_SNAG/5 plots	C
XN_SNAGS	Mean number of dead trees and snags	∑ number of dead trees and snags across all DBH classes/5 plots	C
			C
SECTION 10	**TREES - COUNTS AND COVER**		
SECTION 10.1	***TREE COVER METRICS***		
N_TREESPP	Richness tree species	Count unique tree species (taxa) across all 5 plots	C
N_VSMALL_TREE	Richness tree species, trees < 0.5m tall	Count unique tree species (taxa) in VSMALL_TREE height class across all 5 plots	C
N_SMALL_TREE	Richness tree species, trees 0.5m to 2m tall	Count unique tree species (taxa) in SMALL_TREE height class across all 5 plots	C
N_LMED_TREE	Richness tree species, trees > 2 to 5m tall	Count unique tree species (taxa) in LMED_TREE height class across all 5 plots	C
N_HMED_TREE	Richness tree species, trees > 5m to 15m tall	Count unique tree species (taxa) in HMED_TREE height class across all 5 plots	C
N_TALL_TREE	Richness tree species, trees > 15m to 30m tall	Count unique tree species (taxa) in TALL_TREE height class across all 5 plots	C
N_VTALL_TREE	Richness tree species, trees > 30m tall	Count unique tree species (taxa) in VT_TREE height class across all 5 plots	C
N_TREE_ GROUND	Richness tree species in ground layer (e.g., seedlings, saplings), trees < 2m	Count unique tree species (taxa) in GROUND LAYER (VSMALL_TREE and SMALL_TREE height classes) across all 5 plots	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
N_TREE_MID	Richness tree species in subcanopy layer, trees 2m to 15m tall	Count unique tree species (taxa) in MID LAYER (LMED_TREE and HMED_TREE height classes) across all 5 plots	C
N_TREE_UPPER	Richness tree species in subcanopy layer, trees > 15m	Count unique tree species (taxa) in UPPER LAYER (TALL_TREE and VTALL_TREE height classes) across all 5 plots	C
PCTN_TREE_ GROUND	Percent richness of tree species found in ground layer (e.g., seedlings, saplings), trees < 2m	(N_TREE_GROUND/N_TREESPP) x 100	C
PCTN_TREE_MID	Percent richness of tree species found in subcanopy layer, trees 2m to 15m tall	(N_TREE_MID/N_TREESPP) x 100	C
PCTN_TREE_ UPPER	Percent richness of tree species found in subcanopy layer, trees > 15m	(N_TREE_UPPER/N_TREESPP) x 100	C
FREQ_VSMALL_ TREE	Frequency (proportion of plots) of VSMALL trees, trees < 0.5m tall	(Number of 100-m^2 plots in which any species of VSMALL trees occurs/5 plots) x 100	C
FREQ_SMALL_ TREE	Frequency (proportion of plots) of SMALL trees, trees 0.5m to 2m tall	(Number of 100-m^2 plots in which any species of SMALL trees occurs/5 plots) x 100	C
FREQ_LMED_ TREE	Frequency (proportion of plots) of LMED trees, trees > 2 to 5m tall	(Number of 100-m^2 plots in which any species of LMED trees occurs/5 plots) x 100	C
FREQ_HMED_ TREE	Frequency (proportion of plots) of HMED, trees > 5m to 15m tall	(Number of 100-m^2 plots in which any species of HMED trees occurs/5 plots) x 100	C
FREQ_TALL_TREE	Frequency (proportion of plots) of TALL trees, trees > 15m to 30m tall	(Number of 100-m^2 plots in which any species of TALL trees occurs/5 plots) x 100	C
FREQ_VTALL_ TREE	Frequency (proportion of plots) of Frequency of individual, trees > 30m tall	(Number of 100-m^2 plots in which any species of VTALL trees occurs/5 plots) x 100	C
FREQ_TREE_ GROUND	Frequency (proportion of plots) of ground layer trees < 2m	(Number of 100-m^2 plots in which any species of GROUND LAYER (VSMALL or SMALL) trees occurs/5 plots) x 100	C
FREQ_TREE_MID	Frequency (proportion of plots) of subcanopy, trees 2m to 15m tall	(Number of 100-m^2 plots in which any species of MID LAYER (LMED or HMED) trees occurs/5 plots) x 100	C
FREQ_TREE_ UPPER	Frequency (proportion of plots) of CANOPY trees, trees >15m	(Number of 100-m^2 plots in which any species of UPPER LAYER (LMED or HMED)trees occurs/5 plots) x 100	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
XCOV_VSMALL_ TREE	Mean absolute cover VSMALL trees, trees < 0.5m tall	∑ of cover for <u>all</u> tree species in VSMALL height class across all plots/5 plots	C
XCOV_SMALL_ TREE	Mean absolute cover SMALL trees, trees 0.5m to 2m tall	∑ of cover for <u>all</u> tree species in SMALL height class across all plots/5 plots	C
XCOV_LMED_ TREE	Mean absolute cover LMED trees, trees > 2 to 5m tall	∑ of cover for <u>all</u> tree species in LMED height class across all plots/5 plots	C
XCOV_HMED_ TREE_	Mean absolute cover HMED trees, trees > 5m to 15m tall	∑ of cover for <u>all</u> tree species in HMED height class across all plots/5 plots	C
XCOV_TALL_TREE	Mean absolute cover TALL trees, trees > 15m to 30m tall	∑ of cover for <u>all</u> tree species in TALL height class across all plots/5 plots	C
XCOV_VTALL_ TREE_	Mean absolute cover VTALL trees, trees > 30m tall	∑ of cover for <u>all</u> tree species in VTALL height class across all plots/5 plots	C
XCOV_TREE_ GROUND	Mean absolute cover trees in ground layer (e.g., seedlings, saplings), trees < 2m	∑ of cover for <u>all</u> tree species in GROUND LAYER (VSMALL_TREE and SMALL_TREE height classes) across all plots/5 plots	C
XCOV_TREE_MID	Mean absolute cover trees in MID layer, trees 2m to 15m tall	∑ of cover for <u>all</u> tree species in MID LAYER (LMED_TREE and HMED_TREE height classes) across all plots/5 plots	C
XCOV_TREE_ UPPER	Mean absolute cover trees in UPPER layer, trees >15m	∑ of cover for <u>all</u> tree species in UPPER LAYER (TALL_TREE and VTALL_TREE height classes) across all plots/5 plots	C
IMP_VSMALL_ TREE	Importance of VSMALL trees, trees < 0.5m tall	(FREQ_VSMALL_TREE + XCOV_VSMALL_TREE)/2	C
IMP_SMALL_TREE	Importance of SMALL trees, trees 0.5m to 2m tall	(FREQ_SMALL_TREE + XCOV_SMALL_TREE)/2	C
IMP_LMED_TREE	Importance of LMED trees ,trees > 2 to 5m tall	(FREQ_LMED_TREE + XCOV_LMED_TREE)/2	C
IMP_HMED_TREE	Importance of HMED trees, trees > 5m to 15m tall	(FREQ_HMED_TREE + XCOV_HMED_TREE)/2	C
IMP_TALL_TREE	Importance of TALL trees, trees > 15m to 30m tall	(FREQ_TALL_TREE + XCOV_TALL_TREE)/2	C
IMP_VTALL_TREE	Importance of VTALL trees, trees > 30m tall	(FREQ_VTALL_TREE + XCOV_VTALL_TREE)/2	C
IMP_TREE_GROU ND	Importance of trees in GROUND layer (e.g., seedlings, saplings), trees < 2m	(FREQ_TREE_GOUND + XCOV_TREE_GROUND)/2	C
IMP_TREE_MID	Importance of trees in MID layer, trees 2m-15m tall	(FREQ_TREE_MID + XCOV_TREE_MID)/2	C

METRIC NAME	METRIC DESCRIPTION	**CALCULATION** (listed in White Metric Row), **SPECIES TRAIT TYPE** (if applicable, indicated in Colored Banners)	**METRIC TYPE** (C = condition, S = stress)
IMP_TREE_UPPER	Importance of trees in UPPER layer, trees > 15m	(FREQ_TREE_UPPER + XCOV_TREE_UPPER)/2	C
SECTION 10.2	***TREE COUNT METRICS***		
TOTN_XXTHIN_ TREES	Total number of tree stems in XXTHIN class, trees 5 to 10 cm DBH (diameter breast height)	∑ number of tree stems in XXTHIN_TREE class across all species and across all 100-m^2 plots	C
TOTN_XTHIN_ TREES	Total number of tree stems in XTHIN class, trees 11 to 25cm DBH	∑ number of tree stems in XTHIN_TREE class across all species and across 100-m^2 plots	C
TOTN_THIN_ TREES	Total number of tree stems in THIN class, trees 26 to 50cm DBH	∑ number of tree stems in THIN_TREE class across all species and across all 100-m^2 plots	C
TOTN_JR_TREES	Total number of tree stems in JR class, of trees 51 to 75cm DBH	∑ number of tree stems in JR_TREE class across all species and across all 100-m^2 plots	C
TOTN_THICK_ TREES	Total number of tree stems in THICK class, trees 76 to 100cm DBH	∑ number of tree stems in THICK_TREE class across all species and across all 100-m^2 plots	C
TOTN_XTHICK_ TREES	Total number of tree stems in XTHICK class, trees 101 to 200 cm DBH	∑ number of tree stems in XTHICK_TREE class across all species and across all 100-m^2 plots	C
TOTN_XXTHICK_ TREES	Total number of tree stems in XXTHICK class, of trees > 200 cm DBH	∑ number of tree stems in XXTHICK_TREE lass across all species and across all 100-m^2 plots	C
TOTN_TREES	Total number of tree stems across all classes DBH	∑ number of tree stems across all size classes, across all species, and across all 100-m^2 plots	C
XN_XXTHIN_ TREES	Mean number of tree stems in XXTHIN class, trees 5 to 10 cm DBH (diameter breast height)	TOTN_XXTHIN_TREES/5 plots	C
XN_XTHIN_TREES	Mean number of tree stems in XTHIN class, trees 11 to 25cm DBH	TOTN_XTHIN_TREES/5 plots	C
XN_THIN_TREES	Mean number of tree stems in THIN class, trees 26 to 50cm DBH	TOTN_THIN_TREES/5 plots	C
XN_JR_TREES	Mean number of tree stems in JR class, of trees 51 to 75cm DBH	TOTN_JR_TREES/5 plots	C
XN_THICK_TREES	Mean number of tree stems in THICK class, trees 76 to 100cm DBH	TOTN_THICK_TREES/5 plots	C
XN_XTHICK_ TREES	Mean number of tree stems in XTHICK class, trees 101 to 200 cm DBH	TOTN_XTHICK_TREES/5 plots	C
XN_XXTHICK_TRE ES	Mean number of tree stems in XXTHICK class, of trees > 200 cm DBH	TOTN_XXTHICK_TREES/5 plots	C
XN_TREES	Mean number of tree stems across all classes DBH	TOTN_TREES/5 plots	C

Chapter 7: Wetland Condition – Vegetation Multimetric Index

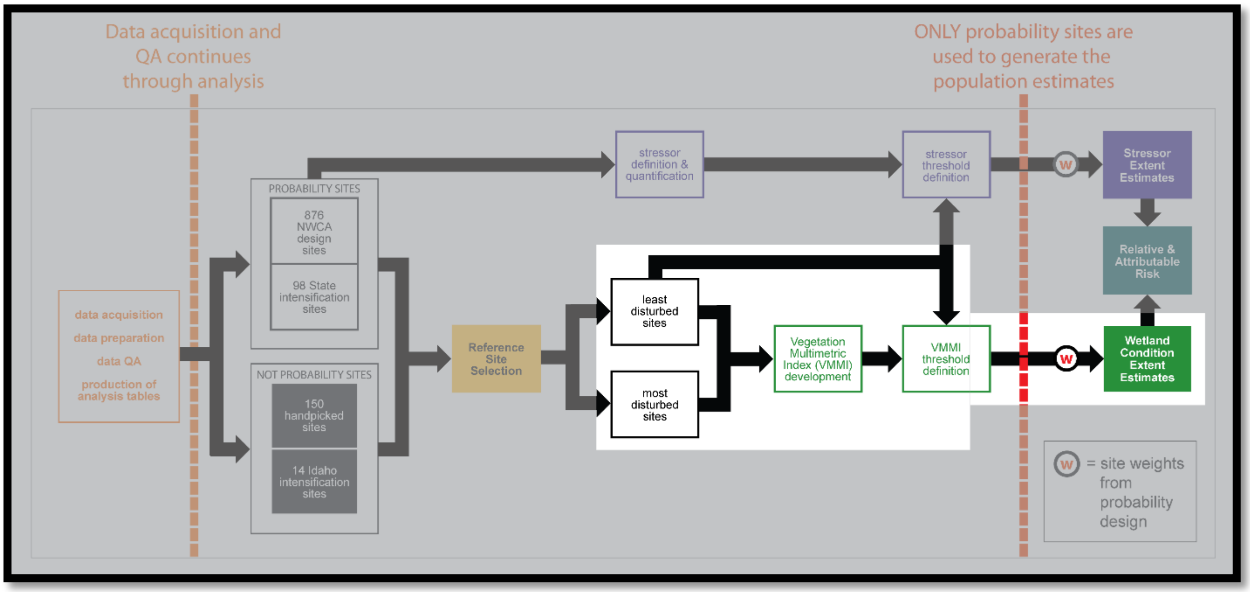

Figure 7-1. The major components of the 2011 National Wetland Condition Assessment Analysis Pathway that pertain to evaluating wetland condition are highlighted. A full-page, unhighlighted version of this figure may be found on **page 14** of this report.

7.1 Background – Vegetation Multimetric Index Development Approach

Multimetric indices of ecological condition based on biota have been widely used for other biological assemblages (e.g., fish, birds, periphyton, macroinvertebrates, etc.) and are a cornerstone of USEPA National Aquatic Resource Surveys (NARS). For MMIs (also known as IBIs – Index of Biotic Integrity), ecological condition is defined relative to the biota in least disturbed sites. In this chapter, we focus on the development of a ***Vegetation Multimetric Index (VMMI)*** as an indicator of wetland condition. **Figure 7-1** illustrates the portion of the NWCA Analysis Pathway that applies to 1) VMMI development, 2) determination of ecological condition thresholds, and 3) the use of VMMI values, condition thresholds, and site weights in estimating wetland area in good, fair, or poor ecological condition.

Several regional or state VMMIs have previously been developed and applied within the United States (e.g., Mack 2007; Gara and Stapanian 2015; MPCA 2015; see **Chapter 5: Section 5.1** for additional example citations). Existing VMMIs for wetland or riparian systems are comprised of several metrics describing different components or traits (representing aspects of plant species composition, floristic quality, native status, vegetation structure, and functional or life history guilds) of the vegetation. Candidate metrics of vegetation condition are evaluated for their utility in distinguishing least disturbed sites from those that are most disturbed. The most effective metrics representing different elements of vegetation ecology are typically combined into a VMMI reflecting overall ecological condition.

NWCA criteria for an effective VMMI were that it should:

- Accurately reflect ecological condition (i.e., distinguish least disturbed (reference) sites from most disturbed sites),
- Be parsimonious (i.e., based on a limited number of easy-to-measure metrics that describe condition in relation to least-disturbed condition), and
- Account for biotic variability that is related to natural environmental gradients or to regional differences in least-disturbed condition.

Accounting for variability related to natural gradients or regional differences in least-disturbed condition (see **Section 6.3**), is particularly critical to VMMI development because the former can influence the performance of candidate metrics of condition and the latter has implications for setting appropriate VMMI thresholds for ecological condition classes.

A variety of methods have been used to develop MMIs for vegetation or for other biotic assemblages. In selecting an approach to use for the NWCA VMMI, three principal methods were explored:

- Stoddard et al. (2008) – Traditional NARS MMI development using reporting groups to account for environmental and wetland type variation.

- Hawkins et al. (2010) – An approach that uses MMI development criteria similar to the traditional NARS approach, but which uses multivariate, nonparametric (Random Forests) modeling to account for environmental and wetland type variation and to inform metric selection.

- Van Sickle (2010) – An adaptation of the Stoddard et al. (2008) method that evaluates numerous MMIs based on randomly selected or all possible metric combinations of an optimum or set number of metrics.

In initial analyses for the NWCA, preliminary VMMIs developed using the Random Forest method appeared to perform similarly to those developed using the Stoddard approach. However, the Random Forest approach is complex and can be difficult to communicate to general audiences. Also, it has received limited testing for wetland systems. Although potentially promising, we considered the Random Forest approach to need further research before application to VMMI development for wetlands at the national scale. In addition, the traditional MMI methods result in robust and repeatable MMIs, allow straightforward communication of results on ecological condition and provide consistency between the NWCA and other NARS.

Consequently, we developed an approach to generating and evaluating potential VMMIs for the 2011 NWCA (see **Section 7.2**) that was adapted from the methods of Stoddard et al. (2008) and Van Sickle (2010). All analyses for VMMI development were conducted using the R software, version 3.1.1 (R Core Team 2014) using R code written for the NWCA.

7.1.1 *Wetland Condition Assessment in the NWCA*

Evaluating wetland condition in the NWCA VMMI involved three major components: VMMI development, threshold determination, and condition estimates. These components are briefly outlined below along with a listing of the sections of this report where each is discussed:

VMMI Development (**Sections 6.3 through 6.5**, and **Sections 7.2 and 7.3**)

- Account for natural gradients across the conterminous US using various NWCA Site Groups (e.g., Aggregated Ecoregions, Aggregated Wetland Types, or Reporting Groups) (**Section *6.3***).
- Divide site level vegetation data into calibration and validation data sets for use in evaluating candidate vegetation metrics and potential VMMIs (**Section 6.4**).
- Evaluate candidate metrics to identify those with utility for use in potential VMMIs (**Section *6.5***).
- Construct and evaluate potential VMMI(s) across all sites (nationally) and within various NWCA Site Groups, then select the final VMMI(s) for the 2011 NWCA (**Sections 7.2 and 7.3**).

Threshold Determination (**Section 7.4**)

- Define threshold values for good, fair, and poor ecological condition for the final VMMI(s), based on least disturbed sites in each applicable Reporting Group.

Condition Estimates (see **Section 7.5 and Chapter 9**)

- Use site weights from the survey design, condition thresholds, and VMMI values for each site to estimate wetland area in good, fair, and poor condition for the Nation, by Aggregated Ecoregion or Aggregated Wetland Type.

7.2 Developing the Vegetation Multimetric Index (VMMI) – Methods

The NWCA used a two-step process in developing a set of candidate VMMIs. **Table 7-1** lists the NWCA Site Groups for which VMMIs were developed and evaluated using the approaches adapted from Stoddard et al. (2008) and Van Sickle (2010). First, VMMIs were created within the hierarchy of NWCA Site Groups (reflecting various aspects of natural and regional variability) using a traditional NARS approach (Stoddard et al. 2008). We began by generating 10 to 30 potential VMMIs per Site Group. The potential VMMIs were constructed from combinations of 4 to 12 of the highest performing metrics (**Sections 6.5 and 6.6**) representing various metric types, and metrics which were not strongly correlated with one another ($r \leq |0.75|$). The set of preliminary VMMIs for each Site Group were then evaluated for their ability to distinguish least from most disturbed sites based on Kruskal-Wallis tests and boxplot discrimination. Although, a number of VMMIs that performed adequately were observed for many of the Site Groups, it was not always clear that the best possible VMMI was obtained because it was logistically practical to generate only a few VMMIs for comparison in each group. Sites Groups that were based on wetland types tended to produce the most robust VMMIs.

Consequently, several wetland type Site Groups were evaluated further using an approach developed by Van Sickle (2010) to evaluate numerous potential MMIs and identify those with the highest performance. We refer to this method as the MMI Permutation Approach. For each Site Group, many potential VMMIs were created, including: 1) 5,000 VMMIs based on random combinations of metrics, for a given number of metrics (4, 6, 8, or 10) selected from the available list of candidate metrics (see **Table 6-6**), or 2) all possible VMMIs based on all possible metric combinations for a particular number of metrics. The VMMIs for each Site Group were evaluated using a series of performance tests.

Table 7-1. NWCA Site Groups for which potential VMMIs were developed and evaluated using Traditional (adapted from Stoddard et al. (2008)) or Permutation (adapted from Van Sickle (2010)) approaches. Site Groups resulting in the most robust VMMIs are denoted by stars (★), the National VMMI having the overall best performance.

Site Group	Site Group Name	Group Type	Traditional	Permutation	Best Performing
NATIONAL	All Sites	All Sites	✓	✓	★★
EH + EW	*All* - Estuarine	Combined Aggregated Wetland Types	✓	✓	★
EH	*All* - Estuarine Herbaceous	Aggregated Wetland Type/Reporting Group	✓		
EW	*All* - Estuarine Woody	Aggregated Wetland Type/Reporting Group	✓		
PRLH	*All* - Palustrine, Riverine, and Lacustrine Herbaceous	Aggregated Wetland Type	✓	✓	★
CPL-PRLH + EMU-PRLH	*Coastal Plain + Eastern Mountains & Upper Midwest* - Palustrine, Riverine, and Lacustrine Herbaceous	Combined Reporting Groups	✓		
CPL-PRLH	*Coastal Plain* - Palustrine, Riverine, and Lacustrine Herbaceous	Reporting Group	✓		
EMU-PRLH	*Eastern Mountains & Upper Midwest* - Palustrine, Riverine, and Lacustrine Herbaceous	Reporting Group	✓		
IPL-PRLH + W-PRLH	*Interior Plains + West* - Palustrine, Riverine, and Lacustrine Herbaceous	Combined Reporting Groups	✓		
IPL-PRLH	*Interior Plains* - Palustrine, Riverine, and Lacustrine Herbaceous	Reporting Group	✓	✓	
W-PRLH	*West* - Palustrine, Riverine, and Lacustrine Herbaceous	Reporting Group	✓	✓	
PRLW	*All* - Palustrine, Riverine, and Lacustrine Woody	Aggregated Wetland Type		✓	★
PFO	*All* - Palustrine Forested	NWCA Wetland Type		✓	
PSS	*All* - Palustrine Shrub Scrub	NWCA Wetland Type		✓	
CPL-PRLW	*Coastal Plain* - Palustrine, Riverine, and Lacustrine Woody	Reporting Group	✓		
EMU-PRLW	*Eastern Mountains & Upper Midwest* - Palustrine, Riverine, and Lacustrine Woody	Reporting Group	✓		
IPL-PRLW	*Interior Plains* - Palustrine, Riverine, and Lacustrine Woody	Reporting Group	✓		
W-PRLW	*West* - Palustrine, Riverine, and Lacustrine Woody	Reporting Group	✓		
CPL	*Coastal Plain*	Aggregated Ecoregion	✓		
EMU	*Eastern Mountains & Upper Midwest*	Aggregated Ecoregion	✓		
IPL	*Interior Plains*	Aggregated Ecoregion	✓		
W	*West*	Aggregated Ecoregion	✓		

Details of the MMI Permutation Approach for constructing and identifying robust VMMIs, from which to select the final VMMI for the 2011 NWCA are described in the remainder of this section.

For each of the Site Groups listed in the VMMI Permutation column of **Table 7-1**, the 47 vegetation condition metrics that passed the screening evaluation (**Section 6.6**) were further screened to tailor the candidate metric list to each specific Site Group. As in the initial screening, only calibration data (see **Section 6.4**) were used in this second evaluation which retained only metrics that distinguished least from most disturbed sites based on a Kruskal-Wallis significance level of 0.01 within a given Site Group.

Calibration data were used to score condition metrics on a 0 to 10 continuous scale within each NWCA Site Group (permutation column, **Table 7-1**). For each Site Group, the selected metrics were scored based on interpolation of metric values between the 5th and 95th percentiles across all calibration sites (Blocksom 2003). For metrics decreasing with increasing disturbance, the 95th percentile was scored as 10 and the 5th as zero. For metrics that increased with increasing disturbance, the 5th percentile was scored as 10 and the 95th as zero. The resulting metric scoring was applied to the corresponding validation (see **Section 6.4**) data. A robust potential VMMI developed using this metric scoring should similarly distinguish least from most disturbed for both the calibration and validation data.

We adapted the procedure of Van Sickle (2010), in which sets of randomly selected metrics of various sizes are used to create multimetric indices (VMMIs) to identify the optimal number of metrics and the best-performing sets of metrics. First, for a given NWCA Site Group, we randomly selected sets of 4, 6, 8, and 10 metrics from the set of metrics passing screening tests. A random set of 10 metrics was first selected, and then 8 metrics were randomly selected from that set of 10. The set of 6 metrics was randomly selected from the 8 metric set, and the set of 4 was randomly selected from the 6 metric set. We repeated this process 5000 times for the 4, 6, 8, and 10 metric combinations, for a total of 20,000 VMMIs. The VMMI for each randomly selected set of metrics consisted of summing metric scores and multiplying the result by (10/(number of metrics)) to place the MMI on a 100-point scale.

Based on the initial traditional VMMI runs (traditional column, **Table 7-1**), we found that none of the VMMIs constructed from best performing metrics ever had all metric types (**Table 6-1**) represented. Also, among these preliminary VMMIs those that encompassed greater numbers of metric types often did not perform as well as VMMIs with fewer metric types. Consequently, in the VMMI permutation procedure outlined above, we chose not to parse metrics into different types, but selected randomly from the full set of metrics.

For each of the 20,000 VMMIs generated for each Site Group by the permutation procedure, we calculated the maximum and mean Pearson correlations among metrics included in the VMMI as a gauge of metric redundancy. In an effort to avoid redundant metrics being included in the same VMMI, we filtered the results of the evaluation tests described below to only examine: 1) VMMIs with component metrics that had a maximum correlation between any two metrics of $< |0.75|$, and 2) a mean correlation among metrics of $< |0.5|$. In addition, we used data from the Revisit Sites to calculate the signal-to-noise ratio, as was done for metric evaluation (**Section 6.5.2**), to measure repeatability of each VMMI.

We evaluated sensitivity and precision for each generated VMMI. Sensitivity was assessed using an interval test (Kilgour et al. 1998; Van Sickle 2010), in which intermediate and most disturbed sites were compared with the reference (least disturbed sites) distribution. The interval test determines for each non-reference site VMMI score whether it is significantly lower than the 5th percentile of reference sites, assuming normally distributed scores among reference sites (Van Sickle 2010). This is a conservative test that accounts for variability around the estimate of the 5th percentile. The percentages of intermediate and most disturbed sites evaluated as different from reference were then used to assess sensitivity of each VMMI. We evaluated precision as the standard deviation of MMI scores among reference sites. This measure may influence the interval test above, with MMIs having less variation among reference sites tending to result in more non-reference sites being considered outside the reference range (van Sickle 2010). We examined plots of the number of metrics in a VMMI against the percentage of non-reference sites evaluated as different from reference and against the standard deviation of reference sites for patterns to aid in selecting the most appropriate number of metrics for an MMI for each Site Group examined.

The best performing VMMIs in each Site Group were identified by reviewing the mean and maximum correlations among metrics within a VMMI, the standard deviation and S:N for each VMMI, and the percent of most or intermediately disturbed sites that were distinguished from least disturbed sites. The top 6 to 10 VMMIs from each metric set size (4, 6, 8, and 10) were then plotted as series of boxplots depicting VMMI values of least and most disturbed sites. Boxplot series for each group included comparisons of least and most disturbed for (where applicable):

- Calibration versus validation data
- 7 NWCA Wetland Types
- 4 NWCA Aggregated Wetland Types
- 4 NWCA Aggregated Ecoregions
- NWCA Reporting Groups that combine wetland types and ecoregions

Taking all this information together, the best one or two VMMIs were selected for each Site Group evaluated using the permutation procedure (‘Permutation’ column, **Table 7-1**). This set of best VMMIs was then compared to select the final NWCA VMMI.

After evaluation of many thousands of potential VMMIs, there were 4 top candidates:

- A National VMMI (4 metrics)
- Three separate Wetland Type VMMIs
    - Estuarine (EH + EW) VMMI (4 or 6 metrics)
    - Palustrine, Riverine, Lacustrine Herbaceous VMMI (4 metrics)
    - Palustrine, Riverine, Lacustrine Woody VMMI (8 or 10 metrics)

The most effective VMMI was a national VMMI with four metrics that have wide applicability across numerous wetland types and regions. The top VMMIs based on NWCA Aggregated Wetland Types contained metrics similar to the national VMMI and also showed promise, but generally did not perform as well as the national VMMI. To ensure that the best National VMMI was obtained we reran the permutation procedures to calculate all possible VMMI combinations based on 4 metrics randomly selected from the 36 metrics that passed the second metric evaluation (see above).

The performance statistics for the final National VMMI were typically similar to, or better than, the performance statistics observed for the best VMMIs based on NWCA Aggregated Wetland Types. In addition, the National VMMI showed the least overlap between least and most disturbed sites for wetlands in the Interior Plains and West Aggregated Ecoregions.

7.3 Final National VMMI – Results

A national level VMMI, which included four metrics with wide applicability (**Table 7-2**), was ultimately selected as having the best overall performance in assessing wetland condition for the 2011 NWCA. Three of the metrics decrease in value with disturbance and one increases. Calculation methods for these three metrics can be found in **Chapter 6, Section 6.8 Appendix D** by referencing the metric names indicated in parentheses in **Table 7-2**. These metric names are highlighted in **blue and bolded** in the appendix to make them easier to locate.

Table 7-2. Four metrics included in the final NWCA Vegetation Multimetric Index (VMMI). Description of calculation methods for these metrics can be found in **Section 6.8, Appendix D**. Note that metric scoring is reversed for metrics that increase with disturbance.

Metric Name	Metric Description	Response to Disturbance
Floristic Quality Assessment Index (**FQAI_ALL**)	Based on all species present at a site	Decreases
Relative Importance of Native Plants **RIMP_NATSPP**)	Combines Relative Cover and Relative Frequency for native species	Decreases
Number of Plant Species Tolerant to Disturbance (**N_TOL**)	Tolerance to disturbance defined as C-value ≤ 4	Increases
Relative Cover of Native Monocots (**XRCOV_MONOCOTS_NAT**)	Relative Cover of native monocot species	Decreases

Metrics are scored or standardized (see **Section 7.2)** on a continuous scale from 0 to 10, with higher values reflecting less disturbed conditions. The floor and ceiling values for scoring each of these metrics at the national scale are provided in **Table 7-3**. Recall, that for metrics that decrease with disturbance, values above ceilings were given a score of 10 and values below the floor a score of 0. For metrics that increase with disturbance, values below the floor are assigned a 10 and above the ceiling a 0. All other metric values are interpolated to scores between 0 and 10.

Table 7-3. Floor and ceiling values for scoring final VMMI metrics based on range of values in the calibration set.

Metric	Floor	Ceiling
FQAI_ALL	6.94	38.59
RIMP_NATSPP	44.34	100
N_TOL	0	40.0
XRCOV_MONOCOTS_NAT	0.065	100

The ***National VMMI*** for each site was calculated on a continuous 0 to 100 scale:

$$\boldsymbol{VMMI} = (\text{FQAI\_ALL\_SC} + \text{RIMP\_NATSPP\_SC} + \text{N\_TOL\_SC} + \text{XRCOV\_MONOCOTS\_NAT\_SC}) * \frac{10}{4}$$

where, the '_SC' suffix is the scored value for a metric.

Performance results for the National VMMI are summarized in **Table 7-4** for the conterminous US, and three wetland type Site Groups (Estuarine, PRLH, and PRLW). The high S:N values reflect consistency in the VMMI across repeat samplings. The low maximum and mean correlations among metrics indicate each metric is contributing unique information about condition. The percentage of most or intermediately disturbed sites distinguished from least disturbed sites, based on the conservative Kilgour test, varies by wetland type group. The Palustrine, Riverine, and Lacustrine Herbaceous (PRLH) group had the lowest separation of least and most disturbed sites. This pattern is likely influenced by higher disturbance levels among reference sites associated with the PRLH type, particularly in the Interior Plains and West (e.g., see **Chapter 4: Table 4-10 and Table 4-11**, for relaxed criteria for least-disturbed status).

Table 7-4. Summary statistics for the **National VMMI**. Statistics for wetland type groups are calculated based on the National VMMI values for all sites in a particular group.

Site Group	n sites by disturbance class	Mean VMMI (L sites)	SD VMMI (L sites)	S:N VMMI	Max r among metrics	Mean r among metrics	% M sites distinguished from L sites	% I sites distinguished from L sites
ALL n=1138	L=277, I=529, M=332	67.0	12.2 n=96	20.9	0.40	0.10	42.7	17.0
EH+EW n=345	L=116, I=128, M=101	74.3	6.4 n=21	49.9	0.53	0.14	55.5	31.3
PRLH n=358	L=75, I=169, M=114	62.3	16.6 n=38	13.2	0.50	0.21	24.6	7.1
PRLW n=435	L=86, I=232, M=117	61.3	8.0 n=37	20.7	0.53	0.11	43.6	17.2

Site Groups defined in Table 7-1. L = least disturbed sites, I = intermediately disturbed sites, M=most disturbed sites, SD =standard deviation, S:N = Signal:Noise (n=revisit sites), r = Pearson correlation. Percent of sites significantly different from least-disturbed site distribution based on an interval test with alpha = 0.05 (Kilgour et al. 1998; Van Sickle 2010).

Comparison of National VMMI values between calibration and validation data **Figure 7-2**, show similar distributions and satisfactory discrimination between least and most disturbed sites. Patterns from this comparison indicate consistent behavior for the VMMI across different data sets, suggesting potential for robust performance with data collected in diverse wetlands going forward.

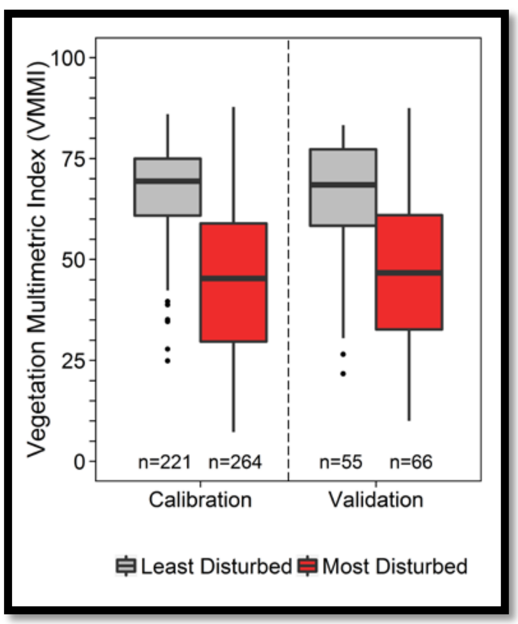

Figure 7-2. Comparison of National VMMI values for calibration and validation data. For each boxplot, the box is the interquartile (IQR) range, line in the box is the median, and each of the whiskers represent the most extreme point a distance of no more than 1.5 x IQR from the box. Values beyond this distance are considered outliers.

The next step was to see how well the national VMMI described conditions for each NWCA Reporting Group. We generated boxplots of VMMI values for least and most disturbed sites within the Reporting Groups (**Figure 7-5**). There was reasonable separation between least and most disturbed sites for 8 of the 10 groups. In the Estuarine Herbaceous (EH) wetland group, there was some overlap of the median for least disturbed sites with upper interquartile of most disturbed sites. However, this was likely due to wide range in most disturbed sites and the fact that a substantial proportion of the most disturbed sites had little disturbance (see **Chapter 4**). The largest overlap occurred in the Interior Plains Palustrine Herbaceous (IPLH) wetland group, where the 25th percentile of least disturbed sites overlapped with the 75th percentile of the most disturbed sites, and the whisker for least disturbed sites overlapped with the median of most disturbed sites. This overlap was likely due to human-mediated disturbance patterns in the Interior Plains and the consequent requirement to relax criteria for least disturbed designation for that region (see **Chapter 4**).

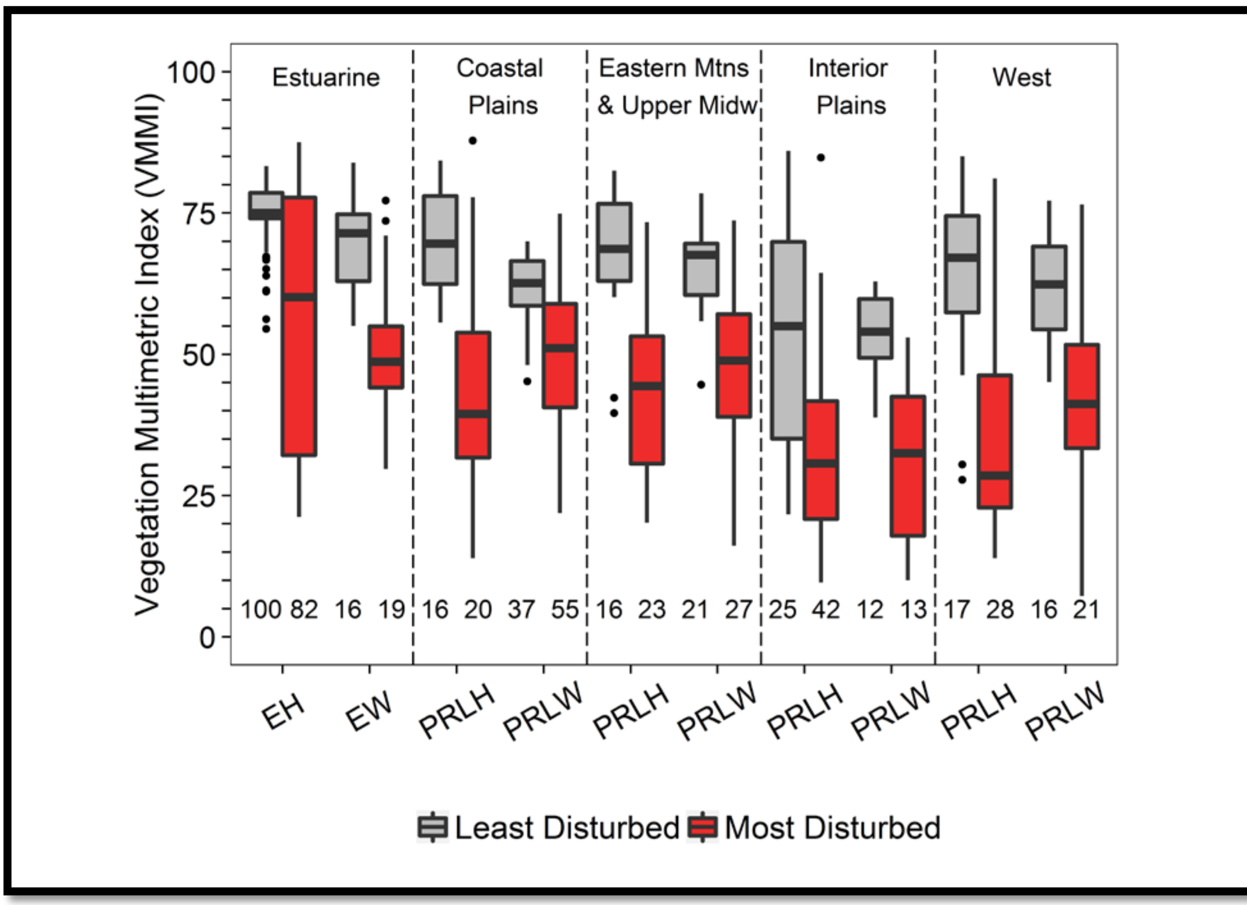

Figure 7-3. NWCA National VMMI values for least and most disturbed sites by NWCA Reporting Group. See **Table 6-4** for definition of Reporting Groups. For each boxplot, the box is the interquartile (IQR) range, line in the box is the median, and each of the whiskers represent the most extreme point a distance of no more than 1.5 x IQR from the box. Values beyond this distance are considered outliers. Numbers are number of sampled least and most disturbed sites (probability and not-probability) for each Reporting Group.

VMMI values for least disturbed sites varied widely across groups, particularly for median and range. To account for this variation across the United States, threshold values for good, fair, and poor condition were set within Reporting Groups based on the National VMMI values of the least disturbed sites in each group.

7.4 Thresholds for Good, Fair, Poor Wetland Condition

Wetland condition thresholds for each Reporting Group (**Table 7-5**) were set using NARS conventions based on the distribution of VMMI Scores in least disturbed (reference) sites (see **Figure 7-4**, Stoddard et al. 2006):

- Good = VMMI scores > 25th percentile of reference,
- Fair = VMMI scores from the 5th up to the 25th percentile of reference, and
- Poor = VMMI scores < 5th percentile of reference.

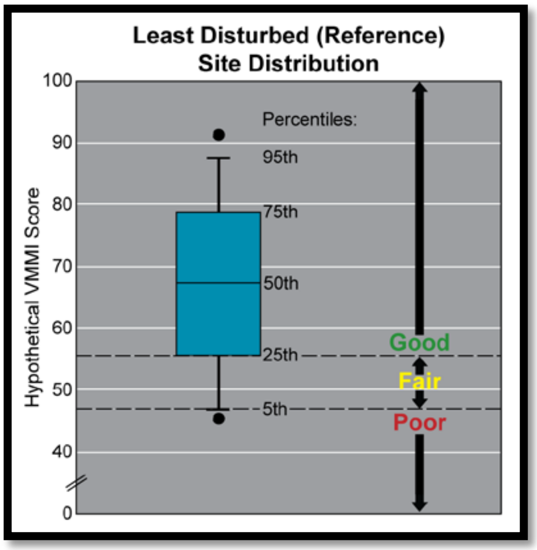

Figure 7-4. Criteria for setting VMMI thresholds for good, fair, and poor condition classes based on VMMI values observed for Least Disturbed (Reference) Sites.

Table 7-5. Thresholds for Vegetation Multimetric Index (VMMI) values to delineate good, fair, and poor ecological condition for sites in each of the NWCA Reporting Groups. Sites with VMMI values that fall from the 5th up to the 25th percentile for least disturbed (reference) sites are considered in fair condition.

NWCA Reporting Group	Description (Ecoregion by Wetland Type)	Poor Condition (VMMI < 5th Percentile Least Disturbed Sites)	Good Condition (VMMI > 25th Percentile Least Disturbed Sites)
ALL-EH	*All* - Estuarine Herbaceous	65.0	74.1
ALL-EW	*All* - Estuarine Woody	56.0	62.9
CPL-PRLH	*Coastal Plain* - Palustrine, Riverine, and Lacustrine Herbaceous	57.3	62.5
CPL-PRLW	*Coastal Plain* - Palustrine, Riverine, and Lacustrine Woody	52.8	58.6
EMU-PRLH	*Eastern Mountains & Upper Midwest* - Palustrine, Riverine, and Lacustrine Herbaceous	41.6	63.0
EMU-PRLW	*Eastern Mountains & Upper Midwest* - Palustrine, Riverine, and Lacustrine Woody	55.8	60.5
IPL-PRLH	*Interior Plains* - Palustrine, Riverine, and Lacustrine Herbaceous	25.3	36.2
IPL-PRLW	*Interior Plains* - Palustrine, Riverine, and Lacustrine Woody	40.3	49.4
W-PRLH	*West* - Palustrine, Riverine, and Lacustrine Herbaceous	30.0	57.4
W-PRLW	*West* - Palustrine, Riverine, and Lacustrine Woody	47.9	54.4

7.5 Ecological Condition Extent Estimates

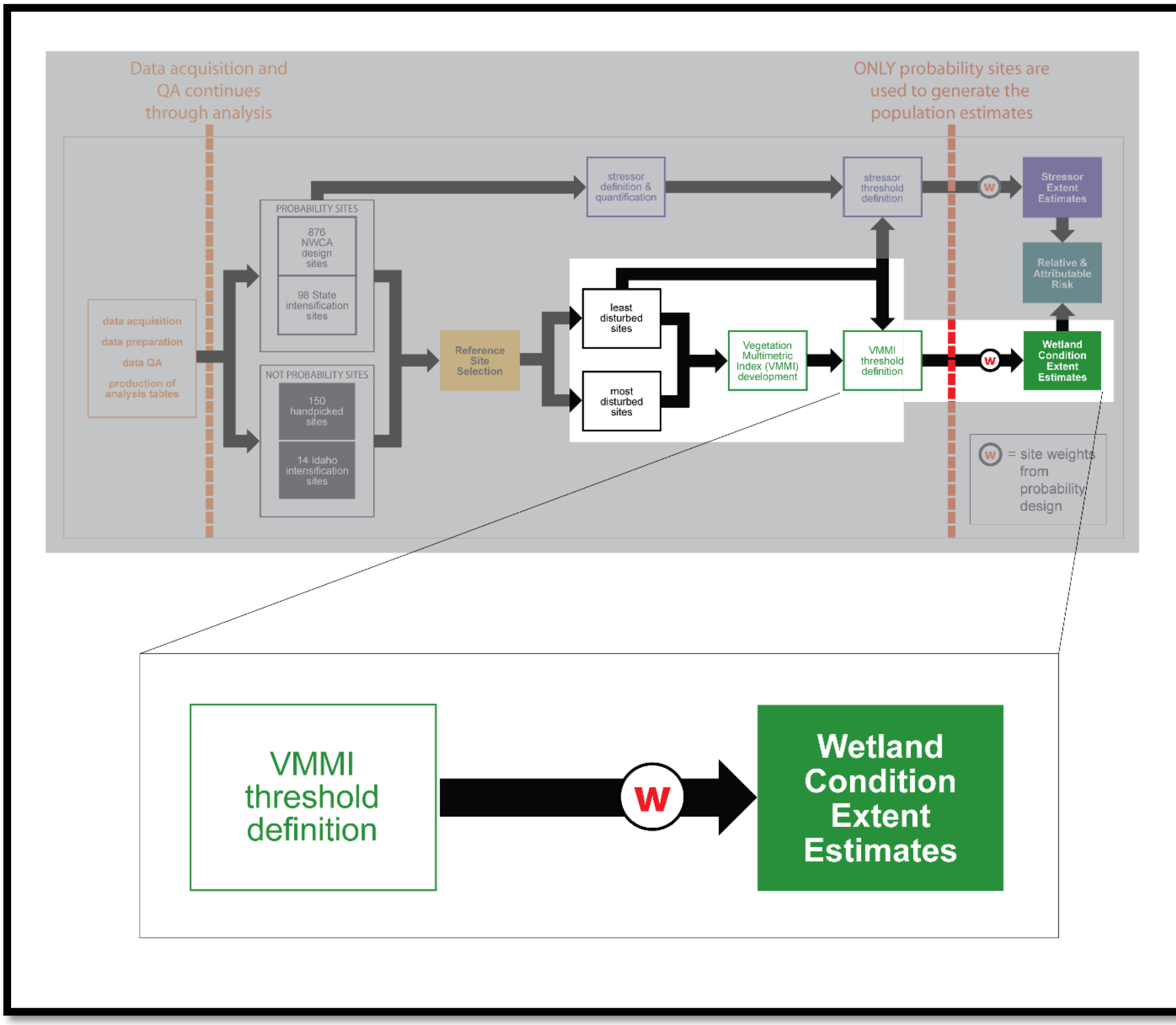

Figure 7-5. NWCA Analysis Pathway section where VMMI condition thresholds for each Reporting Group (see **Table 7-5**) are used to generate estimates of wetland area in good, fair, and poor ecological condition. A full-page, unhighlighted version of this figure may be found on **page 14** of this report.

The 2011 NWCA probability sites (n=967) are used to estimate wetland area in particular condition classes. The thresholds for good, fair, and poor condition based on the Vegetation Multimetric Index (VMMI) for each Reporting Group (see **Table 7-5**), are used in conjunction with site weights for the probability sites from the NWCA survey design (see **Chapters 1 and 9**) to calculate extent estimates for wetland condition (**Figure 7-5**). Site weights reflect the number of acres each site represents across the total population of NWCA Wetland Types. Each NWCA probability site is assigned good, fair, or poor ecological condition based on its VMMI value and the Reporting Group thresholds appropriate to the site. Next, the site weights from the probability design are summed within condition class to estimate the wetland area in good, fair, and poor condition. The survey design allows calculation of confidence intervals around these condition estimates.

Chapter 9, Section 9.2 provides more explanation of population estimates and site weights, as well as illustrating how to interpret the NWCA condition results summarized as bar charts representing wetland area (as number of acres or percent area) for each condition class for a specific NWCA Site Group, e.g., nationally, by Aggregated Ecoregions, etc. (see **Figure 9-2**, for example). Complete wetland condition assessment results, including extent estimates (numbers of acres or percent of wetland area) for wetland condition classes, are detailed in *National Wetland Condition Assessment 2011: A Collaborative Survey of the Nation's Wetlands* (USEPA *In Review*).

Cumulative Distribution Function (CDF) Graphs (Sokal and Rohlf 1995) can be used, in addition to the bar graph presentation of results in USEPA (*In Review*). CDFs illustrate the population extent estimates (percent wetland area) with confidence intervals (Y-axis) across the continuous range of VMMI values (X-axis) for particular NWCA groups of sites. **Figure 7-6** shows the VMMI CDF for the national scale results. CDFs are provided by Reporting Groups, NWCA Aggregated Wetland Types, and NWCA Aggregated Ecoregions in **Section 7.7, Appendix E**. On each graph, the intersection of a VMMI value from the X-axis and the percent wetland area from the Y-Axis provides an estimate of the percent of wetland area with a VMMI score at or below that value. For example, in **Figure 7-6**, at the national scale approximately 15% of the wetland area is represented by VMMI values less than 40, and about 58% of wetland area is estimated to have VMMI values less than 60. Note that at the national scale the confidence intervals are relatively narrow. Small sample sizes associated with some NWCA Site Groups can influence the size of confidence intervals.

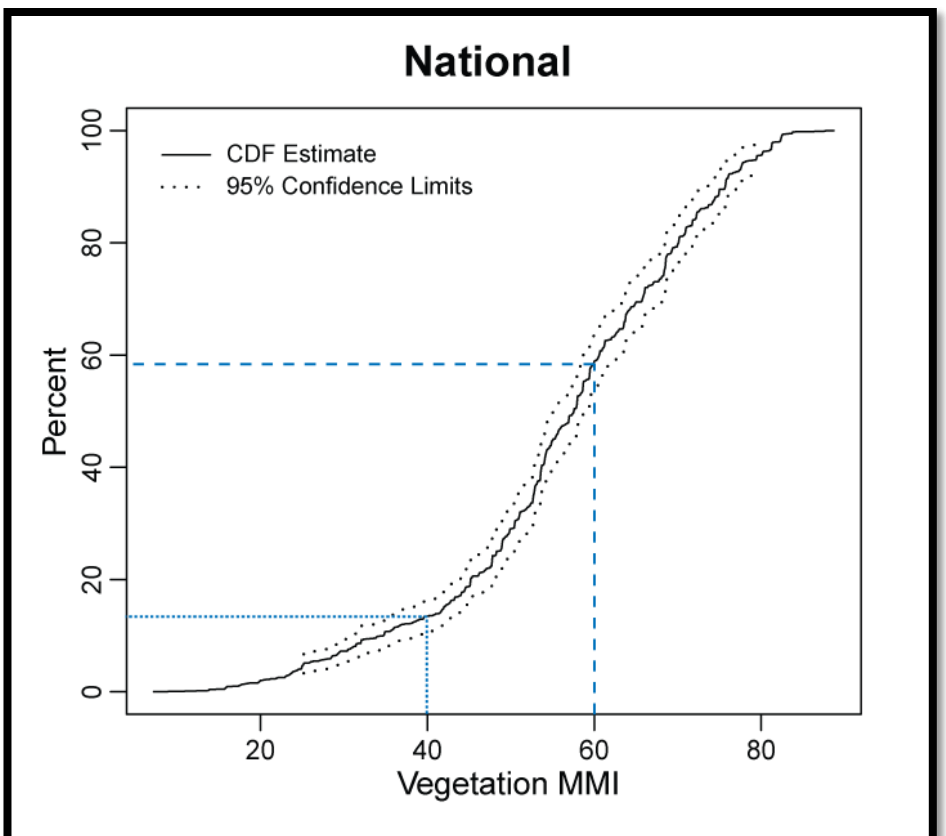

Figure 7-6. Cumulative Distribution Function (CDF) of condition extent estimates, with confidence limits, of wetland condition (VMMI) across the conterminous United States. Blue lines illustrate how to read graph.

7.6 Literature Cited

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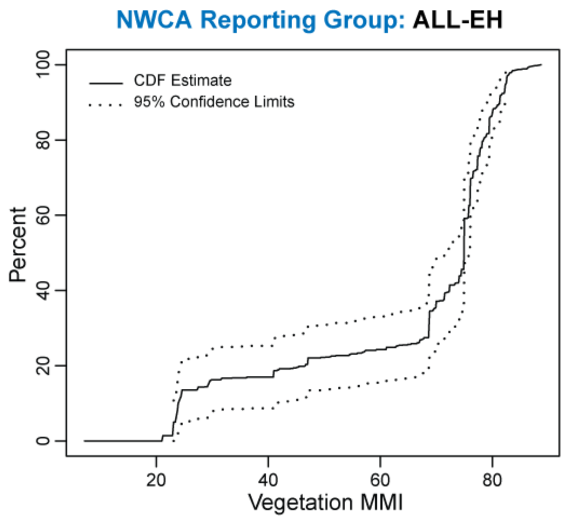
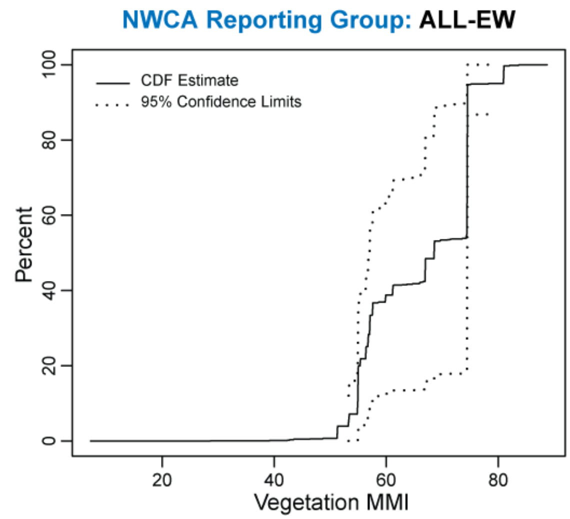
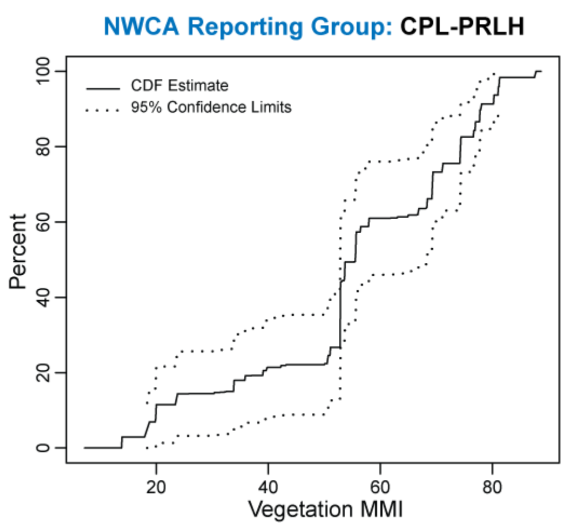
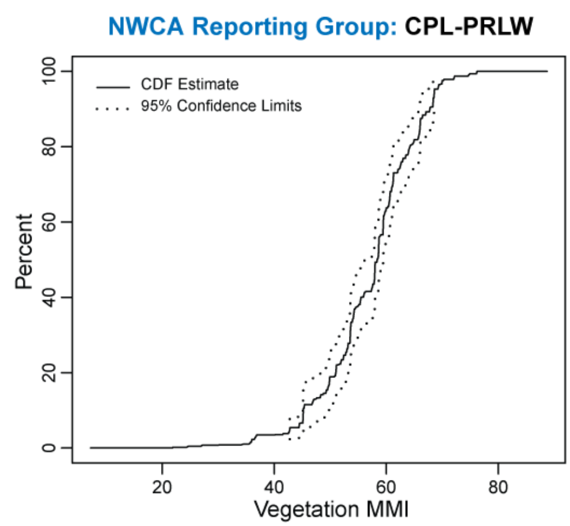
7.7 Appendix E: Cumulative Distribution Function Graphs for VMMI

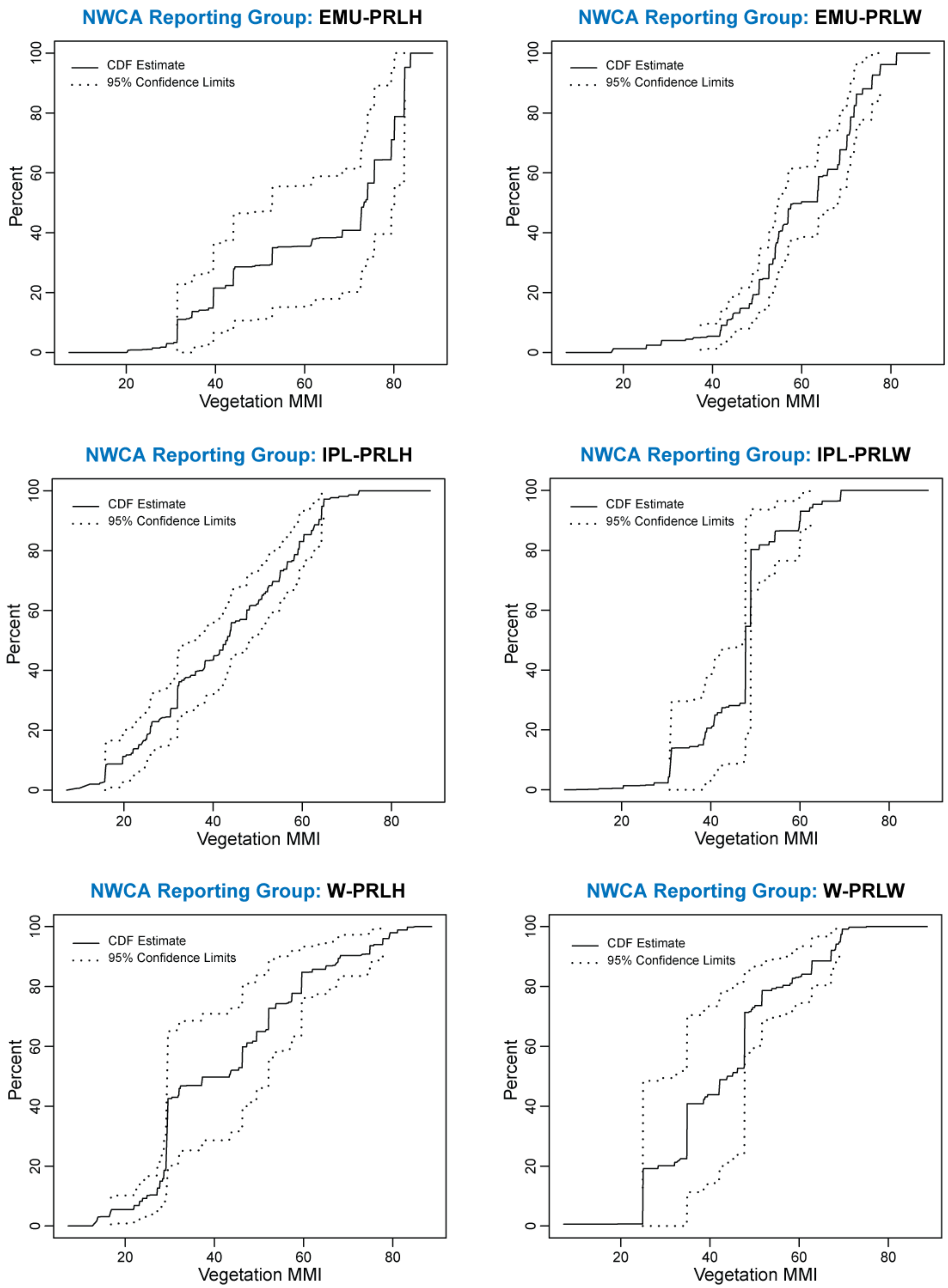
CDF graphs for the population estimates of wetland condition extent based on the Vegetation MMI are presented by NWCA Reporting Group (blue), Aggregated Wetland Type (green), and Aggregated Ecoregion (red). The CDF for the national scale is provided in **Section 7.5**.

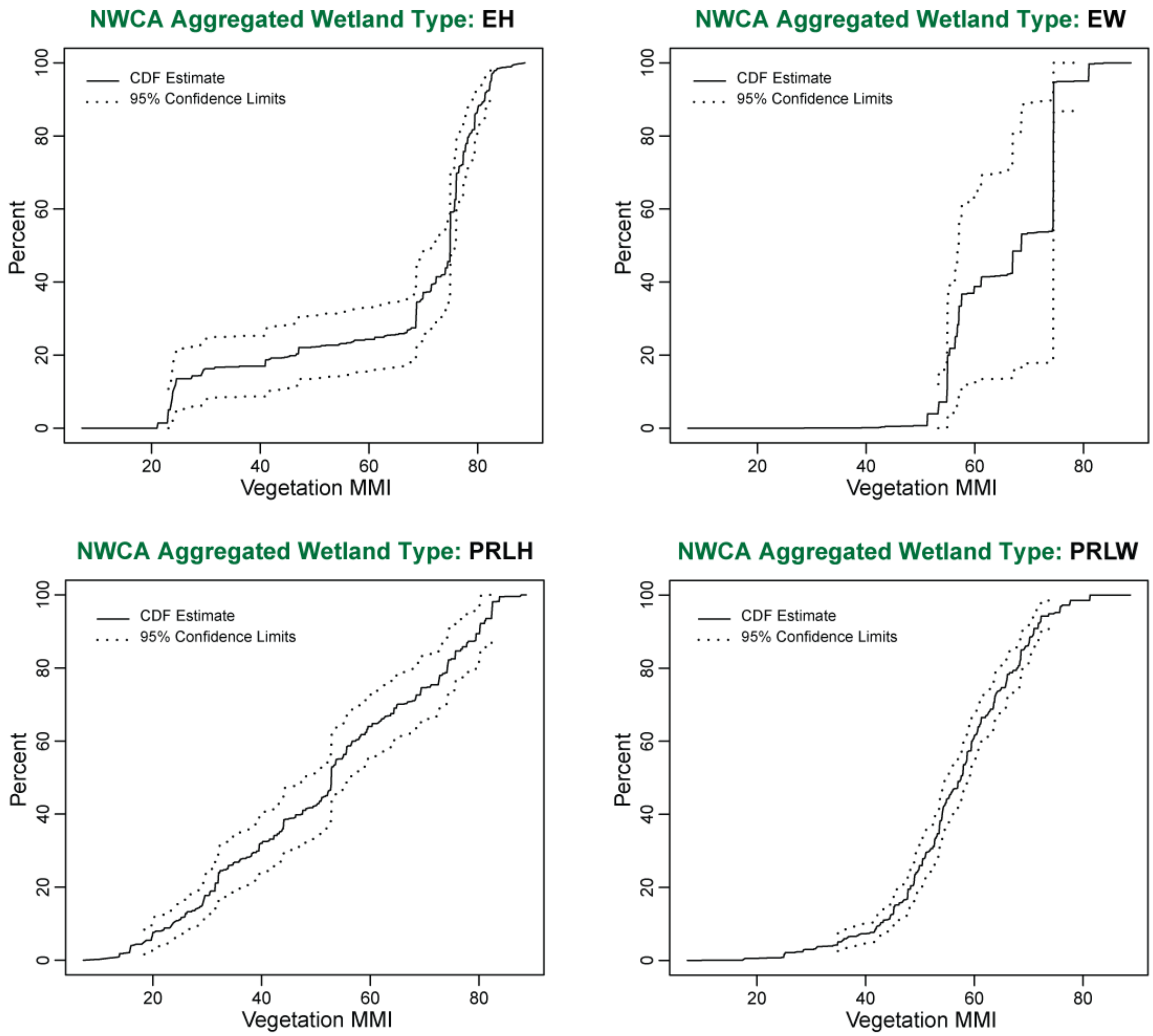









NWCA Reporting Group: EMU-PRLH
NWCA Reporting Group: EMU-PRLW
NWCA Reporting Group: IPL-PRLH
NWCA Reporting Group: IPL-PRLW
NWCA Reporting Group: W-PRLH
NWCA Reporting Group: W-PRLW
CDF Estimate
95% Confidence Limits
Percent
Vegetation MMI


NWCA Aggregated Wetland Type: EH
NWCA Aggregated Wetland Type: EW
NWCA Aggregated Wetland Type: PRLH
NWCA Aggregated Wetland Type: PRLW
CDF Estimate
95% Confidence Limits
Percent
Vegetation MMI
0
20
40
60
80
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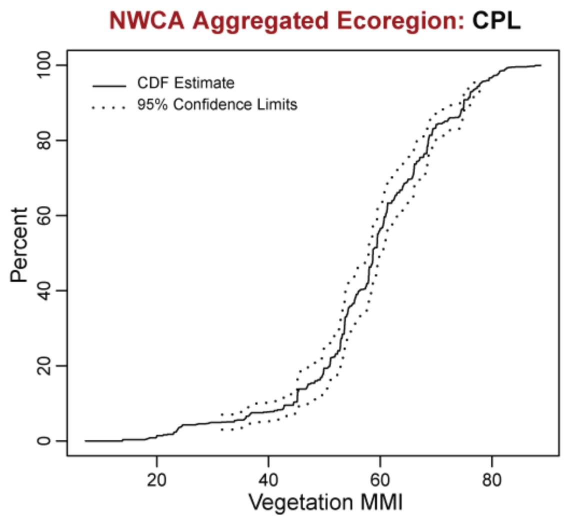
NWCA Aggregated Ecoregion: CPL
CDF Estimate
95% Confidence Limits
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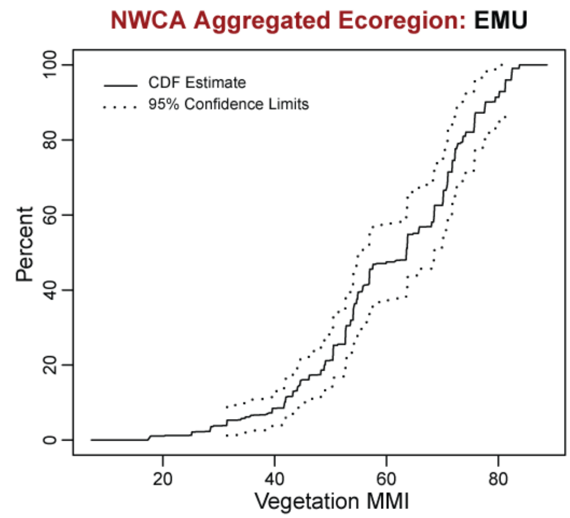
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95% Confidence Limits
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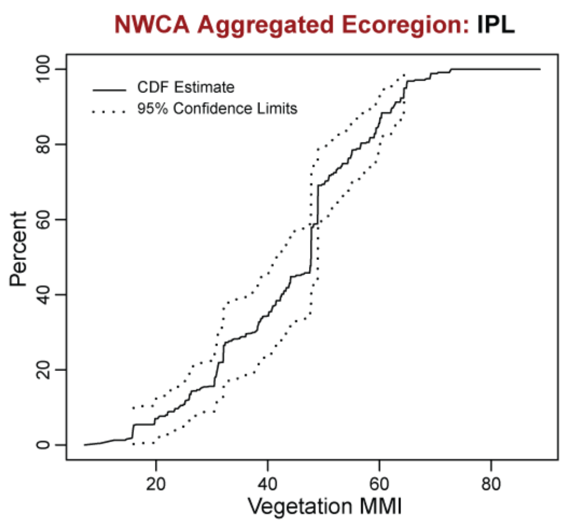
NWCA Aggregated Ecoregion: IPL
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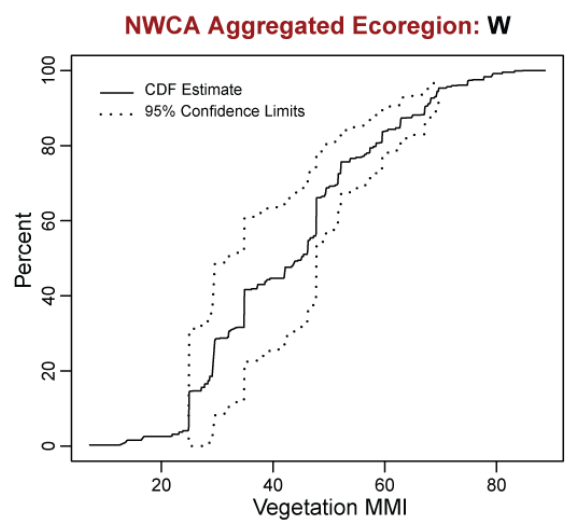
NWCA Aggregated Ecoregion: W
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Chapter 8: Indicators of Stress

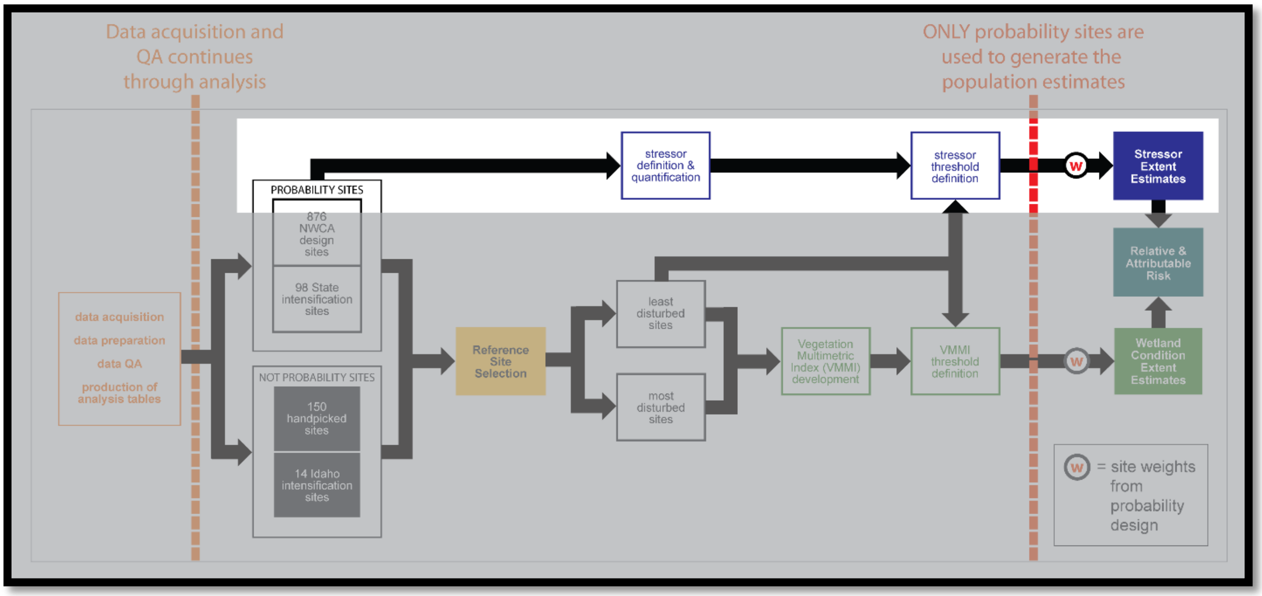

Figure 8-1. The major components of the 2011 National Wetland Condition Assessment Analysis Pathway discussed in this chapter (i.e., stressor definition and quantification, and stressor-level threshold definition, which enable stressor extent estimates). A full-page, unhighlighted version of this figure may be found on **page 14** of this report.

8.1 Background Information

Like other National Aquatic Resource Survey (NARS) assessments, the NWCA data was collected and used specifically to identify connections between the presence of indicators of stress and ecological condition. Indicators of stress act to degrade ecological condition, and consequently, evaluation of indicators of stress is an important component of an assessment method (Fennessy et al. 2007). Using biological, chemical, and physical indicators of stress, the NWCA analysis examined a variety of stressor data to detect factors likely affecting ecological condition. The use of physical, chemical, and biological stressor data is consistent with current approaches to assess wetlands and recognizes the connection between the presence of stressors and wetland condition. For example, rapid assessment methods have been developed which use only stressors as indicators of condition (e.g., the Delaware Rapid Assessment Method (Jacobs 2007)) and models comprising an HGM assessment (a Level 3, intensive assessment) use stressors as variables (e.g., Whigham et al. 2007; Wardrop et al. 2007). The sources of the stressor data used in the NWCA analysis were primarily from data collected during field sampling of a site in the Assessment Area (AA) and its buffer. However, GIS provided other supporting data on land use, presence of roads, and other characteristics of the landscape in a set area surrounding the point that were also available to be used as indicators of stress.

Indicators and thresholds are used in different ways throughout the NWCA analysis. For example, indicators of disturbance and disturbance thresholds are described in **Chapter 4**, and the Vegetation Multimetric Index (VMMI), an indicator of condition, and condition thresholds are described in **Chapter 7**. In this chapter, we discuss indicators of stress and stressor-level thresholds. While some of the general methods used to develop indicators and thresholds are similar among specific applications (i.e., for disturbance, condition, and stressors), the specific indicators and/or thresholds used for each application are different.

Indicators of stress are used as descriptors of the potential impact of anthropogenic activities on wetland condition. Although indicators of stress do not necessarily imply causation of ecological decline, they are often associated with impaired condition. For simplicity, they are sometimes referred to using the shorthand term 'stressors'. Indicators of stress are used to support analyses that provide three types of information (i.e., results), which will be discussed in detail in the following chapter (**Chapter 9**):

- ***Stressor Extent –*** an estimate (by percent of the resource or relative ranking of occurrence) of how spatially common an indicator of stress is based on the population design;

- ***Relative Risk –*** the probability (i.e., risk or likelihood) of having poor condition when the stressor-level class is high relative to when it is low; and,

- ***Attributable Risk –*** an estimate of the proportion of the population in poor condition that might be reduced if the effects of a particular stressor were eliminated (Van Sickle and Paulsen 2008)**.**

Nine indicators of stress were developed for reporting stressor extent, and relative and attributable risk (**Figure 8-1**). In this chapter, we focus on documenting:

- The selection process for indicators of stress (**Section 8.2**);
- Steps to develop indicators of stress for each stressor category (**Sections 8.3, 8.4, and 8.5**), including:
  - *Stressor definition*
  - *Data collection*
  - *Data preparation*
  - *Indicator or index development*
  - *Stressor-level threshold definition*
- How stressor indicators are used to report stressor extent estimates (**Section 8.6**).

Stressor extent is crucial for determination of relative and attributable risk. Discussion and an example calculation of relative and attributable risk are presented in **Chapter 9**. The 2011 results for stressor extent and stressor relative and attributable risk are presented in *National Wetland Condition Assessment 2011: A Collaborative Survey of the Nation's Wetlands* (USEPA *In Review*).

8.2 Selection of Indicators of Stress

8.2.1 *Conceptual Model Overview*

Because the magnitude of data generated from the NWCA was extensive, there were many potential indicators of stress from field data and GIS data. A conceptual model was developed to help guide the selection a few strong indicators of stress from all the possibilities, and to illustrate how data related to wetland condition estimates, stressor extent estimates, and relative and attributable risk are used (**Figure 8-2**). There were two types of stressor data collected as part of the 2011 NWCA; GIS data and data collected in the field. GIS data represent landscape information, specifically human land uses, that are posited to affect physical, chemical, and biological properties of wetlands. The NWCA field data were used as indicators of stress (see **Section 8.2.2** for an explanation of why this decision was made). While the presence and magnitude of these stressors are expected to affect wetland condition, the relationship between indicators of stress and condition was not explicitly determined as part of the NWCA analysis. Wetland condition was independently estimated using a vegetation multimetric index (VMMI) as discussed in **Chapter 7.** The presence and magnitude of measured indicators of stress at a wetland site above stressor-specific thresholds in combination with site weights (discussed in detail in **Chapter 9**) were used to determine the stressor extent estimates. Finally, both wetland condition estimates and stressor extent estimates are used to calculate relative and attributable risk of each indicator of stress as described in the following chapter.

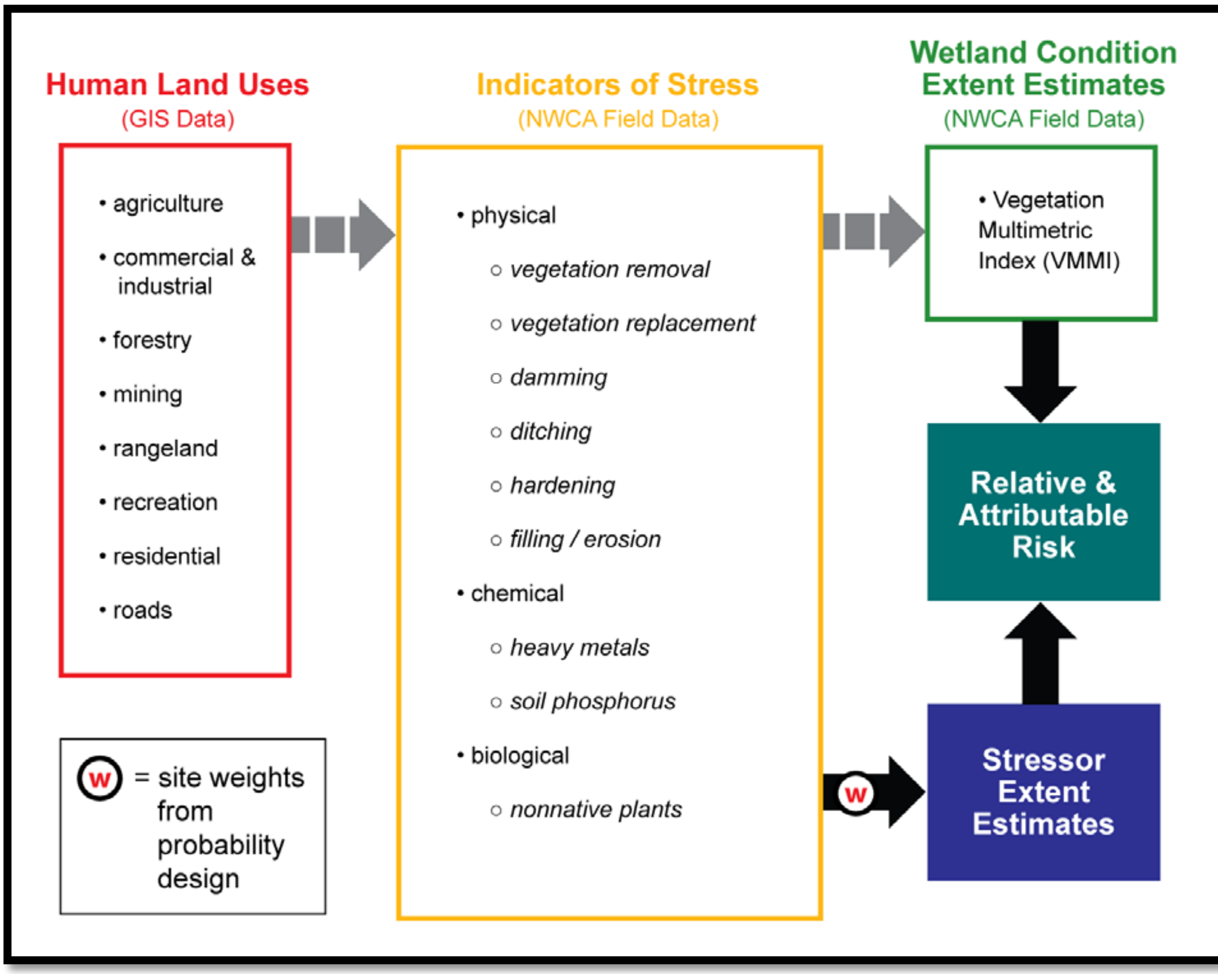

Figure 8-2. Conceptual model of how specific data collected as part of the 2011 NWCA (red and yellow boxes containing bulleted lists) are used to estimate Stressor Extent Estimates (purple box) and, ultimately, Relative & Attributable Risk (teal box). Grey, dashed arrows indicate that a cause-and-effect relationship is expected to exist among the data, but these relationships were not explicitly quantified as part of the 2011 NWCA data analysis. Black arrows represent the explicit information flow (e.g., data represented in one box were used in the calculations represented by the following box). The arrow with the black circle containing a red “w” indicates that site weights from the probability design were used to calculate Stressor Extent Estimates.

8.2.2 *Choosing the Type of Data Used for Indicators of Stress*

For reporting, it is highly desirable that indicators of stress be as independent from one another as possible to avoid redundancy. For example, percent agriculture in the buffer *or* soil phosphorus concentrations could be used as an indicator of stress, but not both, because they are often strongly related and essentially represent the same anthropogenic stress. In other words, it was important to separate the cause of stress from the impact of the stress. With this simple principle, the human land uses collected using GIS data were separated from the data collected in the field (**Figure 8-2**, red and yellow boxes with bulleted text inside). Therefore, when choosing between the GIS data set and the field data set, it was determined that field data were more appropriate to use as indicators of stress for this assessment, as they were based on direct observations of condition at the randomly-selected sample point. NWCA field data were used to develop indicators of stress, with indicators representing physical, chemical, and biological categories. Each indicator of stress and the methods by which it was used to estimate stressor extent are described in detail in subsequent sections of this chapter:

- ***Physical*** (**Section 8.3**)
  - Vegetation Removal
  - Vegetation Replacement
  - Damming
  - Ditching
  - Hardening
  - Filling/Erosion
- ***Chemical*** (**Section 8.4**)
  - Heavy Metals
  - Soil Phosphorus
- ***Biological*** (**Section 8.5**)
  - Nonnative Plants

Although water chemistry was part of the NWCA field protocol, only 56% of the wetlands sampled had sufficient surface water to collect and analyze. For this reason, and because wetland hydroperiod– especially during the growing season when NWCA sampling occurred – can greatly influence water chemistry (e.g., nutrients can become highly concentrated during drawdowns), water chemistry was excluded from the core NWCA indicators. However, water chemistry was retained as a research indicator and specific results are discussed in **Chapter 11** of this report.

8.3 Physical Indicators of Stress

8.3.1 *Defining Physical Indicators of Stress*

Physical site information was collected as part of the 2011 NWCA Buffer and Hydrology Protocols. To consolidate the extensive data into a few, meaningful indicators of stress that could be used for reporting, nearly all the data collected as part of these protocols was assigned to one of six indicator categories representing vegetation alterations or hydrologic alterations. In the following subsections, data collection, data preparation, index development, and stressor-level threshold definition for these physical indicators of stress are described.

8.3.2 *Data Collection*

Physical indicators of stress include vegetation and hydrologic alterations to the wetland sites. These data were primarily observational and collected by Field Crews using the Buffer and Hydrology Protocols detailed in the *NWCA Field Operations Manual* (USEPA 2011a). Data collection was guided by extensive lists of items (that were marked when an item was observed) on both the Buffer and Hydrology Forms (Form B-1 and Form H-1 for buffer and hydrology, respectively; see **Section 8.8** and **Section 8.9**. Field Crews recorded the presence of physical stressors in 13 proximity-weighted plots located at the center of the AA and along four 140-m transects aligned with cardinal directions from the AA center for the Buffer Protocol. Presence/absence of stressors was also recorded within the AA for the Hydrology Protocol.

8.3.3 *Data Preparation*

To categorize physical indicators of stress, items from the Buffer Form and Hydrology Form were assigned to one of six indicators representing vegetation or hydrological alterations: vegetation removal, vegetation replacement, damming, ditching, hardening, and filling/erosion. **Table 8-1** provides a description and the items from the field forms assigned to each of these six categories. While all the items from the Hydrology Form were assigned to hydrological alteration indicators (i.e., damming, ditching, hardening, and filling/erosion), the items from the Buffer Form were split among indicators of vegetation alteration and hydrological alteration.

Because the AA was established within a designated wetland, regardless of the wetland size, the buffer was often also in wetland. It is incorrect to assume that the buffer always represents upland. Regardless of whether the buffer is wetland or upland, anthropogenic disturbances in the buffer indicate that the point represented by the AA may be disturbed. Furthermore, the *NWCA Field Operations Manual* (USEPA 2011a) clearly instructs that a valid AA does not contain more than one hydrogeomorphic (HGM) class and may have up to 10% of upland or anthropogenic features (e.g., road, culverts, etc.). There were no restrictions on anthropogenic features in the buffer.

8.3.3.1 *Decision-process for assigning form items to stressor categories*

Each item from the Buffer and Hydrology Form was assigned to one – and only one – stressor category based on the dominant type of disturbance (**Table 8-1**). To consistently and logically assign items from the Buffer and Hydrology Forms to one of the six stressor categories, several rules were applied:

- Both domesticated animal and mechanical removal of vegetation were considered anthropomorphic stress and placed in the Vegetation Removal category. Animal-mediated vegetation removal was a stressor if it was determined to be human influenced (e.g., grazing by cattle).

- A wholesale change in the natural mix of species native to the area (i.e., lawns, agricultural fields, gardens, landscaping, orchards, nursery, row crops, etc.) was classified as Vegetation Replacement.

- Disturbances leading to an artificial increase in the elevation of the water table, including human-created surface water and evidence of unnatural damming events (e.g., dead pines from human-influenced flooding), were classified as Damming.

- Any form of channeling water was considered ditching, including ditches, visual evidence of drainage tiling, piping and channelization. All were placed in the Ditching category.

- Dumping of material (e.g., soil, rocks, large-scale landfills) and water (e.g., waste water discharge pipes) were considered in the Filling/Erosion category.

- Any activity leading to surface hardening or compaction was placed in the Hardening category. This includes roads, trails trampling, animal tracks, and animal pugging.

- Any development (i.e., urban or residential) or stress thought to cause compaction were categorized as Hardening. Exposed pipelines were included in the Hardening category due to probable compaction and hardening (due to pads) during installation, maintenance, and inspections.

- In a single case, a brick wall (checked off as a fence on the form with a note defining it as a brick wall) was classified as Hardening due to the concrete footing required for stabilization.

Some stressors were more difficult to classify into one of the six categories. For example, if erosion was determined to likely stem from a human activity (e.g., irrigation, aquaculture), the stressor was placed in the Filling/Erosion category. Note that in some cases, observations, such as freshly deposited sediment, could be due to natural causes like storms.

In addition to the listed items on the Buffer and Hydrology Forms, Field Crews could record observations that were not listed using a write-in option called “Other”. The Other items were assigned to stressor categories according to the same rules as the stressors specifically listed on the Buffer and Hydrology Forms. However, a number of Other items were dropped from consideration as stressors to include in the analysis including:

- ***fences***, which were considered as not impacting vegetation or otherwise creating a stress;

- ***garbage*** (e.g., wrack, litter, shopping carts), which was deemed insignificant in terms of affecting the wetland condition;

- ***herbivory or disturbances associated with insects or native/feral animals*** (e.g., beaver, elk, hogs), which were considered natural occurrences; and

- ***other naturally occurring phenomena*** (e.g., sand dunes, rivers), which were sometimes listed in the Other category by Field Crews.

If a listed item could not be readily characterized or determined to be not a stress, it was not categorized as a stressor. Non-stressor items commonly recorded included, for example, ordinary mean high water mark, lake levels, and soil cracks.

Table 8-1. Physical indicators of stress, their descriptions, and form items (i.e., from the H-1 Hydrology or B-1 Buffer Forms) assigned to each indicator.

Indicator of Stress	Description	B-1 Buffer Form Items Included	H-1 Hydrology Form Items Included
Vegetation Removal	any field observation related to loss, removal, or damage of wetland vegetation	*gravel pit, oil drilling, gas wells, underground mine, forest clear cut, forest selective cut, tree canopy herbivory, shrub layer browsed, highly grazed grasses, recently burned forest, recently burned grassland, herbicide use, mowing/shrub cutting, pasture/hay, range*	*N/A*
Vegetation Replacement	any field observation of altered vegetation within the site due to anthropogenic activities	*golf course, lawn/park, row crops*, fallow field, nursery, orchard, tree plantation*	*N/A*
Damming	any field observation related to impounding or impeding water flow from or within the site	*dike/dam/road/RR bed, water level control structure, wall/riprap*	*dikes, berms, dams, railroad beds, sewer outfall*
Ditching	any field observation related to draining water	*ditches, channelization, inlets/outlets, point source/pipe*	*irrigation, water supply, field tiling, standpipe outflow, corrugated pipe, box culvert, outflowing ditches*
Hardening	any field observation related to soil compaction, including activities and infrastructure that primarily result in soil hardening	*gravel road, two lane road, four lane road, parking lot/pavement, trails, soil compaction, offroad vehicle damage, confined animal feeding, dairy, suburban residential, urban/multifamily, rural residential, impervious surface input*	*animal trampling, vehicle ruts, roads, concrete, asphalt*
Filling/Erosion	any field observation related to soil erosion or deposition	*excavation/dredging, fill/spoil banks, freshly deposited sediment, soil loss/root exposure, soil erosion, irrigation, landfill, dumping, surface mine*	*recent sedimentation, excavation/dredging*

*Although actively farmed wetlands did not meet criteria for NWCA Wetland Types, row crops may still have been present in the buffer surrounding an AA or in small quantities (up to 10%) within the AA.

8.3.4 *Index Development*

Two indices were developed for the physical indicators of stress – one that applies to the buffer data and the other that applies to the hydrology data. Depending on whether the indicator was based on buffer data alone (i.e., vegetation removal and vegetation replacement), or hydrology and buffer data (i.e., damming, ditching, hardening, and filling/erosion), one or both of the indices were used to score each of the six indicators of stress. We provide a short summary of how each index was calculated in the following subsections.

8.3.4.1 *Buffer Index*

The stressor observations recorded as part of the Buffer Protocol were proximity-weighted based on the distance of the plot from the AA. For each indicator of stress and for each wetland site, the Buffer Index score was calculated as the sum of proximity-weighted stressor observations (assigned to the stressor category) divided by the total number of plots evaluated (i.e., 13). See **Figure 8-3** for the values used in proximity weighting and **Table 8-2** for the thresholds the low stressor-level and high stressor-level categories.

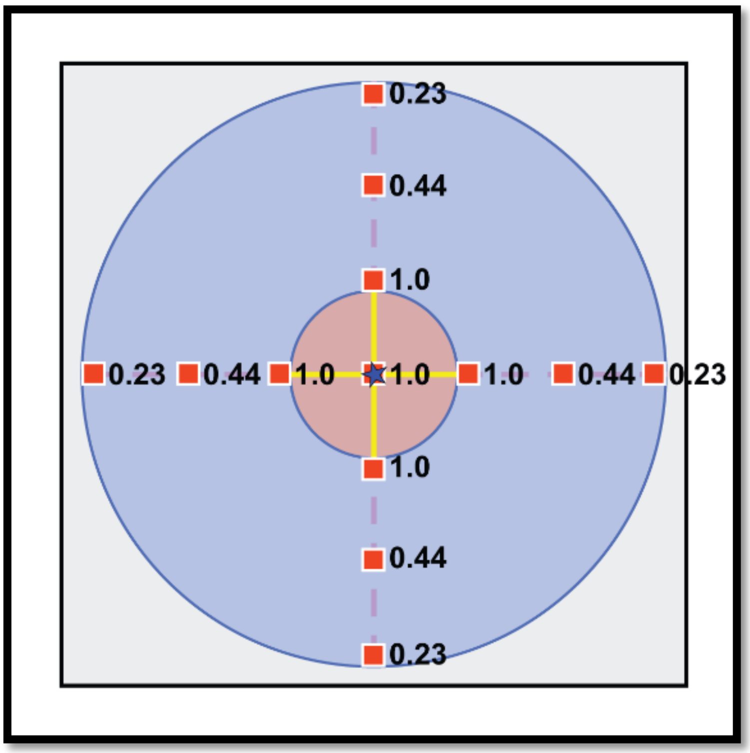

Figure 8-3. Weights assigned to the 13 plots evaluated as part of the Buffer Protocol

8.3.4.2 *Hydrology Index*

Field Crews surveyed the entire AA and recorded all stressor observations as part of the Hydrology Protocol. For each of the hydrologic alteration indicators of stress and for each wetland site, the Hydrology Index score was calculated by summing the number of observed stressors (assigned to the stressor category) at each site. See **Table 8-2**.

8.3.5 *Stressor-Level Threshold Definition*

For each of the Buffer and Hydrology Indices, two stressor-level thresholds were defined – one for "low" and one for "high". Indicators of stress at sites that exceeded the "low stressor-level" threshold but were under the threshold set for "high stressor-level" were categorized as "moderate".

8.3.5.1 *Low Stressor-Level Threshold*
The stressor-level threshold for both indices was assigned using strict criteria, i.e., the stressor-level threshold score was set to zero. In other words, for an indicator of stress at site to be considered low, there were no observed stressors marked on either the Buffer or Hydrology Form.

8.3.5.2 *High Stressor-Level Threshold*
The high stressor-level threshold was assigned using best professional judgement, and the stressor-level threshold differs between Buffer and Hydrology Indices. High stressor-level threshold values were set as ≥0.1 for the Buffer Index and ≥1.0 for the Hydrology Index. A Buffer Index score of ≥0.1 means that, for example, at least two stressors were observed in the closest proximity to the AA, or at least six stressors were observed in the farthest proximity to the AA. On the other hand, Hydrology Index scores are integers, and a value of ≥1.0 represents one or more observations of stressors within the AA.

8.3.5.3 *Applying Stressor-Level Thresholds to Indicators of Stress*
Because the vegetation alteration indicators of stress are based on buffer data alone, index scoring and the application of the stressor-level threshold is straightforward. Hydrologic alteration indicators of stress, on the other hand, which combine buffer and hydrology data, have two index scores and a more complicated application of stressor-level thresholds. For these four indicators of stress (i.e., damming, ditching, hardening, filling/erosion) at a site, ***both*** threshold criteria (buffer and hydrology) had to be met for a stressor-level to be low, while meeting ***either*** buffer or hydrology threshold criteria place a stressor in the high category (**Table 8-2**).

Table 8-2. Threshold definition and physical application to indicators of stress.

Stressor Group	Indicators of Stress	Low Stressor-Level Threshold	High Stressor-Level Threshold
Vegetation Alteration	Vegetation Replacement Vegetation Removal	Buffer Index = 0	Buffer Index ≥ 0.1
Hydrologic Alteration	Damming Ditching Hardening Filling/Erosion	Buffer Index = 0 **AND** Hydrology Index = 0	Buffer Index ≥ 0.1 **OR** Hydrology Index ≥ 1.0

8.4 Chemical Indicators of Stress

8.4.1 *Defining Chemical Indicators of Stress*
Chemical indicators of stress are associated with the soil chemistry analyses conducted as part of the Soils Protocol. Although the soil analyses provided extensive data, only the strongest indicators of stress – heavy metals and soil phosphorus– were used for reporting. In the following subsections, data collection, data preparation, index development, and stressor-level threshold definition for each chemical indicator of stress is described.

8.4.2 *Sample Collection and Analysis*
Chemical indicators of stress include heavy metal and soil phosphorus concentrations in the wetland site soil. Soil samples were collected by Field Crews from each layer greater than 8 cm thick from one (Representative Pit) of four soil pits chosen to represent the entire AA according to the Soils Protocol

(USEPA 2011a). Soil samples were shipped to the Kellogg Soil Survey Laboratory for analysis following the procedures in the *NWCA Laboratory Operations Manual* (USEPA 2011b). The Kellogg Laboratory is located in Lincoln, Nebraska, and is part of the Natural Resources Conservation Service (NRCS) of the US Department of Agriculture.

8.4.3 *Data Preparation*

Soil chemistry data returned from NRCS were merged with soil profile data collected by Field Crews from the Representative Pit (the only pit from which soil was analyzed for chemistry) by layer. Soil chemistry data representing the uppermost layer within 10 cm of the soil surface (as described in **Chapter 4, Section 4.5.4**) was used to develop chemical indicators of stress. By making the decision to use data associated with the uppermost layer, 97% of the sites sampled in the 2011 NWCA and soils most likely to reflect anthropogenic stressors were represented.

8.4.4 *Indicator Development*

Two chemical indicators of stress were developed – a Heavy Metal Index (HMI) and soil phosphorus concentrations. Heavy metal concentrations are excellent indicators of stress, as heavy metals often have specific background ranges above which anthropogenic impacts are indicated. Soil phosphorus can be an important indicator of anthropogenic impacts (especially agricultural and residential stresses that result in eutrophication), but concentrations can be highly influenced by soil type, wetland type, region, and other factors. In the following subsections, we provide a short summary of how these two chemical indicators of stress were developed.

8.4.4.1 *Heavy Metal Index (HMI)*

Heavy metals were analyzed from soil samples using a trace element procedure (HNO_3 and HCl extraction) followed by measurement with an inductively coupled plasma mass spectrometer (ICP-MS; (USEPA 2011b). Twelve heavy metals, with high signal to noise ratios that were closely related to anthropogenic impacts, and which occurred in consistently measureable quantities were used to develop an HMI. These 12 metals are:

- Silver (Ag)
- Cadmium (Cd)
- Cobalt (Co)
- Chromium (Cr)
- Copper (Cu)
- Nickle (Ni)
- Lead (Pb)
- Antimony (Sb)
- Tin (Sn)
- Vanadium (V)
- Tungsten (W)
- Zinc (Zn)

The HMI was created and scored as the sum of the number of metals present at any given site with concentrations above natural background levels based on published values, primarily from Alloway (2013) and reported in detail in **Table 4-8**. Summary of the characteristics of the heavy metals considered for use in the stressor index based on soil chemistry. Natural backgrounds are based on Alloway (2013). Percent of sites exceeding the thresholds is based on data from Visit 1.

8.4.4.2 *Soil Phosphorus Concentration*

Soil phosphorus concentrations were analyzed using four different methods by NRCS; the Olsen P test (OLSEN_P), the Mehlich III method (MEHLICH_P), ammonium oxalate extraction (P), and trace element procedure (P_T). It was decided that the concentration results from the trace element procedure, which uses an HNO_3 and HCl extraction and measurement with an ICP-MS (USEPA 2011b), would be used for the indicator of stress. This procedure extracts a greater proportion of the total phosphorus in the soil and is less influenced by soil type than the other methods. The value for the measured soil phosphorus concentration (from the uppermost layer within 10 cm of the soil surface) at each site was used as a chemical indicator of stress.

8.4.5 *Stressor-Level Threshold Definition*

For each the HMI and soil phosphorus concentration indicator, two thresholds were defined – one for "low stressor-level" and one for "high stressor-level". Indicators of stress at sites that exceeded the "low" threshold but were under the threshold set for "high" were considered "moderate stressor-level". The threshold definition is described in detail for each chemical indicator of stress in the following subsections.

8.4.5.1 *Heavy Metal Index (HMI) Stressor-Level Thresholds*

Stressor-Level thresholds for the HMI were based upon the number of different heavy metals above background concentrations for each site, with the maximum possible number of observed metals equal to 12. The low stressor-level threshold for the HMI was assigned using strict criteria, with the threshold score set at zero. In other words, for an indicator of stress at a site to be considered low stressor-level, all 12 heavy metals included in the index were at or below background concentrations (**Table 8-3**). The high stressor-level threshold, assigned using best professional judgement, was set as 3. Therefore, a site that had soils with 3 or more heavy metals exceeding background concentrations was considered high stressor-level. The greatest number of heavy metals determined above background concentrations at any site was 7.

Table 8-3. Threshold definition for the Heavy Metal Index (HMI).

Indicator of Stress	Low Stressor-Level Threshold	High Stressor-Level Threshold
Heavy Metal Index	All metals ≤ background concentrations	3 or more metals > background concentrations

8.4.5.2 *Soil Phosphorus Concentration Stressor-Level Thresholds*

Soil phosphorus concentrations can be strongly influenced by soil type, wetland type, region, and other factors, so determining low and high stressor-level thresholds based upon published ranges or even best professional judgement is not appropriate. Instead, soil phosphorus concentration stressor-level thresholds for low and high were set using the 75^{th} and 95^{th} percentiles of soil phosphorus concentrations observed in reference sites, respectively (**Table 8-4**). This method is used for lakes and streams nutrient criteria in USEPA National Aquatic Resource Surveys (NARS) as described in Herlihy et al. (2008, 2013) and illustrated in **Figure 8-4**.

Table 8-4. Stressor-level threshold definition for soil phosphorus concentration.

Stressor-Level Threshold Groups	Reporting Groups Included	Low Stressor-Level Threshold (mg P / kg soil)	High Stressor-Level Threshold (mg P / kg soil)
Estuarine	EH, EW	≤ 519	> 969
Coastal Plains	CPL-PRLH, CPL-PRLW	≤ 582	> 1180
Eastern Mountains & Upper Midwest	EMU-PRLH, EMU-PRLW	≤ 914	> 1280
Interior Plains	IPL-PRLH, IPL-PRLW	≤ 1110	> 1810
West	W-PRLH, W-PRLW	≤ 1140	> 2090

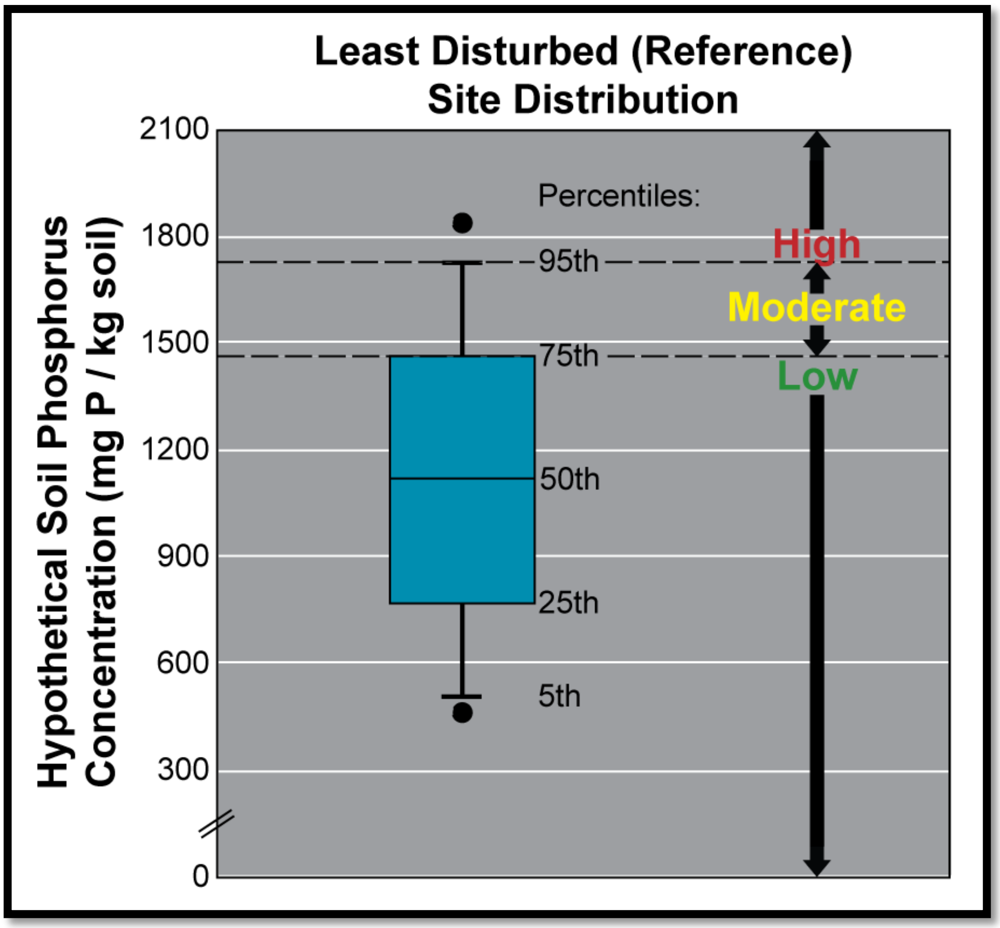

Figure 8-4. Conceptual model of how the 75th and 95th percentiles of reference site soil phosphorus concentrations are used to determine high and low stressor-level thresholds.

A single national threshold for soil phosphorus was not adequate to capture the regional and geological variation in concentrations. Therefore, stressor-level thresholds were determined by combining herbaceous and woody vegetative types for across NWCA Reporting Groups. **Table 8-4** presents low and high stressor-level thresholds for all Estuarine wetland types, and for all PRL wetland types within the Coastal Plains, Eastern Mountains & Upper Midwest, Interior Plains, and West Aggregated Ecoregions.

8.5 Biological Indicator of Stress

8.5.1 *Defining a Biological Indicator of Stress*

The Nonnative Plant Stressor Indicator (NPSI) was developed as a descriptor of stress to ecological condition for the 2011 NWCA. Vegetation was the principle biological ecosystem component evaluated in the NWCA (see **Chapter 5**), and collection of information describing the species-level presence and abundance of nonnative plants was a major component of the NWCA protocols.

Nonnative plant species are recognized as important biological indicators of ecological stress on wetland condition (Mack and Kentula 2010; Magee et al. 2010). Their presence and abundance are often positively related to human mediated disturbance (Lozon and MacIsaac 1997; Mack et al. 2000; Magee 1999; Magee et al. 2008; Ringold et al. 2008). In addition, nonnative plants can act as direct stressors to ecological condition by competing with or displacing native plant species or communities, or by altering ecosystem structure and processes (Vitousek et al. 1997; Dukes and Mooney 2004). Numerous direct and indirect effects of nonindigenous plants on native vegetation and other ecosystem components demonstrate their role as potential stressors. For example, nonnative plant species have been linked to:

- increased risk of local extinction or population declines for many rare, native plant species (Randall 1996; Lesica 1997; Seabloom et al. 2006);
- changes in species composition within and among plant community types, and to homogenization of local and regional floras (McKinney 2004; Rooney et al. 2004; Magee et al. 2008);
- alteration of fire regimes (Dwire and Kauffman 2003; Brooks et al. 2004);
- alteration of geomorphic and hydrologic processes (Rowantree 1991; Sala et al. 1996); and
- alteration of carbon storage patterns (Farnsworth and Meyerson 2003; Bradley et al. 2006); nutrient cycling, and composition of soil biota (Belnap and Phillips 2001; Ehrenfeld 2003).

Major ecological changes like these negatively influence the intactness or integrity of natural ecosystems (Angermeier and Karr 1994; Dale and Beyeler 2001), and can lead to losses of ecosystem services (Dukes and Mooney 1999; Dale et al. 2000; Hooper et al. 2005; Meyerson and Mooney 2007).

For the NWCA, we defined nonnative plants to be comprised of both alien and cryptogenic taxa. Alien plants include taxa that are either 1) introduced to the conterminous United States, or 2) adventive, that is, native to some parts of the conterminous United States but introduced to the location of occurrence on a particular NWCA site. Cryptogenic species include taxa that have both introduced (often aggressive) and native (generally less prevalent) genotypes, varieties or subspecies. Because many cryptogenic species are invasive or act as ecosystem engineers, we grouped them with alien species and considered them nonnative for the purpose of indicating ecological stress.

8.5.2 *Data Collection*

Nonnative plant data were collected as part of the standard Vegetation Protocol (USEPA 2011a). An overview of vegetation field and laboratory methods is provided in **Chapter 5, Section 5.3**.

8.5.3 *Data Preparation*

Preparation and validation of raw data for nonnative plant species are described in **Chapter 5, Section 5.4** and **Section 5.5**. Definition of the native status categories used in the NWCA and the procedures for determining state-level native status for the individual species observed in 2011 are provided in **Chapter**

5, Section 5.8. Numerous metrics summarizing different attributes (e.g., all alien and cryptogenic species, or subgroups of these species based on life history traits) of nonnative species were calculated and are described in **Chapter 6, Section 6.2** and **Section 6.8 Appendix D**.

8.5.4 *Indicator Development*

Approximately 30 of the metrics describing nonnative plants passed initial evaluations for range and repeatability and were considered as potential indicators of stress. Wetlands sampled across the conterminous United States as part of the 2011 NWCA spanned an enormous range of diversity and compositional and structural variability. As a result, nonnative metrics characterizing specific life history groups (e.g., growth habit, duration, hydrophytic status) were less robust across all NWCA sampled sites or across sites within Reporting Groups than were metrics based on all nonnative species. Consequently, metrics that included all nonnative plant species occurring at each site were used in developing the Nonnative Plant Stressor Indicator (NPSI).

Ultimately, three complementary metrics that describe different avenues of potential impact to ecological condition were selected for inclusion in the NWCA NPSI. The NPSI integrates:

- Relative Cover of Nonnative Species (XRCOV_AC)
  - *0 to 100%*
- Richness of Nonnative Species (TOTN_AC)
  - *Number of unique nonnative species*
- Relative Frequency of Nonnative Species (RFREQ_AC)
  - *0 to 100%*

Calculation methods for these three metrics can be found in **Chapter 6, Section 6.8 Appendix D** by referencing the metric names indicated in parentheses in the list above. These metric names are highlighted in red and bolded in the appendix to make them easier to locate. The '_AC' suffix in the metric names refers to combined alien and cryptogenic species.

Relative Nonnative Cover reflects preemption of space and resources, changes in species composition, and alteration of ecosystem processes. Higher values are often associated with greater decreases in ecological condition. ***Total Richness of Nonnative Species*** can be an indicator of potential risk for ecological impact; greater numbers of individual nonnative taxa increases the risk that one or more may be or become invasive or ecosystem engineers. Greater ***Relative Frequency of Nonnative Species*** reflects increasing numbers of loci for further nonnative incursions, and a decreasing proportion of the flora that is native, both of which can lead to decreased resiliency of the vegetation or ecosystem. Of the three metrics, Relative Nonnative Cover is likely to represent the greatest potential impact to ecological condition. The other two metrics provide additional pathways of impact that may have synergistic relationships with Relative Nonnative Cover, potentially increasing the amount overall stress related to nonnative plants.

The composite NPSI derived from these three metrics was used to assign stressor-level classes reflecting potential ecological stress from nonnative species to each site. Four stressor-level classes were defined: low, moderate, high, and very high. Assignment of stressor-level is based on stressor-level threshold values for each of the three metrics. Stressor-level thresholds are described in the following section.

8.5.5 *Stressor-Level Threshold Definition*

Designation of the Nonnative Plant Stressor Indicator (NPSI) stressor-level class (low, moderate, high, or very high) is based on exceedance thresholds for each of the three component metrics (**Table 8-5**). Development of these stressor-level exceedance values were based on best professional judgement.

Stressor-level thresholds were assigned to reflect the strong potential influence of Relative Nonnative Cover, and were set for this metric as though it were a standalone stressor. Stressor-Level thresholds for Nonnative Richness and Relative Frequency of Nonnative Species were then set to reflect additional sources of potential stress at a particular level of Relative Nonnative Cover. Exceedance of a threshold value for a particular stressor-level class for any of the three component metrics (see **Table 8-5**) moves the NPSI designation to next higher stressor-level.

Table 8-5. Nonnative Plant Stressor Indicator (NPSI) Stressor--Level Threshold Exceedance Values for each of the three component nonnative species metrics: Relative Cover of Nonnative Species (XRCOV_AC), Nonnative Richness (TOTN_AC), and Relative Frequency of Nonnative Species (RFREQ_AC).

Stressor-Level Class*	XRCOV_AC	TOTN_AC	RFREQ_AC
Low	≤1	≤5	≤10
Moderate	>1-15	>5-10	>10-30
High	>15-40	>10-15	>30-60
Very High	>40	>15	>60

*Exceedance of a threshold value for a particular stressor-level class for any of the three component metrics moves the NPSI to next higher stress level.

This approach for designating the NPSI stressor-level for each site integrates information from three different pathways from which nonnative species may influence ecological condition. To see how the exceedance thresholds work, consider the two hypothetical examples of nonnative species results that are outlined below.

Hypothetical Site 1 (Stressor-Level Class = High) has:

- XRCOV_AC = 7% → Moderate Stressor-Level Class
- TOTN_AC = 14 nonnative species → High Stressor-Level Class
- RFREQ_AC = 28% → Moderate Stressor-Level Class
-

In this case, Relative Nonnative Cover would place the site in the moderate stressor-level; however the number of unique nonnative species moves the NPSI to the high stressor-level class. Even though Relative Nonnative Cover is not extensive, the number of individual nonnative species and their frequency of occurrence could indicate shifting community composition and strong risk for expansion of nonnative impact.

Hypothetical Site 2 (Stressor-Level Class = Very High) has:

- XRCOV_AC = 80% → Very High Stressor-Level Class
- TOTN_AC = 1 nonnative species → Low Stressor-Level Class
- RFREQ_AC = 59% → High Stressor-Level Class

Here, the stressor-level class for the NPSI would be very high. Even though there is only 1 nonnative species present at the site (which could reflect limited stress), it occurs at very high relative cover (e.g., it occupies 80% of the sampled area) and relative frequency of occurrence (e.g., nearly 60% of all species occurrences across the sampled area are nonnative and represented by this one species).

8.6 Stressor Extent Estimates

Established thresholds for physical, chemical, and biological indicators of stress (defined in the preceding sections) are used in conjunction with site weights to calculate stressor extent estimates (**Figure 8-5**), which are reported in *National Wetland Condition Assessment 2011: A Collaborative Survey of the Nation's Wetlands* (USEPA *In Review*). The following chapter (**Chapter 9**) will provide a detailed explanation of how population estimates are used to estimate for wetland condition and stressor extent (**Chapter 9, Section 9.2**) and how stressor extent estimates are calculated using the thresholds described in this chapter (**Sections 8.3.5, 8.4.5, and 8.5.5**).

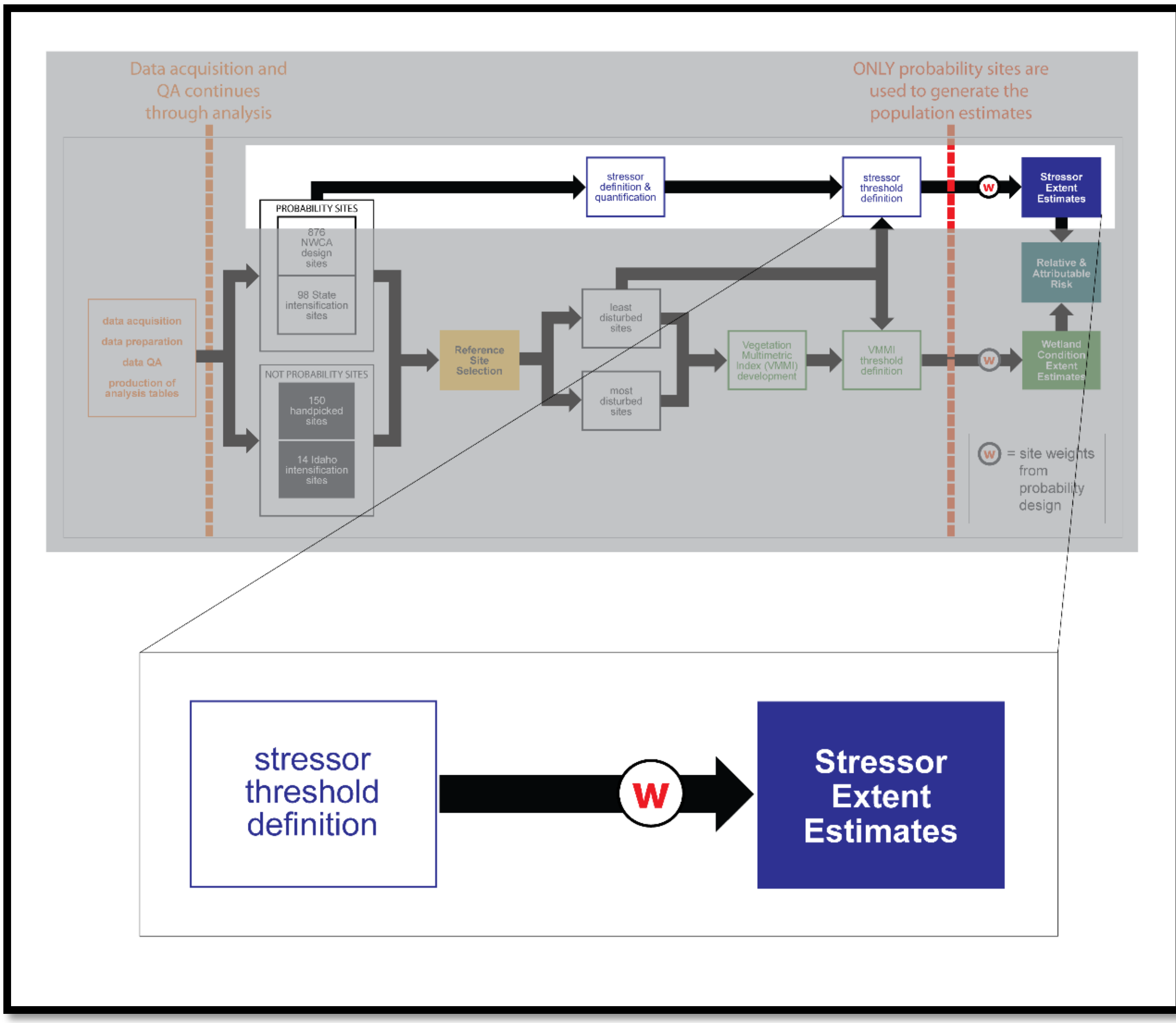

Figure 8-5. The connection from stressor threshold definition (described in the preceding sections) to reporting stressor extent estimates within the 2011 National Wetland Condition Assessment Analysis Pathway.

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8.8 Appendix F: Example Buffer Form (B-1)

FORM B-1: NWCA BUFFER SAMPLE PLOTS (Front) Reviewed by (Initial): HI

Site ID: NWCA11- 1776 **DATE:** 04 / 18 / 2011

Location: ○ AA Center ○ N ○ S ● E ○ W

Fill in bubble(s) if plot(s) could not be sampled and flag → ○ Plot 1 ○ Plot 2 ○ Plot 3

Buffer Natural Cover Strata

Fill in bubbles for all that apply: Canopy Type: D = Deciduous; E = Evergreen. Leaf Type: B = Broadleaf; N = Needle Leaf. Absent: No tree canopy.
Strata Section: Fill in appropriate cover class bubble for each strata type for each plot. 0 = Absent; 1 = Sparse(<10%); 2=Moderate(10-40%); 3 = Heavy (40-75%); 4 = Very Heavy (>75%)

Buffer Plot 1 — Canopy Type: D ○ E ● Absent: ○ Leaf Type: B ○ N ●
Buffer Plot 2 — Canopy Type: D ○ E ○ Absent: ● Leaf Type: B ○ N ○
Buffer Plot 3 — Canopy Type: D ○ E ○ Absent: ● Leaf Type: B ○ N ○

Strata	Plot 1 (0–4)	Flag	Plot 2 (0–4)	Flag	Plot 3 (0–4)	Flag
Big Trees (>0.3m DBH)	0		0		0	
Small Trees (<0.3m DBH)	0		0		0	
Woody Shrubs, Saplings (0.5m-5m HIGH)	1		0		0	
Woody Shrubs, Saplings (<0.5m HIGH)	0		0		0	
Herbs, Forbs and Grasses	4		4		4	
Bare ground	0		0		1	
Litter, duff	2		3		1	
Rock	0		0		0	
Water	3		0		0	
Submerged Vegetation	0		0		0	

Stressor Presence/Absence - Confirm that a filled data bubble indicates presence and an unfilled bubble indicates absence by filling this bubble. ●

Residential and Urban Stressors

Fill bubble if present - Plot	1	2	3	Flag
Road - gravel	○	○	○	
Road - two lane	○	○	○	
Road - four lane	○	○	○	
Parking Lot/Pavement	○	○	○	
Golf Course	○	○	○	
Lawn/Park	○	○	○	
Suburban Residential	○	○	○	
Urban/Multifamily	○	○	○	
Landfill	○	○	○	
Dumping	○	○	○	
Trash	○	○	○	
Other:	○	○	○	
Other:	○	○	○	

Hydrology Stressors

Fill bubble if present - Plot	1	2	3	Flag
Ditches, Channelization	○	○	○	
Dike/Dam/Road/RR Bed (IMPEDE FLOW)	○	○	○	
Water Level Control Structure	○	○	○	
Excavation, Dredging	○	○	○	
Fill/Spoil Banks	○	○	○	
Freshly Deposited Sediment (UNVEGETATED)	○	○	○	
Soil Loss/Root Exposure	○	○	○	
Wall/Riprap	○	○	○	
Inlets, Outlets	○	○	○	
Point Source/Pipe (EFFLUENT OR STORMWATER)	○	○	○	
Impervious surface Input (SHEETFLOW)	○	○	○	
Other:	○	○	○	
Other:	○	○	○	

Agricultural & Rural Stressors

Fill bubble if present - Plot	1	2	3	Flag
Pasture/Hay	○	○	○	
Range	○	○	○	
Row Crops	○	○	○	
Fallow Field (RECENT-RESTING ROW CROP FIELD)	○	○	○	
Fallow Field (OLD - GRASS, SHRUBS, TREES)	○	○	○	
Nursery	○	○	○	
Dairy	○	○	○	
Orchard	○	○	○	
Confined Animal Feeding	○	○	○	
Rural Residential	○	○	○	
Gravel Pit	○	○	○	
Irrigation	○	○	○	
Other:	○	○	○	

Industrial Development Stressors

Fill bubble if present - Plot	1	2	3	Flag
Oil Drilling	○	○	○	
Gas Wells	○	○	○	
Mine (surface)	○	○	○	
Mine (underground)	○	○	○	
Military	○	○	○	
Other:	○	○	○	
Other:	○	○	○	
Other:	○	○	○	

Habitat/Vegetation Stressors

Fill bubble if present - Plot	1	2	3	Flag
Forest Clear Cut	○	○	○	
Forest Selective Cut	○	○	○	
Tree Plantation	○	○	○	
Tree Canopy Herbivory (INSECT)	○	○	○	
Shrub Layer Browsed (WILD OR DOMESTIC)	○	○	○	
Highly Grazed Grasses (OVERALL <3" HIGH)	○	○	○	
Recently Burned Forest Canopy	○	○	○	
Recently Burned Grassland (BLACKENED)	○	○	○	

Fill bubble if present - Plot	1	2	3	Flag
Herbicide Use	○	○	○	
Mowing/Shrub Cutting	○	●	●	
Trails	○	○	○	
Soil Compaction (ANIMAL OR HUMAN)	○	○	○	
Offroad vehicle damage	○	○	○	
Soil erosion (FROM WIND, WATER, OR OVERUSE)	○	○	○	
Other:	○	○	○	
Other:	○	○	○	

NWCA Buffer Sample Plots 03/10/2011 8621005046

8.9 Appendix G: Example Hydrology Form (H-1)

FORM H-1: NWCA ASSESSMENT AREA HYDROLOGY (Front) Reviewed by (initial): ______

Site ID: NWCA11-1314 Date: 06/23/2011

Time of Sampling (hh:mm): 24 hr clock 10:54 Tidal Stage: ○ NA ○ Incoming ○ Outgoing ○ Slack ○ Flood

Weather description: Day of sampling: SUNNY, HIGH 90'S TO LOW 100'S

Week prior to sampling: 0.64 in RAIN, HIGH 90'S TO LOW 100'S

Identify and Rank Water Sources / Stressors:
Rank the top 3 Water Sources (1 = most influential). Rank the top 3 Stressors (1 = most stress) by perceived influence on the Site/Assessment Area Hydrology.

Water Sources - Natural
● Fill in this bubble to confirm that all water sources were considered, but only those present were marked.

	Present	Rank Top 3 Sources from 1-3	Flag		Present	Rank Top 3 Sources from 1-3	Flag
Stream Inflow (creeks, rivers)	●	○1 ●2 ○3	F1	Snow Melt	○	○1 ○2 ○3	
Outflow	●	○1 ○2 ●3		Overbank Flooding	○	○1 ○2 ○3	
Springs (seeps)	○	○1 ○2 ○3		Estuary Tidal Channel	○	○1 ○2 ○3	
Lake	○	○1 ○2 ○3		Tidal Surge	○	○1 ○2 ○3	
Precipitation (rain, snow)	●	○1 ○2 ○3		Other (describe with flag)	○	○1 ○2 ○3	
Groundwater	●	●1 ○2 ○3					

Hydrologic Stressors
● Fill in this bubble to confirm that all hydrologic stressors were considered, but only those present were marked.

Damming Features	Present	Rank Top 3 Stressors from 1-3	Flag	Pumps	Present	Rank Top 3 Stressors from 1-3	Flag
Dikes	○	○1 ○2 ○3		Irrigation	○	○1 ○2 ○3	
Berms	●	●1 ○2 ○3		Water Supply	○	○1 ○2 ○3	
Dams	○	○1 ○2 ○3		Other	○	○1 ○2 ○3	
Railroad Bed	○	○1 ○2 ○3		Field Tiling	○	○1 ○2 ○3	
Roads	●	○1 ●2 ○3		Excavation / Dredging	●	○1 ○2 ●3	
Shallow Channels				Pipes			
Animal Trampling	○	○1 ○2 ○3		Sewer Outfall	○	○1 ○2 ○3	
Vehicle Ruts	●	○1 ○2 ○3		Standpipe outflow	○	○1 ○2 ○3	
Impervious Surfaces				Culverts			
Roads	○	○1 ○2 ○3		Corrugated Pipe	○	○1 ○2 ○3	
Concrete	○	○1 ○2 ○3		Box	○	○1 ○2 ○3	
Asphalt	○	○1 ○2 ○3		Ditches			
Recent Sedimentation	○	○1 ○2 ○3		Inflowing	○	○1 ○2 ○3	
				Outflowing	○	○1 ○2 ○3	
				Other (describe with flag)	○	○1 ○2 ○3	

Depth of Deepest Ditch:
Measure cross sectional depth in 3 places if a ditch is present in the AA

				Flag
● No Ditch Present	Depth 1 = (cm)	Depth 2 = (cm)	Depth 3 = (cm)	

Flag	Comments
F1	SHEETFLOW + SMALL SWALES AND CHANNELS < 25cm
	IN DEPTH THROUGH AA. MAY BE SOME SEEP + GW FLOW
	FROM NORTH SLOPE.

Flag codes: K = No measurement made, U = Suspect measurement, F1,F2, etc. = misc. flags assigned by each field crew. Explain all flags in comment section.

NWCA Assessment Area Hydrology 03/10/2011 9911639020

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Chapter 9: Transition from Analysis to Results

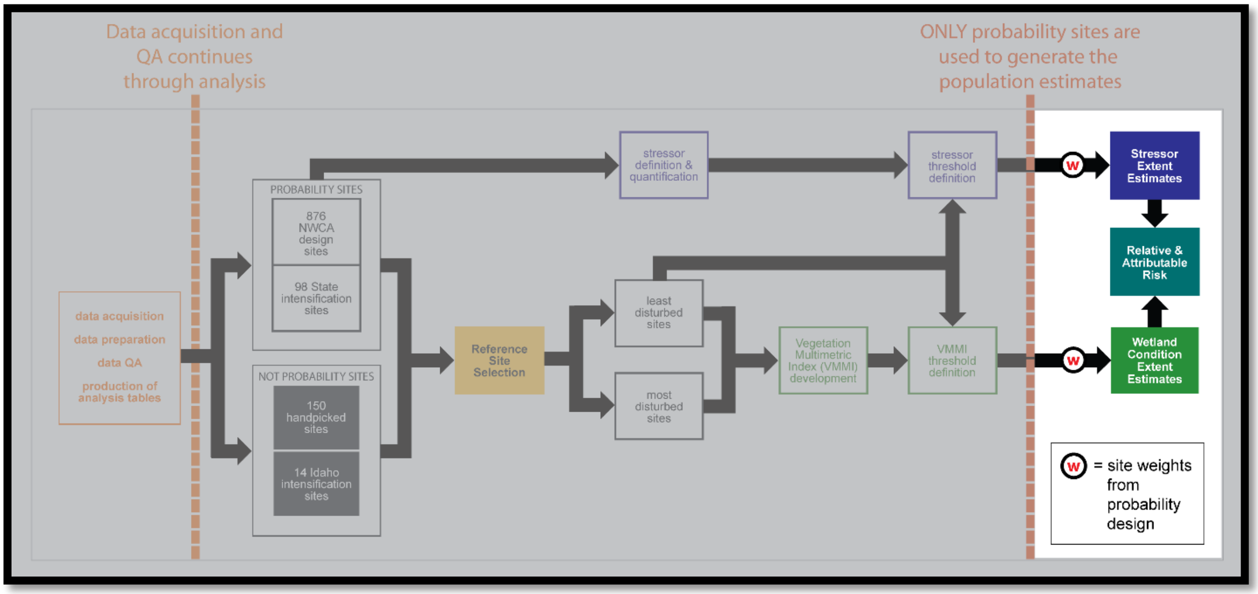

Figure 9-1. The major components of the 2011 National Wetland Condition Assessment Analysis Pathway discussed in this chapter (i.e., wetland condition and stressor extent estimates, and relative and attributable risk). A full-page, unhighlighted version of this figure may be found on **page 14** of this report.

9.1 Introduction

The information provided in the previous chapters is intended to provide a solid understanding of how the 2011 NWCA was designed, conducted, and data were analyzed. Up to this point in the *NWCA Technical Report*, details have been provided on the development of:

- survey design (**Chapter 1**),
- data acquisition, preparation, and quality assurance (**Chapter 3**),
- selection of reference sites and definition of disturbance gradient (**Chapter 4**),
- vegetation indicator development (**Chapters 5 through 7**),
- definitions associated with wetland condition and condition thresholds (**Chapter 7**), and
- definitions associated with indicators of stress and stressor-level thresholds (**Chapter 8**).

This chapter of the *NWCA Technical Report* will describe how definitions and thresholds associated with the data (discussed in **Chapters 7 and 8**) are used to calculate:

- wetland condition extent estimates (**Section 9.2.1**) and
- stressor extent estimates (**Section 9.2.2**).

Wetland condition and stressor extent estimates are expressed as wetland area in acres or percent of the resource; therefore, site weights from the probability design must be used to generate population estimates along with the data from the probability sites sampled (n=967) . The role of population estimates and site weights in these calculations is discussed in **Section 9.2**. Ultimately, stressor extent and wetland condition estimates are used to calculate relative and attributable risk (**Figure 9-1**), which is discussed in detail in **Section 9.3**.

The results from the wetland condition estimates, stressor extent estimates, and relative and attributable risk are presented in *National Wetland Condition Assessment 2011: A Collaborative Survey of the Nation's Wetlands* (USEPA *In Review*) primarily as bar graphs. This *NWCA Technical Report* provides guidance on how to interpret the results summarized by USEPA (*In Review*).

9.2 Population Estimates

The survey design for the NWCA, discussed in **Chapter 1** of this report, produces a spatially-balanced sample using USFWS Status and Trends wetland polygons as the sample frame (Dahl 2006, Dahl and Bergeson 2009). Each point (n=967) has a known probability of being sampled (Stevens and Olsen 1999, Stevens and Olsen 2000, Stevens and Olsen 2004), and a sample weight is assigned to each individual site as the inverse of the probability of that point being sampled. Sample weights are expressed in units of acres.

The probability of a site being sampled, as discussed in **Chapter 1, Section 1.4 "Site Selection Summary"**, was stratified by state and wetland type for the NWCA. Site weights for the survey were adjusted to account for additional sites (i.e., oversample points) that were evaluated when the primary sites were not sampled (e.g., due to denial of access, being non-target). These site weights, designated by the red "W" enclosed in a circle (i.e., Ⓦ) in the NWCA Analysis Pathway (**Figure 9-1**), are explicitly used in the calculation of wetland condition and stressor extent estimates, so results can be expressed as estimates of wetland area (i.e., numbers of acres or percent of the entire resource) in a particular condition class or stressor-level for the Nation. For examples of how this has been done for other National Aquatic Resource Survey (NARS) assessments, see USEPA (2006), Olsen and Peck (2008), and USEPA (2009). In the following sections, the methods by which estimates are calculated and reported are described for wetland condition (**Section 9.2.1**) and stressor extent (**Section 9.2.2**). It is important to note that the NWCA was not designed to report on individual sites or states, but to report at national and regional scales (see **Chapter 1**).

9.2.1 *Wetland Condition Extent Estimates*

Wetland condition is defined at each wetland site as "good", "fair", or "poor". These condition classes were assigned using Vegetation Multimetric Index (VMMI) thresholds, as described in **Chapter 7**. To calculate condition extent estimates, site weights were summed by condition class and applied to the NWCA inference population (i.e., the area) of wetlands across the conterminous US or other Reporting Groups. Note that only Visit 1 (i.e., the index visit) data and only probability sites are used in this calculation (not-probability sites have a weight of zero). Using this method, wetland area in a particular condition class is estimated and reported in numbers of acres, by percent of the resource, or by a relative ranking of occurrence (**Figure 9-2**).

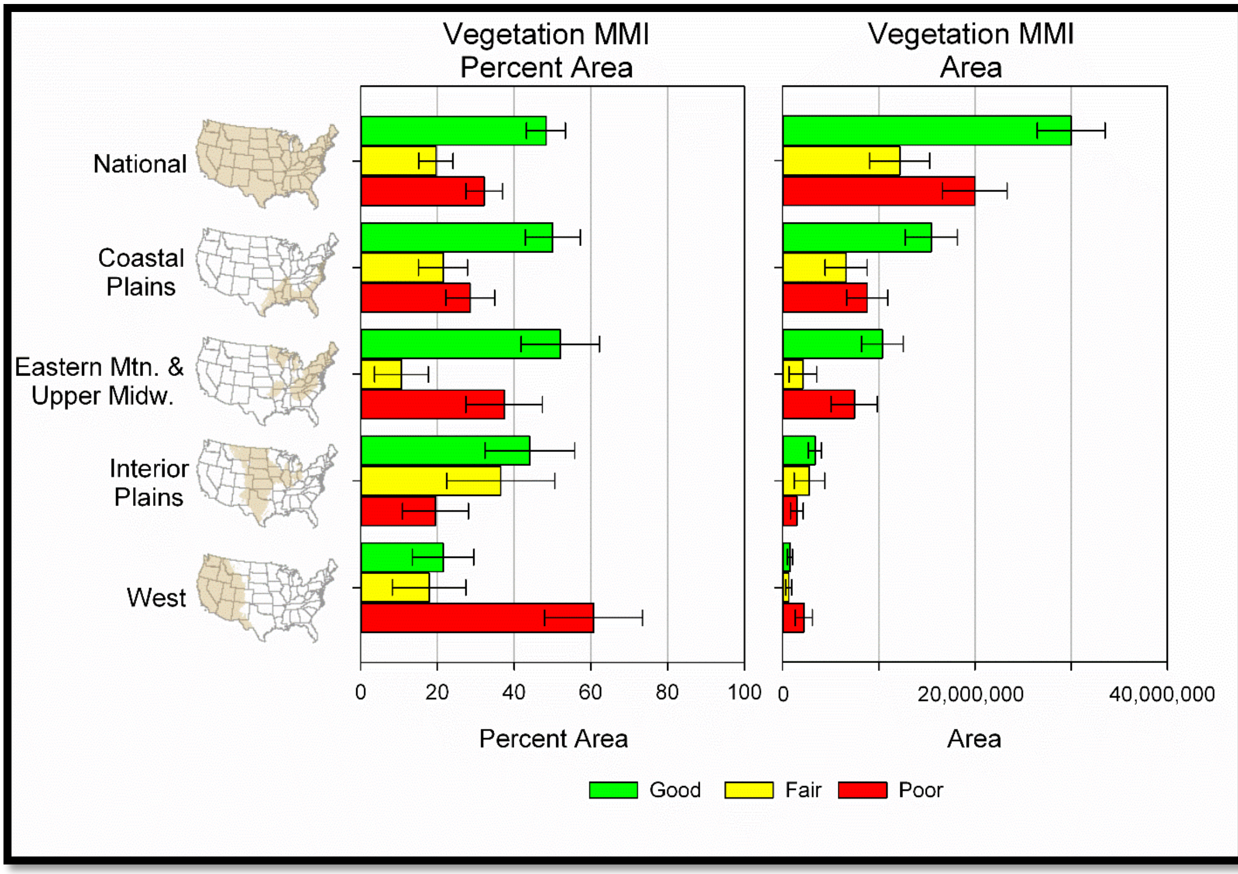

Figure 9-2. An example of how wetland condition extent estimates (based on the Vegetation MMI) are reported. In this example, wetland condition extent is presented by percent of the resource (i.e., percent of total wetland area for the Nation or region) in the left half of the figure, and by wetland acres in the right half of the figure.

9.2.2 *Stressor Extent Estimates*

Stressor extent is an estimate of how spatially common a stressor is. Stressor-level classes is defined at each wetland site as "low", "moderate", or "high". These stressor-level classes (hereon shortened to "stressor-levels") were assigned for multiple physical, chemical, and biological indicators of stress based on specific stressor-level thresholds, as described in **Chapter 8**. To calculate stressor extent estimates, site weights were summed by stressor-levels and applied to the population (i.e., the area) of wetlands in the Nation (or other Reporting Group) to estimate wetland area low, moderate, and high stressor-level classes. Note that only Visit 1 (i.e., the index visit) data and only probability sites are used in this calculation. Using this method, wetland area affected by a particular stressor-level is estimated and reported in numbers of acres, by percent of the resource, or by a relative ranking of occurrence (**Figure 9-3**).

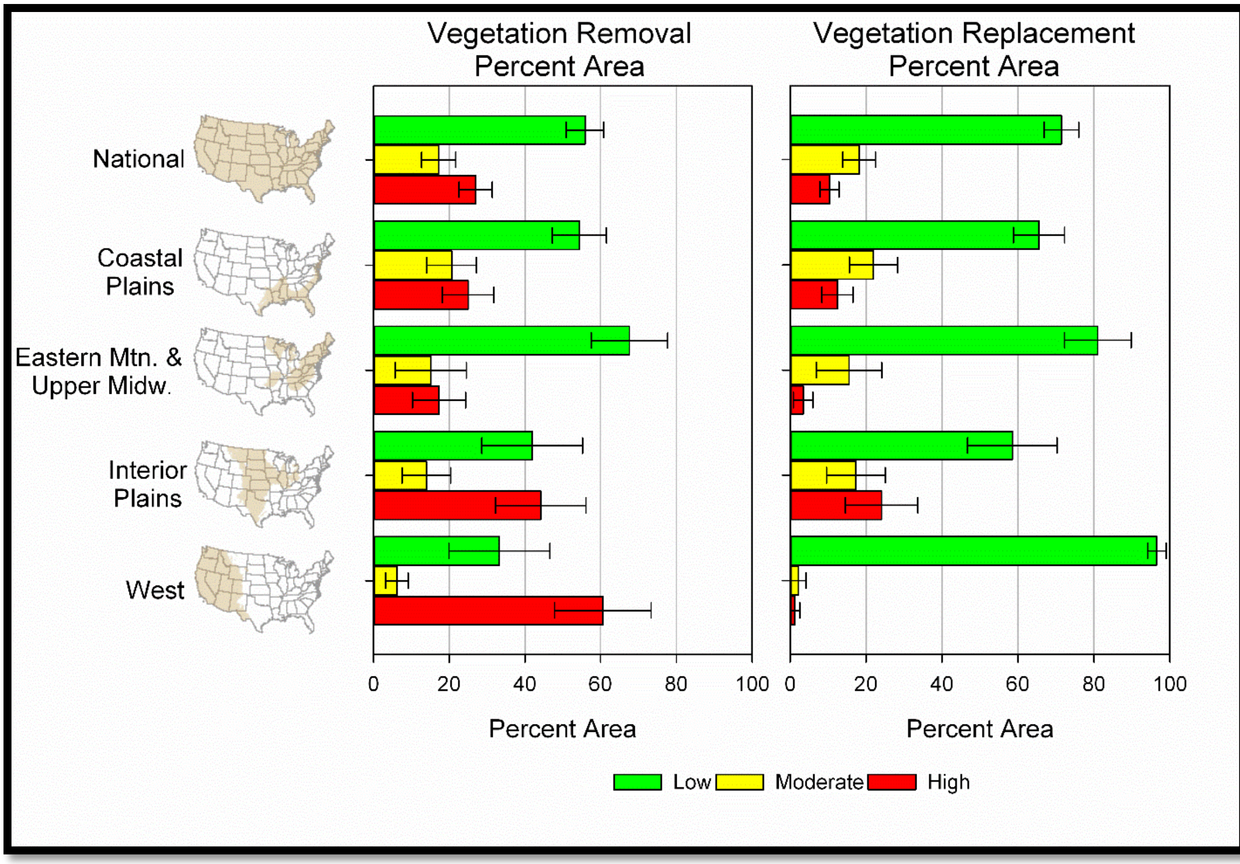

Figure 9-3. An example of how stressor extent estimates are reported using vegetation alteration stressor data. In this example, stressor extent is presented by percent of the resource (i.e., percent of total wetland area for the Nation or region).

9.3 Relative and Attributable Risk

The relationship between the extent of stressors and wetland condition can be described by calculating relative and attributable risk.

9.3.1 *Relative Risk*

Relative risk is the probability (i.e., risk or likelihood) of having poor ecological condition when the stressor-level class is high relative to when the stressor-level class is low. Relative risk analysis was derived from medical literature, where it is used commonly to describe, for example, the risk of having a heart attack based on cholesterol levels. The fact that relative risk is used so commonly to report human health risks is an advantage because, as a result, relative risk is an understandable concept to the general public. Applied to the NWCA, a relative risk analysis can be used to evaluate the relative effect of a stressor on wetland condition. Relative risk analyses are standard for reporting results in NARS assessments (e.g., USEPA 2006; USEPA 2009), and examples can be found for lake and stream NARS assessments in the literature (e.g., Van Sickle et al. 2006; Van Sickle et al. 2008; Van Sickle 2013).

9.3.1.1 *Example Calculation of Relative Risk*

Risk is calculated using contingency tables and expressed as a probability, which is unitless. Consider the example two-by-two contingency table[7] presented as **Table 9-1**, which relates stream condition indicated by Fish Index of Biotic Integrity (IBI) and stress indicated by total nitrogen (TN). The probabilities in the contingency table are calculated from weighted analysis of the data and reflect the proportion of the resource, stream length in the case of **Table 9-1**, which is in each of the four cells of the table. For wetland analysis, the resource is areal and the probabilities would reflect the proportion of wetland area in the population in each of the cells.

Table 9-1. Example contingency table for relative risk that reports the proportion of stream length associated with good and poor condition (as indicated by Fish Index of Biotic Integrity, IBI) and low and high stress levels (as indicated by stream water total nitrogen concentration, TN). Results are hypothetical.

STRESS LEVEL

CONDITION		**TN: Low**	**TN: High**
	Fish IBI: Good	0.598	0.275
	Fish IBI: Poor	0.070	0.056
	Total	*0.668*	*0.331*

Using the hypothetical example data provided in **Table 9-1**, the risk of a stream having ***poor*** fish condition when the TN stress level is ***high*** is calculated as:

$$\frac{0.056}{0.331} = 0.169$$

The risk of a stream having ***poor*** condition when the TN stress level is ***low*** can also be calculated in the same manner:

$$\frac{0.070}{0.668} = 0.105$$

Comparing these two results, it is apparent that the risk of a stream having poor condition when the TN stress level is high (0.169) is greater than when the TN stress level is low (0.105). The relative risk (RR) can then be simply calculated as the ratio of these two probabilities (Pr):

$$RR = \frac{\Pr(Poor\ condition\ given\ High\ stressor\text{-}level)}{\Pr(Poor\ condition\ given\ Low\ stressor\text{-}level\ level)} = \frac{0.169}{0.105} = 1.61$$

Therefore, in this example, we can conclude that the risk of poor condition is 1.61 times greater in streams with high TN stressor-level than in streams with low TN stressor-level.

[7] The numbers used in this example are hypothetical and were not measured as part of any USEPA NARS assessment.

These calculations are repeated for each appropriate[8] indicator of stress so relative risk can be reported for each of them. If the stressor has no effect on condition, the relative risk is 1. Confidence intervals are also used in reporting to express uncertainty in the estimate of relative risk (see Van Sickle et al. 2006).

9.3.1.2 *Considerations When Calculating and Interpreting Relative Risk*

It is important to understand that contingency tables are created using a categorical, two-by-two matrix; therefore, only two condition classes / stress levels can be used. There are three ways in which condition classes / stress levels can be used for contingency tables:

- Good vs. Poor / Low vs. High,
- Good vs. Not-Good / Low vs. Not Low, or
- Not-Poor vs. Poor / Not High vs. High,

where, “Not Good” combines fair and poor condition classes, “Not Low” combines moderate and high stressor-levels, “Not Poor” combines good and fair condition classes, and “Not High” combines low and fair stressor-levels. In the first bulleted method, “Good vs. Poor / Low vs. High”, data associated with the fair condition class and the moderate stressor-level is excluded from the analysis. Therefore, the results of the associated calculation of relative risk are affected by which one of the above combinations is used to make the contingency tables, and it is crucial that the objectives of the analysis are carefully considered to help guide this decision.

A second consideration is that relative risk does not model joint effects of correlated stressors. In other words, each stressor is modeled individually, when in reality, stressors may interact with one another potentially increasing or decreasing impact on condition. This is an important consideration when interpreting the results associated with relative risk.

9.3.1.3 *Application of Relative Risk to the NWCA*

For the NWCA, wetland condition is defined at each wetland site as good, fair, or poor and assigned using Vegetation Multimetric Index (VMMI) thresholds, as described in **Chapter 7**. Stressor-level is defined at each wetland site as low, moderate, or high using multiple physical, chemical, and biological indicators of stress and thresholds, as described in **Chapter 8**. For each indicator of stress (except the Nonnative Plant Stressor Index (NPSI); see **Section 9.4** for details), a wetland condition / stressor-level contingency table was created, comparing the Not Poor condition class (i.e., a combination of good condition and fair condition) to Poor condition class, and Not High stressor-level (i.e., a combination of low and moderate) to High stressor-level. This decision was made because the objective of reporting relative risk in the NWCA is to indicate which stressors policy makers and managers may want to prioritize for management efforts to improve poor wetland condition. After creating contingency tables, relative risk for each indicator of stress was calculated. **Figure 9-4** provides an example of how relative risk is reported for the NWCA; with stressor extent, relative risk provides an overall picture of the relative importance of individual stressors on condition.

[8] In some cases, it may not be appropriate to calculate relative risk for a stressor, for example, when a stressor and condition index are based on the same type of data. See **Section 9.4** for details.

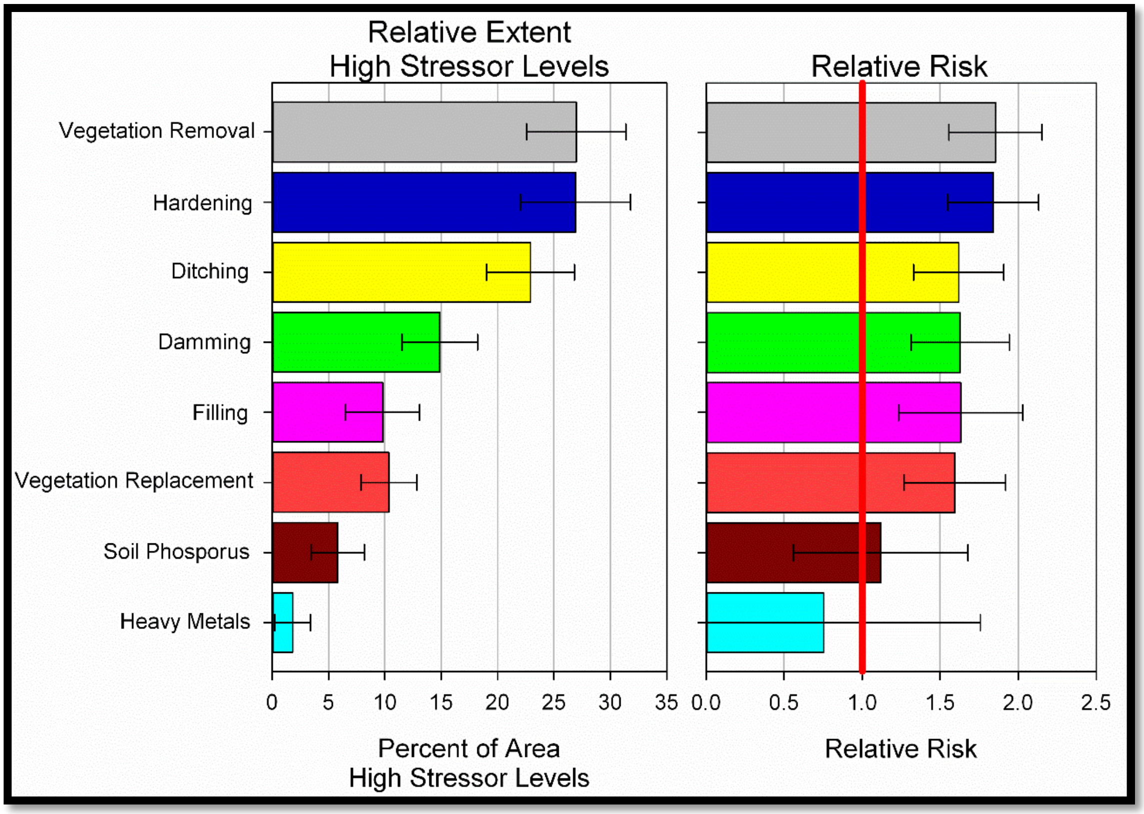

Figure 9-4. An example of how relative risk is reported in the NWCA. In this example, stressor extent estimates (for the high stress level) are presented (left) with relative risk for each indicator of stress (right). Note that large stressor extent does not necessarily translate to high relative risk (or *visa versa*).

9.3.2 *Attributable Risk*

Attributable risk provides an estimate of the proportion of the resource population (i.e., extent) in poor condition that might be reduced if the effects of a particular stressor were eliminated. Attributable risk (AR) combines estimated stressor extent with relative risk into a single index using the following formula (see Van Sickle et al. 2008 for details):

$$AR = \frac{\Pr(\textit{Extent with High stressor-levels}) * (RR - 1)}{1 + \Pr(\textit{Extent with High stressor-levels}) * (RR - 1)}$$

Where RR is relative risk and Pr is probability. Similar to the consideration presented in **Section 9.3.1.2**, it is critical to define relative extent (i.e., percent of the resource) and relative risk in the same way. Therefore, for the NWCA data, the same categories were used for calculating attributable risk as relative risk (i.e., Not Poor and Not High was compared to Poor and High condition classes and stressor-levels, respectively).

The ranking of stressors according to attributable risk (e.g., **Figure 9-5**) represents their relative magnitude or importance relative to decreased ecological condition and can be used by policy makers and managers to inform prioritization of actions for specific stressors, geographic area, and/or wetland type.

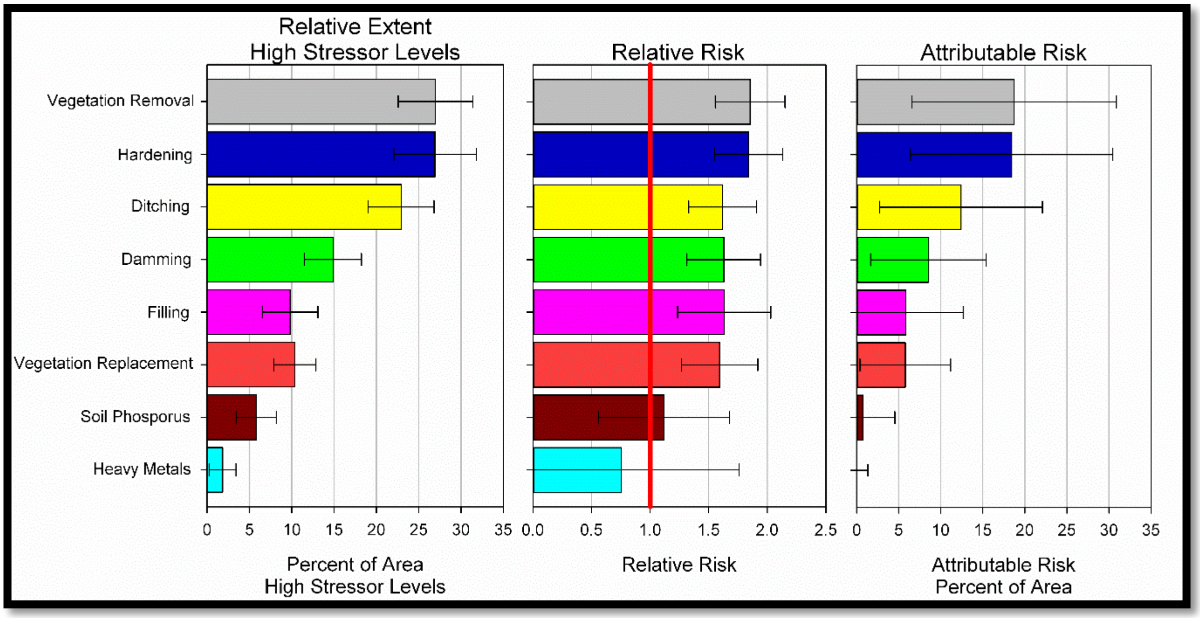

Figure 9-5. An example of how attributable risk (right panel) is reported in the NWCA.

9.3.2.1 *Considerations When Interpreting Attributable Risk*

To appropriately interpret attributable risk, it is important to understand that attributable risk is associated with the following three major assumptions:

- ***Causality***, or that the stressor causes an increased probability of poor condition;
- ***Reversibility***, or that if the stressor is eliminated, causal effects will also be eliminated; and,
- ***Independence***, or that stressors are independent of each other, so that individual stressor effects can be estimated in isolation from other stressors.

These assumptions should be kept in mind when applying these results to management decisions. Attributable risk provides much needed insight into how to prioritize management for the improvement of our Nation's aquatic ecosystems – wetlands, in the case of the NWCA. While the results of attributable risk estimates are presented as percent area in poor condition that could be reduced if the effects of a particular stressor were eliminated, these estimates are meant to serve as general guidance as to what stressors are affecting condition and to what degree (relative to the other stressors evaluated).

9.4 Appropriate Use of Nonnative Plant Stressor Indicator (NPSI)

The Nonnative Plant Stressor Indicator (NPSI) is a biological descriptor of stress based on data collected as part of the Vegetation Protocol (see **Chapter 8, Section 8.5** for details). Estimates of the extent of wetland area with low, moderate, high, or very high stress levels for the NPSI were calculated using an approach that mirrors the extent estimates for other stress indicators (see **Section 9.2.2** and **Figure 9-3**). NPSI extent estimates are provided in USEPA (In Review). Relative and attributable risk associated with NPSI are ***not*** reported; this is because ***both*** the NPSI and the Vegetation Multimetric Index (VMMI) (see **Chapter 7**) used to determine wetland condition are based on the NWCA vegetation data. Because relative and attributable risk specifically relate stressors to condition, and both the NPSI and VMMI are based on related data (albeit, not the *same* data, see **Chapters 7 and 8** for details), it is not appropriate to include NPSI in reporting relative and attributable risk.

9.5 Where to Find the Summary of NWCA Results

All of the methods presented in Chapters 1 through 9 of this *NWCA Technical Report* are the scientific basis for what is reported in *National Wetland Condition Assessment 2011: A Collaborative Survey of the Nation's Wetlands* (USEPA *In Review*) and future peer-reviewed manuscripts. This report (USEPA, *In Review*) provides an overview of the important results from the 2011 NWCA. The presentation of results is geared toward the lay public, environmental managers, and government decision makers.

9.6 Literature Cited

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2011 National Wetland Condition Assessment

Research Features

Chapter 10: Microcystins

Chapter 11: Water Chemistry

Chapter 12: USA-Rapid Assessment Method (USA-RAM)

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Chapter 10: Research Feature – Microcystins

10.1 Background Information

Microcystins are one group of naturally occurring toxins produced by various cyanobacteria (blue-green algae) that are common to surface waters (Chorus and Bartram 1999). Microcystins have been detected nationally in lakes and reservoirs (Beaver et al. 2014; USEPA 2007) and are considered to be the most commonly occurring class of cyanobacteria toxins (cyanotoxins) (Chorus and Bartram 1999). Microcystin exposure risk is typically elevated when an overabundance of cyanobacteria occurs in surface water cyanobacteria harmful algal bloom (cyanoHABs). There is concern that changes in weather patterns, human population expansion, and associated behaviors are leading to perceived increases in occurrence and severity of cyanoHABs (Paerl and Scott 2010). Three main exposures scenarios are of potential concern regarding microcystins and wetlands: direct ecological impacts on plants and animals, human consumption of exposed organisms, and direct human exposure through recreational contact.

Adverse ecological impacts due to microcystin exposure on plants and animals have been summarized in several sources. Various adverse impacts of microcystins on cellular processes in a variety of aquatic and terrestrial plants resulting in diminished plant growth and accumulation of microcystins have been reported (Crush et al. 2008; Corbel et al. 2013; Romero-Oliva et al. 2014). Some macrophytes common to certain types of wetlands have shown sensitivity to microcystins also. Microcystins have been shown to inhibit the growth and oxygen production of some wetland macrophytes at concentrations of 1 µg/L or less (Rojo et al. 2013). Additionally, illness and mortality due to microcystin exposure has been reported in wildlife, livestock, companion animals and all trophic levels of freshwater, brackish and marine aquatic life. Animal illness and mortality has been reported in numerous cases including amphibians, cats, cattle, chickens, deer, dogs, frogs, horses, muskrat, sheep, turkey, and waterfowl, but the true number of cases remains unknown since many are not reported or observed (Chorus and Bartram 1999; Landsberg 2002; Briand et al. 2003; Handeland and Østensvik 2010; Vareli et al. 2013).

While Zhang et al. (2013) reported that mammals (especially humans) are more susceptible to microcystin poisoning compared to fish, it has been shown that humans should have some measure of caution for consumption of animals contaminated by microcystins (Ibelings and Chorus 2007; Poste et al. 2011). Papadimitriou et al. (2012) found measureable microcystins present in in all trophic levels of an aquatic ecosystem including phytoplankton, zooplankton, freshwater shrimp, crayfish, mussels, frogs, and fish when total microcystin water column concentrations ranged from non-detect up to approximately 20 µg/L for the study year between January and December. Microcystin concentrations were not found to bioaccumulate and tissue concentrations tended to decrease as trophic level increased, but concentrations were a function of exposure route and length of exposure. Higher water column microcystin concentrations did relate to higher tissue concentrations. Microcystin concentrations were typically greater in organs versus the more commonly eaten muscle tissues. Tissue concentrations did exceed the World Health Organization (WHO) suggested tolerable daily intake (TDI) value of 0.04 µg of microcystin/kg human body weight (Chorus and Bartram 1999; Papadimitriou et al. 2012). Boiling and microwave techniques were evaluated for preparation of different aquatic organisms contaminated by microcystins typically consumed by humans and found that microcystin concentrations in tissues can be reduced by 25 to 59% (Gutiérrez-Praena et al. 2013). However, microcystins have been shown to resist degradation at temperatures up to 300°C or after boiling for several hours, and studies have suggested that water used in boiling instead becomes contaminated with microcystins

(Wannemacher et al. 1989; van Apeldoorn et al. 2007; Gutiérrez-Praena et al. 2013). Other techniques such as frying, roasting, or grilling are yet to be evaluated to our knowledge.

Direct human toxicity by microcystin exposure is also of concern during recreation. Microcystins and associated cyanobacteria have been associated with adverse symptoms in humans ranging in severity from nausea, diarrhea, weakness, to liver and kidney failure, potentially cancer, and even death in severe cases (Chorus and Bartram 1999; Giannuzzi et al. 2011; Meneely and Elliott 2013). While there are currently (as of 2015) no known, documented human fatalities indicating microcystin exposure was the cause of death in the United States, fatalities have been observed in other countries on occasion (Chorus and Bartram 1999). Relative probability of adverse recreational health risks for humans due to microcystin exposure is frequently assessed based on WHO guidance thresholds (Chorus and Bartram 1999), for example:

- Low: < 10 µg/L
- Moderate: < 20 µg/L
- High: < 2000 µg/L
- Very High: > 2000 µg/L

Many US states have also developed their own guidance thresholds that are usually similar to WHO guidance (summarized in Graham et al. 2010; Chorus 2012).

10.2 Methods

Samples were collected for microcystin analysis from sites with standing water ≥ 15 cm and included a composited water and epiphyte sample following procedures outlined in the *2011 NWCA Field Operations Manual* (USEPA 2011). Samples were shipped overnight, frozen from the USEPA National Health and Environmental Effects Research Laboratory (NHEERL) in Corvallis, Oregon, to the US Geological Survey's Organic Geochemistry Research Laboratory in Lawrence, Kansas. Samples were lysed by three sequential freeze/thaw cycles and filtered with 0.45 micron HVLP syringe filters (Loftin et al. 2008; Graham et al. 2010). Samples were then analyzed by one of two methods depending on whether practical salinity units (PSU) were ≤ 3.5 PPT (part per thousand, Method 1) or > 3.5 PPT (Method 2). Samples were stored frozen prior to further extraction (Method 2) and analysis for microcystins by enzyme-linked immunosorbent assay (Abraxis ADDA kit, Warminster, PA) at -20°C.

10.2.1 *Method 1 (Salinity ≤ 3.5 PPT PSU)*

Lysed and filtered samples with salinity ≤ 3.5 PPT PSU were analyzed as previously reported by the Abraxis, LLC microcystins/nodularins ADDA enzyme-linked immunosorbent assay (ELISA) kit as described by Graham et al. (2010) and in National Lakes Assessment: A Collaborative Survey of the Nation's Lakes (USEPA 2009). No additional sample preparation was needed.

10.2.2 *Method 2 (Salinity > 3.5 PPT PSU)*

Lysed and filtered samples with salinity > 3.5 PPT PSU were further extracted to remove the elevated levels of salt and eliminate adverse performance effects on the Abraxis, LLC microcystins/nodularins ADDA enzyme-linked immunosorbent assay kit. False positives and enhanced recovery were observed if salt was not removed from samples when salinity was > 3.5 PSU. Samples with salinity above 3.5 PPT were extracted to remove salt prior to analysis according to procedures provided by Abraxis, LLC

(Warminster, PA, USA, Abraxis Bulletin R110211). Salinity was calculated based on specific conductance measured at 25°C and barometric pressure (Schemel et al. 2001). All samples were then analyzed by the Abraxis microcystins/nodularins ADDA ELISA (Graham et al. 2010).

Samples with salinity greater than 3.5 PPT PSU were extracted using the Abraxis Brackish water or Seawater sample preparation kit for microcystins (Abraxis Bulletin R110211). Extraction cartridges were assembled by placing approximately 5 mm of glass wool (Abraxis, LLC, Warminster, PA) into a 5 3/4" Pasteur pipette and loading with approximately 1.5 g of Seawater Sample Clean-up Resin (Abraxis, LLC, Warminster, PA). One mL of sample was pretreated with 50 µL of Microcystin-ADDA Seawater sample treatment solution (Abraxis, LLC, Warminster, PA). Sample was loaded onto seawater sample clean-up resin and allowed to drain by gravity through resin into a glass conical test tube. Remaining sample from the resin was evacuated using positive air displacement into the conical test tube. The resin retains the sample salt while allowing microcystins to pass through. Samples were stored frozen (-20°C) until analysis.

Minimum reporting level (MRL) for microcystins reported by Method 1 (≤ 3.5 PPT PSU) and Method 2 (> 3.5 PPT PSU) was 0.10 µg/L and 0.53 µg/L as microcystin-LR equivalents. Method performance was evaluated by the use of ELISA Microcystin-LR kit controls, laboratory sample replicates, laboratory sample spiked replicates, and blanks. Assay performance was deemed acceptable if values were within 28.3% relative standard deviation (RSD) which is equivalent to ± 20% of expected or average values. Microcystin concentrations were quantitated by a 4-parameter curve fit and high values above the upper calibration standard were diluted back onto the curve. Dilution corrected concentrations were reported in those cases.

10.3 Results

Microcystins were detected in 26% (N=591) of all samples with standing water with a maximum concentration of 21 µg/L. **Figure 10-1** shows national occurrence of microcystins in wetlands as a function of method used. Of the 591 sampling sites with standing water, 66% (n=391) had a salinity of ≤ 3.5 PPT PSU (microcystins measured by Method 1) and 34% (n=200) had a salinity greater than 3.5 PPT PSU (Microcystins measured by Method 2). Microcystins were detected more frequently in wetlands with salinity less than or equal to 3.5 PPT PSU (38%) where concentrations ranged from 0.10 to 13 µg/L. However, when microcystins were detected in the samples with salinity greater than 3.5 PPT (1.5% of sampled sites) the microcystin concentrations ranged from 3.7 to 21 µg/L. The majority of microcystin detections (22% of sampled sites) were 0.50 µg/L or less, but samples exceeded microcystin concentrations of 1.0 µg/L in 3.4% of samples. Microcystins were detected in 12% of assessed wetland area nationally. Within each NWCA reporting ecoregion, microcystins were detected in 9% of wetland area in the Coastal Plains, 10% of wetland area in the Eastern Mountains & Upper Midwest, 34% of wetland area in the Interior Plains, and 8% of wetland area in the West.

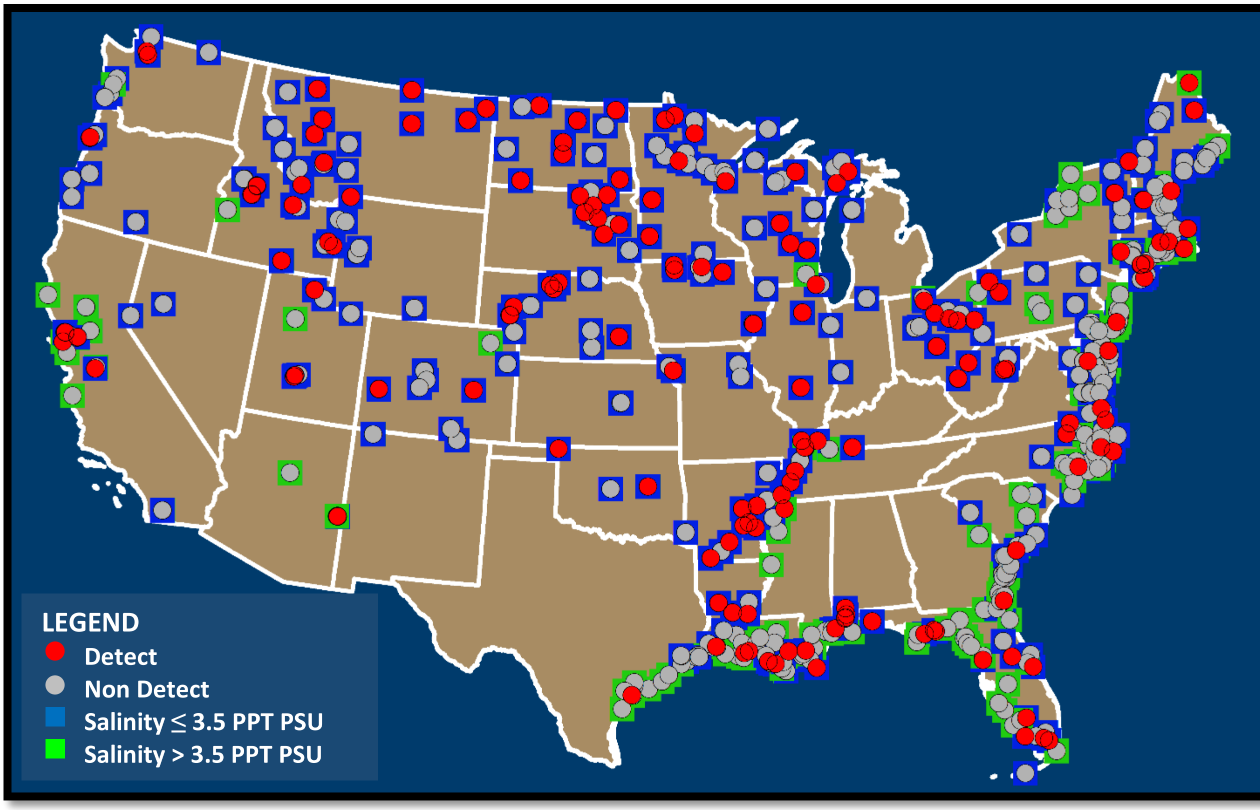

Figure 10-1. National Microcystin Occurrence for 2011 National Wetland Condition Assessment.

Samples from this study were categorized using the WHO guidance thresholds for recreational health risks of human exposure to microcystins. All samples were categorized as having low relative recreational risk with the exception of two. One sample from a site in the Coastal Plains was categorized as having moderate relative recreational risk (13 µg/L) and one sample from a site in the Eastern Mountains & Upper Midwest was categorized as having high relative recreational risk (21 µg/L). 38.9% of wetland area nationally had a low relative risk for recreational purposes, while 0.04% and 0.01% had moderate and high relative risks, respectively (**Figure 10-2**). 61.1% of wetland area nationally could not be assessed for microcystin presence because surface water was not present at the time of sampling.

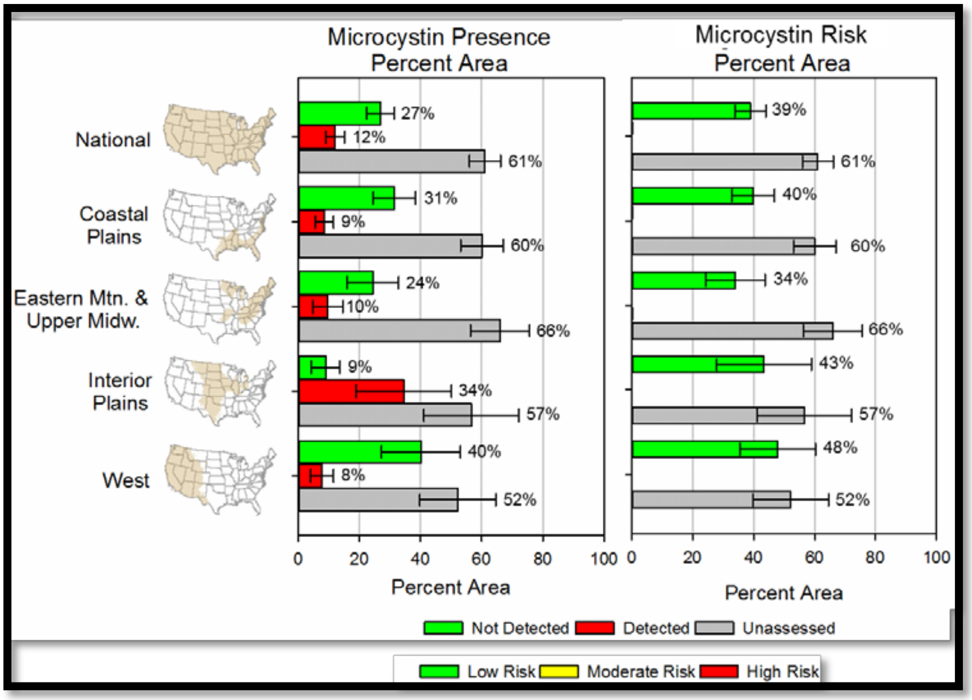

Figure 10-2. Percent of Wetland Acres as a Function of World Health Organization Relative Probability of Adverse Recreational Human Health Risks Based on Microcystin Concentration.

10.4 Discussion

In the first national survey of microcystins in wetlands of the United States, results from this study clearly identified microcystins were present in wetlands nationally. Microcystins were detected in 27% of the samples collected at sites with standing water ≥ 15 cm, representing 12% of wetland acres nationally. Wetland resources are used for a variety of human recreational activities, including hunting, trapping, fishing, and swimming with the extent of use related to opportunity and regional influences. Samples from most wetland sites were categorized as having low relative human recreational risk based on WHO guidelines for this study. Two sites had values exceeding the low WHO microcystin human recreational guideline of 10 µg/L and one site had a microcystin value that exceeded the moderate WHO threshold of 20 µg/L. The highest microcystin concentration of 21 µg/L occurred in a coastal wetland with a salinity of 27 PPT PSU. Microcystins were rarely detected above a salinity of 3.4 PPT PSU, but three of the six highest microcystin concentrations occurred in wetlands with salinities ranging from 11.1 to 38 PPT PSU. While limited information is available regarding the physical, chemical, and biological controls over cyanotoxin occurrence in wetland settings, there are well known adverse impacts of microcystins on some macrophytes common to wetlands. Microcystins exceeded 1.0 µg/L in 3.4% of samples; this microcystin concentration was shown by Rojo et al. (2013) to limit growth and photosynthetic oxygen production in some charophyte species. Additionally, seedling germination and macrophyte density were impeded in experiments with microcystin concentrations of 8 to 16 µg/L in sediments, where concentrations are more persistent relative to the water column (Rojo et al. 2013).

Concerns regarding microcystin concentration in tissues of wetland organisms consumed by humans cannot be directly evaluated from the results of this study. However, they cannot be summarily dismissed even with what may currently be believed to be lower level microcystin concentrations in many of the wetlands in this survey. The WHO developed a microcystin tolerable daily intake (TDI) value of 0.04 µg of microcystin-LR/kg body weight as the basis for recreational and consumption guidance regarding human microcystin exposure. Poste et al (2011) noted that a person weighing 60 kg and eating 100 g of fish daily would not want the edible portions of fish to exceed an available microcystin concentration of 24 µg/kg of fish on a wet weight basis. Several cases were summarized by Ibelings and Chorus (2007) indicating that there were multiple cases where edible portions of various fish, mussels, crayfish, and shrimp species have exceeded the WHO TDI. More work is needed to better relate ambient water column microcystin concentrations and exposure duration with potential food web accumulation, impacts of cooking, microcystin concentrations after consumption, and relationships tied to adverse human health impacts. Additional research is also needed to understand depuration rates for microcystin excretion and metabolism compared with water column concentrations which are currently used to provide risk assessment guidance to the public in many cases.

As this is the first survey of the ecologic condition of the Nation's wetlands, it is not clear yet how microcystin occurrence might change in time. Changing environmental conditions and anthropogenic influences exert pressures on complex ecosystems that are sometimes threatened by multiple stressors. Salinity and nutrients have frequently been considered as the two important variables regarding phytoplankton succession in wetlands when all other aspects are suitable for phytoplankton life (López-Flores 2014). Salinity is relevant to cyanobacteria, a form of phytoplankton, since some species are more tolerant of salt than others and is therefore relevant to what cyanotoxins can be produced. Coastal wetlands tend to have elevated salinity related to their degree of connectivity to the marine setting. Elevated salinity in inland wetlands is usually associated with natural processes (such as evaporation, drought, and geology), but there are also potential anthropogenic sources of salinity such as road salt, brine spills, and other human activities (López-Flores et al. 2014).

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Chapter 11: Research Feature – Water Chemistry

11.1 Background

Characterizing water chemistry is an integral part of the assessment of aquatic resources, because the physical and chemical properties of water directly reflect the geochemical setting and anthropogenic influences on water bodies. Water chemistry measures can provide context for understanding patterns of biological productivity and composition, can be sensitive indicators of ecological condition in and of themselves, can be used to infer potential stressors, and are important in determining the human use and enjoyment of aquatic ecosystems. Furthermore, having broad-scale, consistently measured water chemistry data can inform areas of management and regulatory concern such as the development of nutrient criteria. NARS surveys of lakes, streams, rivers, and coastal waters therefore have made a practice of allocating substantial resources to measuring water chemistry, and the water chemistry data play a major role in the resulting condition reports and related scientific analyses (e.g., Herlihy and Sifneos 2008; Herlihy et al. 2013).

Wetlands, however, differ from lakes, streams, and coastal waters in that standing water is not necessarily present and its makeup might be less reflective of broad watershed features because of the great variability among wetlands in hydrologic sources, hydroperiod, landscape connectivity, internal biogeochemical processing, and geomorphic setting (Carter 1986; Mitsch and Gosselink 2000). Water chemistry data have played a central role in assessments of wetlands in some parts of the US (e.g., Great Lakes coastal wetlands – Lougheed et al. 2007; Trebitz et al. 2009), but these reflect only a subset of the wetland types across the nation. This first ever NARS assessment of wetlands provides an opportunity to explore the value of water chemistry data in reporting on wetland resources nationwide. Compared to other NARS surveys, the suite of water chemistry parameters collected in the 2011 NWCA is relatively small, but the core measurements are consistent with other NARS surveys.

Objectives of the water chemistry data analyses presented here are to examine the extent to which water chemistry could be sampled across US wetlands, to evaluate the various measurement endpoints obtained (e.g., variability, repeatability, information content), to present broad patterns in water chemistry across the nation and relate them to possible classification variables and natural and anthropogenic drivers, and to generate recommendations concerning further research and protocols for future NWCA assessments.

11.2 Methods

11.2.1 Sample Collection and Laboratory Analysis

Water chemistry parameters measured or analyzed were chlorophyll-a (CHLA), conductivity (COND), ammonia (NH_3), nitrate and nitrite (NO_3 and NO_2, abbreviated as NO_x hereafter), total nitrogen (TN), total phosphorus (TP), and pH (PH). Water temperature and dissolved oxygen levels were also measured at some sites at the option of the states or regions involved; however because they were not consistently measured across all sites, these parameters are not included in the water chemistry analysis presented here. A quantitative measure of water clarity was not made, although water clarity was qualitatively assessed by noting on field sheets whether water appeared clear, turbid, stained, or milky.

Water samples were collected if surface water of sufficient depth to sink the pole-mounted dipper (~15 cm) was present within the assessment area. Water was dipped from the middle of the inundated area if possible and away from any inlets or outlets. Crews were requested to collect water samples prior to 11:00 am local time if possible, so as to reduce diurnal changes in water chemistry (e.g., due to metabolic activity of organisms in water). Dippers and bottles were rinsed with site water before filling and vegetation and surface debris was gently moved aside if needed. Enough water to fill a one-liter cubitainer to overflowing (i.e., without air being retained) was collected, and another up to 500 ml volume of water was filtered with a hand-held vacuum pump on site for later chlorophyll analysis (Whatman GF/F 0.7 um glass fiber filter). At approximately every tenth site, duplicate water samples were collected for quality assurance purposes (chlorophyll measures were not ordinarily duplicated). Cubitainers and chlorophyll filters were placed out of the sun and on ice as soon as possible, and later express-shipped to the analytical laboratory (generally arriving within 24 to 48 hours of collection).

The bulk of the samples (89%) were analyzed by the WRS laboratory (Willamette Research Station, in Corvallis OR), however four other laboratories each analyzed some samples:

- GLEC – Great Lakes Environmental Center in Traverse City MI
- ND – North Dakota Department of Health Laboratory Services, Bismark ND
- USGS – US Geological Survey Laboratory in Denver Colorado
- WI – Wisconsin State Laboratory of Hygiene in Madison WI

Briefly, analytical methods used by the WRS lab (and any differences in procedures at other labs) are as follows:

- ***CHLA***: Filters ground and extracted with acetone and then measured by fluorescence (WI lab sonicated samples prior to extraction instead); detection limit 0.5 at WRS lab and ranging from 1.4 to 20 at the ND lab (all samples above detection limits at other labs).

- ***NO_3 and NO_2 (NO_x)***: Determined via ion chromatography for freshwater samples but via cadmium reduction method on a flow injection analyzer for brackish samples (other labs ran all samples with the cadmium reduction method); detection limits 0.004 or 0.02 for the WRS lab (brackish and freshwater respectively), 0.001 mg/L for the GLEC lab, 0.02 for the USGS lab, 0.019 for the WI lab, and 0.03 for the ND lab.

- ***NH_3***: Determined colorimetrically; detection limits 0.004 mg/L for the WRS lab and 0.03 mg/L for the ND lab (all samples above detection limits at the other labs).

- ***TN and TP***: Determined colorimetrically following persulfate digestion; TP detection limits 4 µg/L for all laboratories, all samples above detection limits for TN.

- ***PH and COND***: Measured on an auto-titrater or manually with a YSI or similar meter, no samples below detection.

Results for NH_3 and NO_x are reported as the concentration of nitrogen (i.e., mg N/L, although hereafter abbreviated simply as mg/L).

11.2.2 Data Handling

In screening data for use in analyses, we rejected (i.e. set to missing) only measurements affected by sample loss (e.g., cracked test-tube) or errors in filtration (failure to record filtration volume or wrong filter medium for some CHLA samples, accidental filtration before analysis of some samples intended for TN and TP). We decided to accept for analyses samples with hold-time exceedance, minor deviations in laboratory procedures (e.g., extraction by soaking rather than grinding), or shipping-related issues (usually a generic "ship flag" indicating delay in transit, a few samples noted as arriving "warm"). There was also few samples (~15) for which laboratory data were simply missing for all analytes measured on the unfiltered sample (i.e., lab COND and pH, TN, TP) although present for analytes measured on the filtered sample (i.e., NH_3, NO_x). The rate of missing data due to rejection or the laboratory not providing a value was ~2% for CHLA, COND, NH_3, pH, TN, and TP but <0.2% for NO_x. A decision to reject all samples with shipping flags would have eliminated a large portion of the data (~30%).

Nitrogen samples were analyzed for TKN rather than TN at two labs (GLEC and WI) and the ND lab analyzed its samples for both TKN and TN. Since TN as computed from TKN + NO_x was perfectly correlated with measured TN for the 44 samples where both TN and TKN were run; we substituted the value of TKN + NO_x for samples where TN was not measured directly. Mass-based ratios of nitrogen to phosphorus were computed by dividing TN and TP (both expressed in microgram per liter units) by their respective atomic weights (i.e., N:P = (TN /14.0076)/(TP /30.9738)).

COND and PH were measured only in the field at some sites, only in the laboratory at others, and in both the lab and field for still others. Conductivity lab and field measurements were fully interchangeable (Pearson correlation = 0.99, slope essentially 1:1), despite a few outliers that may represent recording errors (**Figure 11-1**). On the premise that recording errors were more likely in the field than the lab, we merged lab- and field-measured COND into a single variable for analyses by retaining the lab value when available and the field value otherwise. For pH, the slope of lab vs. field measurements was again essentially 1:1 but the correlation was lower (r = 0.83) and there was a tendency for laboratory values to lie above field values at lower PH values versus below field values at higher pH values (**Figure 11-1**). Our interpretation is that pH is not entirely stable in sample containers but rather changes in ways consistent with exposure to atmosphere despite care being taken to exclude air. Nevertheless, the difference between field and lab-measured pH did not seem sufficient to warrant the complication of treating them separately in statistical analyses, so they were merged into a single pH variable by using the field measure when available (about 1/3 of the sites) but the lab measure otherwise.

We checked water chemistry data for suspicious values before proceeding to statistical analyses. All data points passed basic logic checks (e.g., within legitimate ranges for water in the environment, combined value of NH_3 and NO_x not exceeding the value for TN). There were a few distributional outliers but absent information to suggest the measurements were invalid our philosophy was to retain them. The only data point rejected as an outlier (i.e., replaced with a missing value) was one CHLA value of 2059 µg/L from a revisit at a site where CHLA at the first visit was only 16 µg/L. While this second visit data point was not the highest CHLA value in the dataset, its magnitude seemed excessive given the modest nutrient levels at this site, and its inclusion weakened the otherwise substantial correlation among Visit 1 and Visit 2 CHLA.

Analyte values that were below the reported laboratory detection limit (for NOx, NH3, TP, and CHL) were replaced with a value equal to half the detection limit prior to further analyses (Hornung & Reed 1990; USEPA 2006). Detection limits varied among laboratories and accordingly the value substituted for below-detection samples also varied.

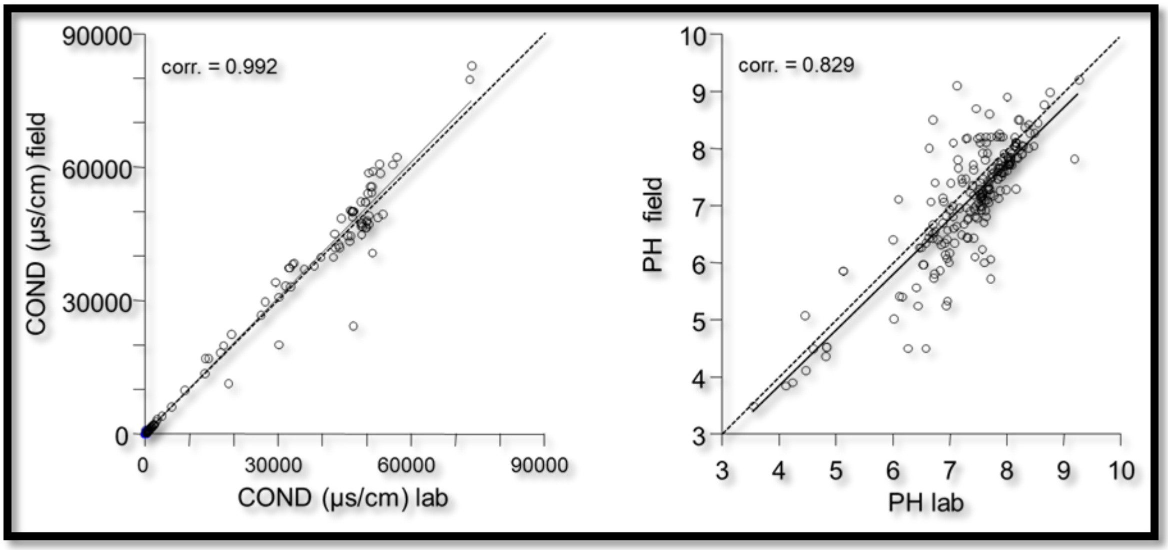

Figure 11-1. Relationship between laboratory and field measured COND (left) and PH (right) for the sites at which both lab and field measurements were made. The longer, dashed line in both plots is the 1:1 line; the shorter solid line is the linear regression.

11.2.1 *Graphical and Statistical Analysis*

The main data set analyzed for water chemistry combines sites selected based on the probability design with hand-picked sites (i.e., all sites sampled in 2011) but examines only data from the first site visit and the primary water chemistry sample. A duplicate water-quality sample was collected at every 10th site for QA purposes. Two secondary data sets are also analyzed: one comparing the primary to the duplicate water chemistry data from first-visit sites where duplicate samples were taken, and one comparing first-visit to second-visit primary water chemistry data from sites that received two independent sampling visits. All results concerning water chemistry patterns and conditions stem from analyses of this main data set; the secondary data sets are used only to evaluate temporal variability and repeatability.

Site classification variables used in the analyses included:

- four NWCA Aggregated Ecoregions (Coastal Plains, Eastern Mountains & Upper Midwest, Interior Plains, and West)
- estuarine wetlands
- NWCA Aggregated Wetland Types (woody or herbaceous)
- 10 NWCA Reporting Groups obtained by crossing geographic reporting units with vegetation type
- HGM categories (depression, flats, lacustrine fringe, riverine, slope, and tidal

The three sites where field crews had not assigned an HGM category were assigned based on a desktop review of Google Map imagery surrounding the sampling coordinates. Salinity status (freshwater or brackish) was also used as a classification variable; wetlands can be considered freshwater if <0.5 ppt salt and brackish otherwise (Cowardin et al. 1979). Since salinity was not measured directly in the NWCA, we used 833 µS/cm COND as the threshold between fresh and salt (an approximation assuming COND in µS/cm x 0.6 = salinity in ppm; precise conversion of conductivity to salinity depends on temperature, pressure, and component salts; Clesceri et al. 1998). The 16 sites at which conductivity was not measured were assumed to be freshwater based on location (all from the inland states of Arkansas or North Dakota).

A suite of potential anthropogenic stressor variables were used in the analyses. Landuse/landcover in concentric circles of various radii (200 m, 500 m, and 1 km) around the assessment area was summarized from the 2006 National Land Cover Database, road density data (km/sq km) based on 2010 TIGER road data obtained from the US National Park Service), and population density data (people/sq mi) compiled from 2010 US census data. Because water chemistry is generally considered a function of anthropogenic influences over an entire watershed, analyses focused on landuse/landcover, road density, and population density summarized for the largest, 1 km radius, circle. The NLCD category combinations used in computing percentage of the total area were: agriculture (pasture/hay + cultivated crops), developed (combining low, medium, and high-density development plus developed open-space), forested (combining deciduous, evergreen, and mixed), and wetland/water (combining open water and woody and emergent herbaceous wetland), as well as the percent impervious value that NLCD tallies separately from the other categories (i.e., the rest are additive while percent impervious is not).

Potential site disturbance was also classified using a buffer disturbance index (B1H_ALL) that is a proximity-weighted summary of potential stressors noted in thirteen buffer plots assessed by NWCA field crews(see **Chapter 4**, **Section 4.5**). Sites with a B1H_ALL score of zero were classified as undisturbed; sites with non-zero B1H_ALL scores were classified as “least disturbed”, “intermediate disturbed”, or “most disturbed” based on the distribution of values within their NWCA Reporting Group (i.e., thresholds for disturbance categories differed among ecoregions and wetland types).

Analyses comparing primary vs. duplicate samples and Visit 1 versus Visit 2 values for each water chemistry analyte are based primarily on Pearson correlations (for actual water chemistry values) or spearman rank correlations (to examine relative values). Diagnostics considered include magnitude of the correlation and degree to which the correlation line corresponds to the 1:1 line (assessed graphically). We examined whether the time lag between Visit 1 and Visit 2 had any systematic effect on water chemistry by using the number of weeks elapsed as a plotting symbol in correlation plots and looking for whether the magnitude of departure from the 1:1 correlation line depended on weeks elapsed.

Analyses of patterns in primary sample water chemistry data used correlation and regression analyses for assessing relationship among analytes and to anthropogenic stressor variables. Given the large sample size even relatively small magnitude correlations can be significant with this dataset, so analyses focused on relationship magnitude rather than p-value. Differences in water chemistry among site classification variables were assessed with box plots and ANOVA. Following methods used in other NARS assessments, assignment of sites into good, fair, or poor categories for various water chemistry analytes were attempted using the 75th percentile and the 90th percentile of sites classified as least-disturbed (i.e., the undisturbed and low disturbance sites) as thresholds between good and fair, and fair and poor, respectively.

Ranges for COND, CHLA, NH_3, NO_x, TN, and TP were large enough (several orders of magnitude) to warrant log transformation. Accordingly, correlation and regression analyses presented for these parameters are based on log10-transformed units, and graphical analyses use log10-transformed axes. Data medians, min/max values, and percentiles (which are invariant to log-transformation) are however presented in untransformed units for greater interpretability. Because of using ½ the detection limit as a minimum value, there were no zero values for any of these analytes meaning that log-10 transformation did not result in any undefined (and therefore missing) values.

For all of the primary data-set analyses that examined relationships by the NWCA Reporting Group or NWCA Ecoregion Group, sites that were not classified as an Estuarine wetland yet had COND > 3000 µS/cm were omitted. These sites have water chemistry that appeared unusual for their reporting group and would skew results were they included in group analysis (not only COND but also higher nutrients and CHLA). These sites are however included in any overall description of the water chemistry data (overall means and ranges, correlations among analytes).

11.3 Results

11.3.1 *Data Set Overview*

A total of 631 of the 1138 sites sampled yielded water chemistry data on the primary visit, with 51 (of the 96 sites that were revisited) also having water chemistry data collected at a second visit. Water chemistry data were collected from at least one wetland in all conterminous US states except Kansas (Alaska and Hawaii were outside the scope of the NWCA). Sample sizes for the primary analysis data set (i.e., excluding samples from second visits and QA duplicates) ranged from 615 to 630 depending on the analyte. The distribution of wetland water chemistry samples across the five water chemistry reporting units (the four NWCA Aggregated Ecoregions plus a separate reporting unit representing Estuarine wetlands) and six HGM categories is given in **Table 11-1**.

Table 11-1. Statistics concerning frequency with which water samples were or were not obtained across various NWCA reporting units. Percent of sites without water samples is also broken out by herbaceous and woody type wetlands within the estuarine and geographically-based reporting units.

Reporting unit	# with water sample	# without water sample	% without water sample overall	% without water sample herbaceous	% without water sample woody
All sites	631	507	44.5	33.6	58.1
Estuarine	220	167	43.1	31.9	52.8
Coastal Plains	94	125	57.0	56.3	66.8
Eastern Mountains & Upper Midwest	111	89	44.5	28.8	53.5
Interior Plains	116	74	38.9	29.7	63.5
West	90	52	36.6	30.7	43.2
HGM type					
Depressional	170	113	39.9	--	--
Flats	54	132	71.0	--	--
Lacustrine fringe	28	21	42.9	--	--
Riverine	143	126	46.8	--	--
Slope	26	20	43.5	--	--
Tidal	207	92	30.8	--	--

The NWCA expected that water would be collected at only a subset of all sites because wetlands do not always have standing water. Reasons water chemistry was not obtained from the remaining 507 sites were:

- ***411 sites***: no standing water
- ***94 sites***: standing water in the assessment area was not deep enough to meet the sampling criteria (at least 15 cm deep)
- ***2 sites***: lost samples

The inability to collect a water sample occurred more than 30% of the time in all wetland type and geographic reporting unit combinations. Surprisingly, given the generally more arid climate in the western US compare to the east, the inability to collect a water sample was lowest in the West reporting unit and highest in the Coastal Plains reporting unit (**Table 11-1**). Lack of water or of sufficient water was substantially higher in woody than herbaceous wetlands (58 versus 34 percent overall). This pattern was found in all NWCA Aggregated Ecoregions and Estuarine wetlands. The inability to collect water was highest in the flats HGM type at 71% and lowest in the tidal HGM type at 31% with the depressional, lacustrine fringe, slope, and riverine HGM types intermediate.

The ability to collect a water sample was not generally related to day of year the wetland was sampled, even though sampling extended from April through October and we might have expected wetlands to be generally drier later in the year. This held true within the NWCA Aggregated Ecoregions as well.

Whether a water sample could be collected or not did not appear to be related to wetland condition as measured by the buffer disturbance index, as lack of water or of sufficient water differed little among disturbance categories. Hydrologic alteration is well documented as a major source of wetland disturbance and was frequently noted in the field assessment data sheets. However hydrologic disturbances that tend to increase surface water availability (e.g., impoundment) may balance out hydrologic disturbances that tend to decrease surface water availability.

11.3.2 *Repeatability of Water Chemistry Data*

By design, approximately 10% of the NWCA sites were revisited within the 2011 effort (i.e., sampled at two different points in time), and also approximately 10% of the sites had a duplicate water sample taken during the site visit (i.e., side-by-side samples from same point in time).

Duplicate water chemistry samples were collected on 99 site visits (89 from Visit 1, 10 from Visit 2) and were well-spread geographically with duplicates collected in 42 states (Correlations among primary and duplicate samples were extremely high for all analytes (r = 0.99 for COND, NH_3, NOx, PH-LAB, PH-FIELD, TN, TP). CHLA collection and analyses were duplicated at only 4 sites but here also the correlation was 0.99 (crews were not instructed to duplicate CHLA collection but one crew did so). These results indicate that variability due to sample collection, handling, or analytical procedures is negligible. Duplicate samples were always collected from a single location in the wetland; accordingly these results do not speak to spatial variability in water chemistry within wetlands.

Forty-eight sites have water chemistry data from two points in time as part of the revisit effort. The number of days between visits ranged from 10 to 133 (mean of 37 days). We coded points in the plots by the number of weeks elapsed between visits but there was no obvious tendency for larger water chemistry differences to be associated with longer elapsed times (**Figure 11-2**). The water chemistry analytes fall into two groups with regard to temporal stability, with the heavily biologically influenced analytes (NH_3, NO_x, and CHLA) being less stable than the less biologically influenced analytes (COND, pH, TN, TP). OND, TN, TP, and pH all had between-visit Pearson correlations >0.8 and regression-line slopes close to 1:1 indicating little change between visits. In contrast, NH_3, NO_x, and CHLA have substantially lower between-visit correlations and line slopes substantially flatter than 1:1 (i.e., typically lower values at Visit 2 than Visit 1; **Figure 11-2**). Spearman correlations among Visit 1 and 2 were very similar to the Pearson correlations (COND = 0.99, TN = 0.82, TP = 0.88, pH = 0.89, NH_3 = 0.53, NO_x = 0.47, CHLA = 0.64), indicating that wetland rank order varied by an amount similar to the water chemistry values themselves. Stability of wetland rank order is of interest because percentiles of the site distribution (which depend only on rank order) are commonly used to bin sites into condition categories with respect to some measurement variable.

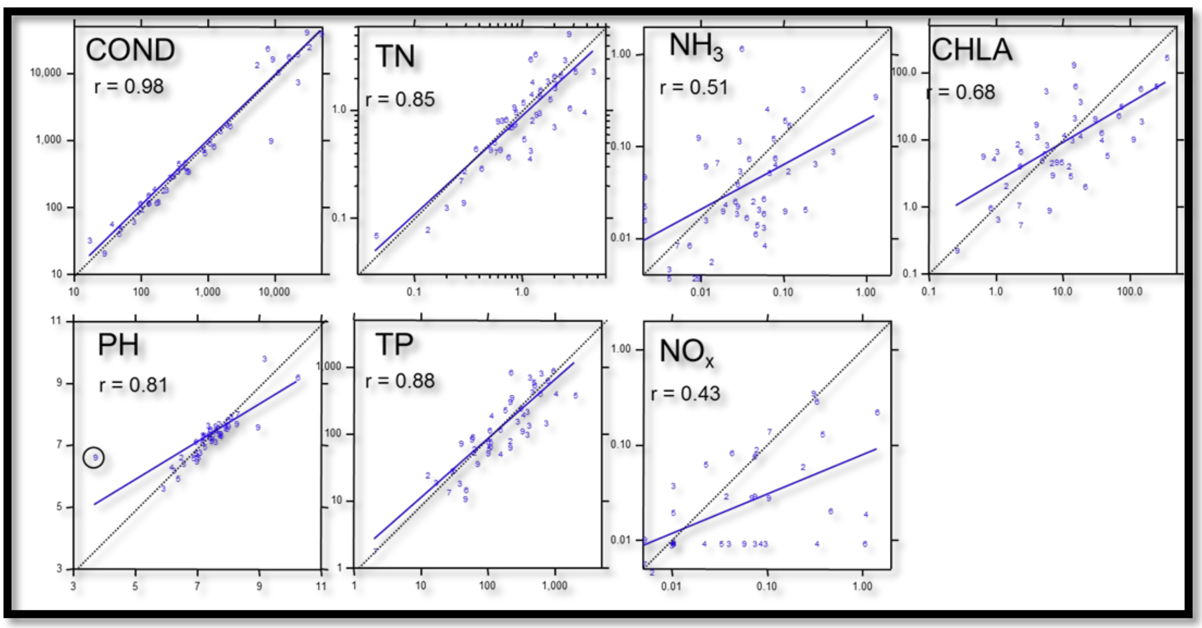

Figure 11-2. Bi-plots of water chemistry values as measured at Visit 1 (x-axis) vs. Visit 2 (y-axis). Long dashed lines are 1:1 lines , shorter solid lines are linear regressions, and the plotted symbol show the number of weeks elapsed between sample 1 and sample 2 (all values greater than 9 weeks are coded as "9"). The pH slope is ~ 1:1 after removal of the circled outlier.

11.3.3 *Broad Patterns in Water Chemistry*

The range in water chemistry across the 2011 NWCA dataset was quite large. Across all sites, pH ranged from quite acidic to alkaline (3.3 to 10.2), and conductivity ranged from 10 uS/cm to exceeding 73000 uS/cm (**Table 11-2**). The "flats" HGM type accounted for the largest proportion of the sites with pH<5 (as would be expected since peat bogs fall into this HGM category), however there were some sites with pH<5 from every HGM category except slope. The vast majority of sites with brackish conductivity (>833 uS/cm) were of the tidal HGM type, but there were at least one site with COND values well above this brackish threshold in every HGM category.

Table 11-2. Median and range (in parentheses) for water chemistry analytes across the data set as a whole and for geographic reporting unit and wetland type subdivisions. Number of sites is given in parentheses after each reporting unit (sample size for some analytes is slightly lower due to missing values). "BD" denotes values below the most frequently applicable laboratory detection limit for CHLA (0.5 µg/L), NH_3 (0.004 mg/L), NO_x (0.02 mg/L), and TP (4.0 µg/L). Note that some COND values seem inappropriate for their site type (e.g., <1000 in estuarine/tidal; >10,000 in non-estuarine/non-tidal) but statistics reported here are for all sites regardless of COND values.

Reporting unit	COND (µS/cm)	PH	CHLA (µg/L)	NH_3 (mg/L)	NO_x (mg/L)	TN (µg/L)	TP (µg/L)
All sites (N=631)	572 (10-73660)	7.19 (3.3-10.2)	7.5 (BD-2117)	0.03 (BD- 4.7)	BD (BD-7.8)	1080 (43-700500)	121 (BD-11510)
Estuarine (N=220)	28785 (60- 73660)	7.6 (3.5-9.5)	12 (1-1505)	0.09 (BD-2.33)	BD (BD-7.8)	944 (98-23075)	122 (BD-2481)
CPL (N=94)	200 (32-10840)	6.7 (3.3-9.3)	10.5 (BD-49)	0.04 (BD-3.7)	BD (BD-1.5)	1428 (151-18813)	132 (7-3140)
EMU (N=111)	93 (11-1133)	6.7 (3.8-8.9)	3.3 (2-183)	0.02 (BD-0.9)	BD (BD-0.8)	772 (118-35900)	44 (BD-3325)
IPL (N=116)	558 (39-3822)	7.6 (5.7-9.1)	9.5 (BD-2117)	0.04 (BD-4.7)	BD (BD-1.0)	1985 (309-70050)	357 (18-11510)
W (N=90)	184 (11-21670)	7.4 (3.6-10.2)	3.0 (BD-1030)	0.01 (0.01-1.0)	BD (BD-0.9)	421 (43-9313)	93 (7-3612)
<u>HGM</u> depressional (N=171)	339 (11-21670)	7.2 (3.6-10.2)	6.4 (BD-2117)	0.03 (BD-4.7)	BD (BD-0.8)	1703 (70-70050)	226 (BD-11510)
flats (N=54)	201 (17-40480)	6.9 (3.8-8.5)	6.4 (BD-633)	0.02 (BD-1.4)	BD (BD-1.0)	1309 (205-12700)	64 (BD – 1782)
lacustrine fringe (N=28)	292 (23-3713)	7.3 (3.8 – 8.4)	10.8 (1.5-309)	0.3 (0.005-0.8)	BD (BD-0.2)	2145 (155-19675)	196 (BD-5485)
riverine (N=131)	204 (16-18340)	7.2 (3.3-8.8)	3.8 (BD-239)	0.3 (BD-3.7)	BD (BD-1.5)	806 (43-35900)	91 (6-7364)
slope (N=26)	116 (18-3822)	7.4 (5.6-8.7)	2.9 (BD-177)	0.01 (BD-0.6)	BD (BD-0.9)	394 (78-5131)	87 (10-1272)
tidal (N=207)	29450 (60-73660)	7.6 (3.5-9.5)	11 (BD-1505)	0.02 (BD-2.3)	BD (BD-7.8)	933 (98-23075)	121 (BD-2481)

There were some Estuarine wetland sites with COND values more characteristic of freshwater, as well as some Non-Estuarine wetland sites whose conductivity fell into ranges more characteristic of the brackish group. Inspection of the physical location of sites within the estuarine reporting group with COND values typical of freshwater systems showed all of them to be located close to a substantial size river. Inspection of the physical location of the Non-Estuarine sites with COND values typical of brackish systems showed that many (notably all with COND>3000 uS/cm) were located in close proximity to an ocean and might therefore be receiving a marine influence; the COND measure may be indicative of a stressor influencing those sites. Brackish sites in landlocked states such as North Dakota and South Dakota had maximum COND of only ~ 1200 µS/cm (Figure 11-3).

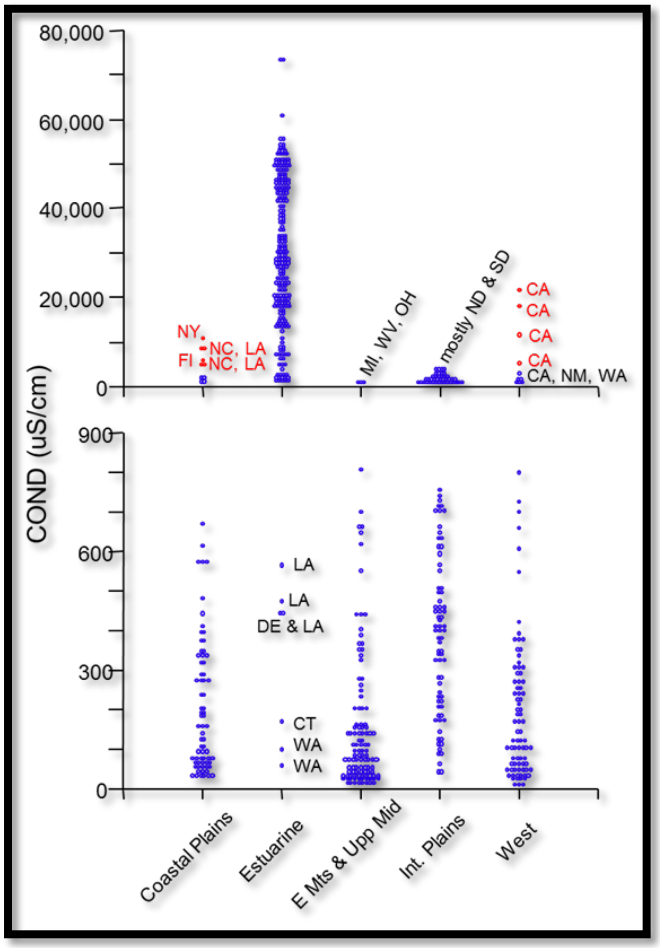

Figure 11-3. Dot plots showing distribution of COND by geographic reporting unit, with bottom panel showing sites classified as fresh-water (COND<833) and top panel showing brackish sites (COND>833) – note difference in scales between the two. Sites with unusual COND for their ecoregion are labeled with the US state (2-letter code) in which they are found. The 10 sites excluded from analyses examining ecoregion and NWCA Reporting Groups are indicated with red symbols and text.

Examining relationships of conductivity to anthropogenic setting is of interest for the NWCA. Conductivity measurements that are significantly higher or lower than what is typical for certain wetland systems may be a sign of anthropogenic influence. Some sites with very high COND in non-estuarine geographically-based reporting units also had elevated levels of other water chemistry analytes, which would potentially skew results when examining water chemistry by reporting unit. Excluding sites having COND>3000 (highlighted in red in **Figure 11-3**) caused maximum values in West-herbaceous sites (W-PRLH) to fall from 9313 to 4508 ug/L for TN; maximum values in Coastal Plains-woody sites (CPL-PRLW) to fall from 5888 to 4683 µg/L TN and from 327.2 to 239.5 µg/L CHLA; and maximum values in Coastal Plains-herbaceous sites (CPL-PRLH) to fall from 19913 to 5938 µg/L TN, from 3140 to 1314 µg/L TP, and from 463.2 to 206.7 µg/L TP. Given their unusual COND and their effect of the distribution of other analytes, these 10 non-estuarine sites with COND>3000 are excluded from all analyses below that are specific to geographic reporting units or NWCA Reporting Group, although the sites are included in other analyses (e.g., across all sites or by HGM type).

Across all sites, there was a 4+ order-of-magnitude range in nutrients and CHLA concentrations, and at least a 3 order-of-magnitude range in these within any one geographically-based reporting units or HGM category (**Table 11-2**, **Figure 11-4**). Given these large ranges, log10 transformations of these variables (or logarithmic intervals on the plot scales) are used in presenting all analyses. Log10 TN and TP were strongly correlated (Pearson r=0.78) and log10 CHLA was correlated to both (Pearson r=0.63 for TN and 0.65 for TP; **Figure 11-5**). Log10 NH_3 was also fairly well correlated with log10 TN (r=0.62); however the correlation of log10 NO_x to TN was weak (only r=0.38), possibly because of the high level of below-detect values for NO_x. No samples were below detection for TN, but 0.5% of samples were below the detection limit for TP (4 µg/L), 6% were below the detection limit for CHLA (which varied among samples), 12% were below detection limits for NH_3 (0.004 to 0.03 mg/L, depending on lab), and 54% were below detection limits for NO_x (0.001 to 0.03 mg/L, depending on lab). The high percentage of below-detection values for NO_x and NH_3 combined with their greater temporal variability (**Figure 11-2**) makes these analytes seem less useful for classifying and comparing sites; accordingly further analyses focused on TN rather than on NO_x and NH_3.

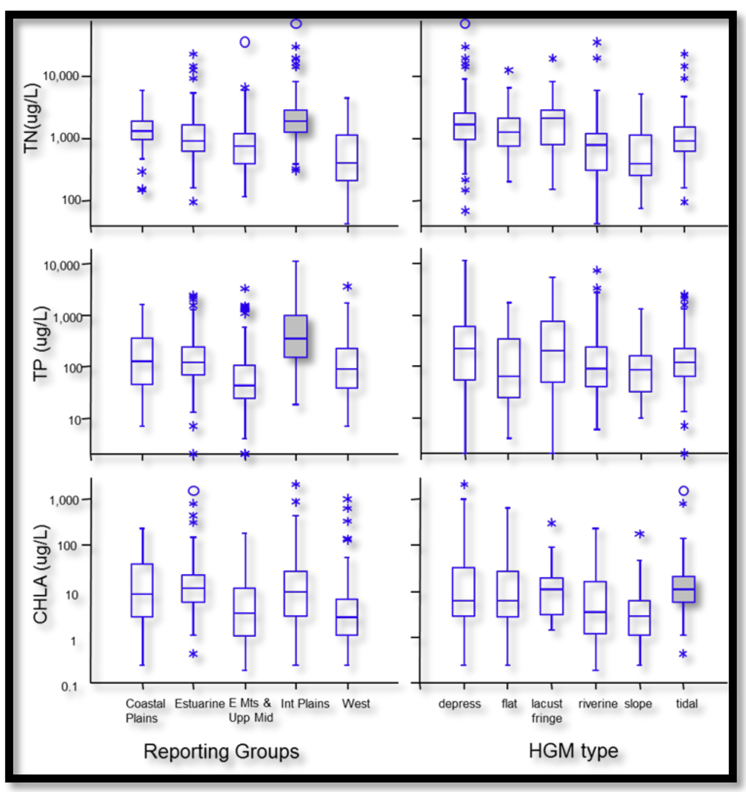

Figure 11-4. Box plots showing distribution of TN, TP, and CHLA by geographic reporting unit (left-hand panels) and by HGM type (right-hand panels). Note log-scale on vertical axes. Nutrient levels are higher in Interior Plains wetlands than all others and CHLA levels are higher in tidal wetlands than others (shaded boxes), but differences among other categories are not strong. Plots by geographic reporting unit exclude 10 sites with unusual conductivity.

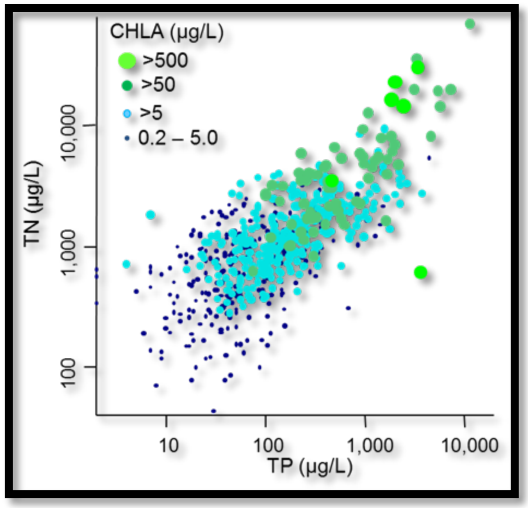

Figure 11-5. Scatterplot showing relationship among TN, TP, and CHLA for all sites. The correlation (in log10 transformed units) of TN to TP is 0.78, and that of CHLA to TN and TP is 0.63 and 0.65 respectively.

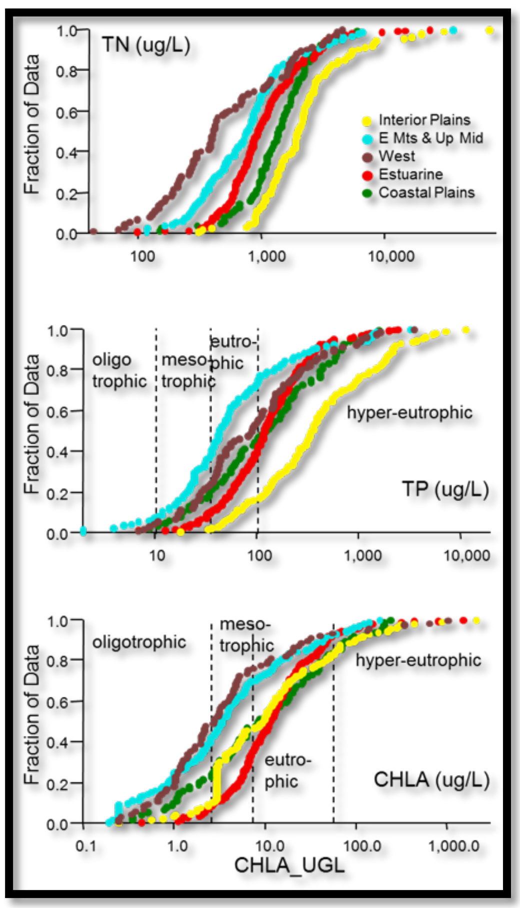

Figure 11-6. Plots showing TP and TN data distribution by geographic reporting unit. Plots for TP and CHLA include vertical lines show divisions between trophic state categories commonly used in classifying lakes (divisions at 10, 35 and 100 ug/L TP and 2.6, 7.3, and 56 ug/L CHLA). Plots exclude 10 sites with unusual conductivity.

Ranges of nutrient and CHLA levels broadly overlapped among the reporting units (**Figure 11-4**), yet data distribution graphs revealed some consistent differences. Distributions of TN and TP in Interior Plains wetlands were shifted towards higher values relative to the other 4 geographically-based reporting units, however CHLA distributions in Interior Plains wetlands were similar to the distributions in Estuarine and Coastal Plains wetlands (**Figure 11-6**). Eastern Mountains & Upper Midwest wetlands had somewhat lower TP values and wetlands in the West had lower TN values than the other reporting units, whereas CHLA levels were lowest in Eastern Mountains & Upper Midwest and West wetlands (**Figure 11-6**). Wetlands are inherently fairly productive environments so it is not surprising that a large proportion of the sites had phosphorus values that in lakes would be indicative of eutrophic or hyper-eutrophic conditions; nevertheless some sites in the Eastern Mountains & Upper Midwest, West, and Coastal Plains geographical reporting units had TP levels associated with an oligotrophic state in lakes and a substantial percentage had mesotrophic TP levels (middle panel, **Figure 11-6**). A far larger percentage of sites in each of the geographically-based reporting units have CHLA levels associated with oligotrophic or mesotrophic conditions in lakes (bottom panel, **Figure 11-6**) than would be expected from the TP levels, suggesting that wetlands do not necessarily channel nutrient-fueled productivity to plankton algae. Levels of pH, TN, TP, and CHLA were typically higher in herbaceous than woody wetlands (**Figure 11-7**).

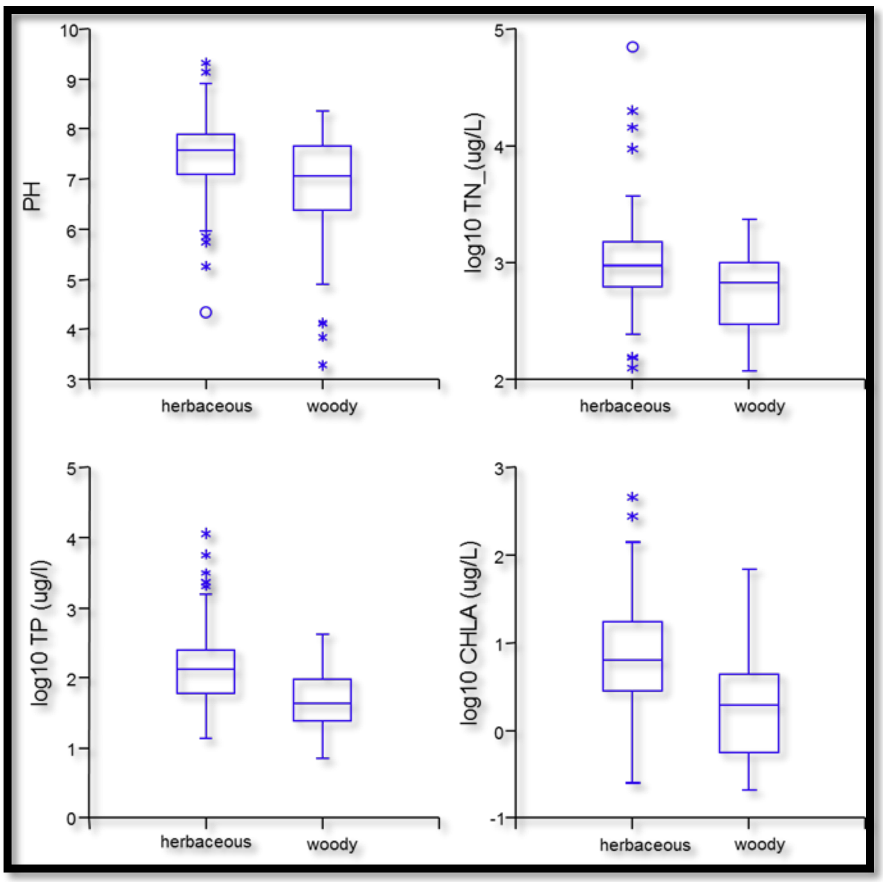

Figure 11-7. Box plot showing difference in pH, TN, TP, and CHLA between wetlands classified as having woody or herbaceous type vegetation.

Ratios of TN to TP (N:P ratios, hereafter) varied from a low of 0.4 to a high of 713, and spanned the range from presumably N-limited (i.e., below Redfield ratio of N:P=16) to presumably P-limited (well above N:P=16) in almost all geographical reporting units and HGM types (**Figure 11-8**). Accordingly, no single type of nutrient limitation can be inferred from across this broad suite of wetlands, although such patterns may be present on a finer spatial scale (e.g., Bedford et al. 1999). N:P ratios were typically lower (i.e., more N-limited) in wetlands with herbaceous than those with woody-vegetation (**Figure 11-8**). This may be because of nitrogen fixation by some plants characteristic of woody wetlands (e.g., alder; Hurd et al. 2001).

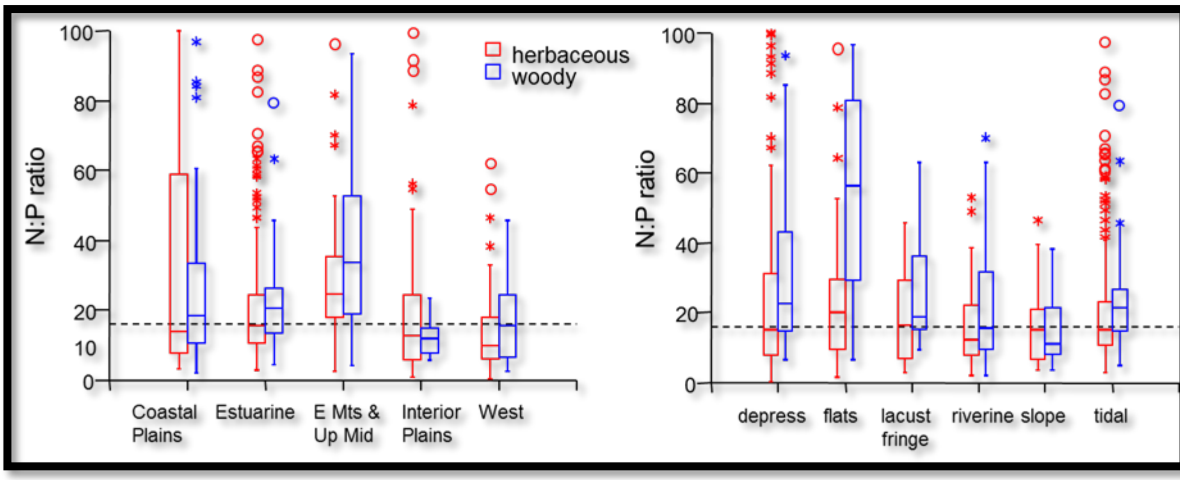

Figure 11-8. Box plots showing N:P ratios by geographic reporting unit (right) and HGM type (left). Boxes do not represent the full data distribution, as sites with N:P ratio > 100 have been excluded to focus on the region where the presumptive limiting nutrient switches from nitrogen (below 16) to phosphorus (above16; horizontal line). Herbaceous wetlands tend to have lower N:P ratios than woody-vegetation wetland, but wetlands in almost all geographic reporting units and HGM types span the range from N-limited to P-limited. Plots by geographic reporting unit exclude 10 sites with unusual conductivity.

The field-assigned water clarity categories (“clear”, “milky”, “turbid”, or “stained”) had no obvious relationship to any of the laboratory water chemistry analytes. We had expected such relationships because numerical measures of water clarity such as turbidity and secchi depth are consistently related to nutrients and planktonic chlorophyll in other water body types, and low pH wetlands are expected to have water stained with humic substances (i.e., tea-colored). We suspect the lack of relationship is because the categories did not adequately capture the water clarity and color gradients actually present.

11.3.4 *Relationships of Water Chemistry to Anthropogenic Setting*

Relationships of water chemistry to potential measures of anthropogenic stress focused on COND, TN, TP, and CHLA (all log-10 transformed) and on potential predictor variables B1H_ALL (the field-checklist based stressor summary over a 100 m buffer zone), and on population density, road density, and percentages of various NLCD 2006-based categories in the 1000 m area around the sample point. Correlation matrices arising from these analyses are presented in **Table 11-3** through **Table 11-6** (one table per analyte), while the major correlation patterns are depicted in **Figure 11-9**. Correlations having magnitude >0.30 are used as a threshold in describing presence of a relationship.

Table 11-3. Correlation matrix for log-10 conductivity vs. anthropogenic stressor variables for various wetland groups ("H" vs. "W" refer to herbaceous and woody in the geographic reporting unit x vegetation type combinations). Correlation coefficients (positive or negative) with magnitude >0.3 are in bold underline. Stressor variable B1H_all is over the 100 m buffer assessed by the field crew, all other stressor variables are over a 1000 m radius circle. The non-estuarine groups omit sites having conductivity suggestive of marine influence.

log10 COND	B1H_ALL	agric (%)	devel (%)	forest (%)	wetl. + water (%)	pop. dens (#/mi^2)	road dens (km/km^2)	imper-vious (%)
All sites	-0.22	-0.19	0.04	**-0.59**	**0.66**	0.17	0.02	0.07
Estuarine	-0.17	-0.11	0.04	-0.01	0.03	0.10	0.04	0.07
Non-estuarine	0.18	**0.40**	0.08	**-0.61**	0.09	0.03	0.12	0.03
Estuarine H	-0.17	-0.22	0.05	0.03	-0.02	0.10	0.07	0.07
Estuarine W	-0.14	0.02	-0.04	-0.29	**0.31**	0.12	-0.18	0.05
Coastal Plains H	0.08	-0.01	0.26	**-0.48**	0.12	0.25	0.01	0.24
Coastal Plains W	0.01	-0.06	0.12	**-0.37**	**0.30**	0.06	0.23	0.20
E Mts&Upp Mid	0.27	**0.47**	**0.45**	**-0.52**	0.03	**0.36**	**0.53**	0.22
E Mts&Upp Mid	0.25	**0.41**	**0.30**	**-0.47**	0.07	**0.30**	**0.38**	0.27
Interior Plains H	0.01	0.06	-0.04	-0.14	0.04	0.03	0.08	-0.04
Interior Plains W	0.22	-0.18	0.15	**-0.48**	-0.12	-0.46	0.09	0.08
West H	0.24	**0.30**	-0.08	**-0.54**	0.23	-0.18	0.28	-0.07
West W	0.24	0.27	0.15	**-0.52**	0.17	0.21	0.23	0.15

Table 11-4. Correlation matrix for log-10 TN vs. anthropogenic stressor variables for various wetland groups ("H" vs. "W" refer to herbaceous and woody in the geographic x vegetation type combinations). Correlation coefficients (positive or negative) with magnitude >0.3 are in bold underline; those of this magnitude but not in the expected direction (positive or negative) are additionally in brackets. Stressor variable B1H_all is over the 100 m buffer assessed by the field crew, all other stressor variables are over a 1000 m radius circle. The non-estuarine groups omit sites having conductivity suggestive of marine influence.

log10 TN	B1H_ALL	agric (%)	devel (%)	forest (%)	wetl+ water (%)	pop. dens (#/mi^2)	road dens (km/km^2)	imper-vious (%)
All sites	-0.02	**0.30**	0.02	**-0.43**	0.13	0.02	0.00	0.00
Estuarine	-0.15	0.20	-0.07	-0.12	0.08	-0.05	-0.06	-0.06
Non estuarine	0.01	**0.38**	0.05	**-0.54**	0.20	0.05	0.00	0.03
Estuarine H	-0.24	-0.01	0.01	-0.14	0.13	0.02	0.01	0.05
Estuarine W	0.25	**0.51**	-0.29	-0.07	-0.06	**[-0.31]**	-0.26	**[-0.30]**
Coastal Plains H	0.22	0.26	0.03	-0.20	-0.16	0.05	0.01	0.08
Coastal Plains W	0.06	0.19	0.01	**-0.37**	0.13	-0.00	-0.06	0.06
E Mts&Upp Mid	-0.03	0.28	**0.33**	**-0.30**	-0.10	**0.31**	**0.40**	0.09
E Mts&Upp Mid	0.06	0.24	0.22	**-0.67**	**0.50**	**0.30**	0.09	0.23
Interior Plains H	0.02	0.07	-0.00	0.19	-0.08	0.01	-0.05	0.08
Interior Plains W	**[-0.34]**	-0.19	0.27	-0.07	**0.30**	0.12	-0.10	**0.40**
West H	0.12	0.18	-0.04	**-0.38**	0.11	-0.09	0.28	-0.01
West W	0.21	**0.32**	-0.08	-0.25	0.11	0.26	0.25	-0.11

Table 11-5. Correlation matrix for log-10 TP vs. anthropogenic stressor variables for various wetland groups ("H" vs. "W" refer to herbaceous and woody in the geographic x vegetation type combinations). Correlation coefficients (positive or negative) with magnitude >0.3 are in bold underline; those of this magnitude but not in the expected direction (positive or negative) are additionally in brackets. Stressor variable B1H_all is over the 100 m buffer assessed by the field crew, all other stressor variables are over a 1000 m radius circle. The non-estuarine groups omit sites having conductivity suggestive of marine influence.

log10 TP	B1H_ALL	agric (%)	devel (%)	forest (%)	wetl+ water (%)	pop. dens (#/mi²)	road dens (km/km²)	imper-vious (%)
All sites	0.10	0.37	-0.00	**-0.36**	-0.01	-0.02	0.01	-0.01
Estuarine	-0.06	0.20	-0.10	0.02	-0.06	-0.03	-0.05	-0.10
Non estuarine	0.13	**0.43**	0.04	**-0.46**	0.01	-0.01	0.03	0.02
Estuarine H	-0.12	0.07	0.00	0.01	-0.05	0.04	0.04	0.02
Estuarine W	0.23	**0.41**	**[-0.30]**	0.07	-0.18	-0.19	-0.26	-0.27
Coastal Plains H	0.27	**0.47**	-0.07	**[0.37]**	**-0.45**	-0.11	0.05	-0.09
Coastal Plain W	0.22	0.21	-0.12	-0.19	0.05	-0.16	-0.24	-0.10
E Mts&Upp Mid	0.05	0.28	**0.33**	**-0.30**	-0.10	**0.31**	**0.40**	0.20
E Mts&Upp Mid	0.08	**0.33**	0.16	**-0.54**	**0.30**	0.20	0.12	0.15
Interior Plains H	0.07	0.16	0.05	0.08	-0.07	-0.03	-0.01	0.08
Interior Plains W	**[-0.35]**	-0.12	0.21	-0.08	0.27	0.05	-0.03	**0.39**
West H	0.04	0.22	0.16	-0.22	-0.05	0.12	**0.32**	0.21
West W	0.26	**0.42**	0.08	**-0.37**	0.13	**0.47**	**0.40**	0.06

Table 11-6. Correlation matrix for log-10 CHLA vs. anthropogenic stressor variables for various wetland groups ("H" vs. "W" refer to herbaceous and woody in the geographic x vegetation type combinations). Correlation coefficients (positive or negative) with magnitude >0.3 are in bold underline; those of this magnitude but not in the expected direction (positive or negative) are additionally in brackets. Stressor variable B1H_all is over the 100 m buffer assessed by the field crew, all other stressor variables are over a 1000 m radius circle. The non-estuarine groups omit sites having conductivity suggestive of marine influence.

log10 CHLA	B1H_ALL	agric (%)	devel (%)	forest (%)	wetl+ water (%)	pop. dens (#/mi²)	road dens (km/km²)	imper-vious (%)
All sites	-0.05	0.13	0.01	**-0.34**	0.23	0.02	-0.02	0.03
Estuarine	-0.05	0.29	-0.14	0.02	-0.00	-0.13	-0.12	-0.15
Non estuarine	0.03	0.25	0.06	**-0.32**	0.14	0.04	0.02	0.08
Estuarine H	-0.17	0.12	-0.04	0.00	0.04	-0.02	-0.03	-0.01
Estuarine W	**0.35**	**0.47**	**[-0.37]**	0.05	-0.10	**[-0.41]**	**[-0.35]**	**[-0.38]**
Coastal Plains H	**0.45**	0.23	0.02	0.19	**-0.31**	0.04	0.07	0.09
Coastal Plains W	0.16	0.21	-0.11	-0.08	-0.05	-0.06	-0.15	-0.06
E Mts&Upp Mid	0.11	-0.07	0.16	-0.19	0.16	0.20	0.21	0.12
E Mts&Upp Mid	-0.04	0.20	-0.03	-0.29	0.28	0.01	-0.14	-0.05
Interior Plains H	-0.14	0.09	-0.01	0.24	-0.01	0.06	-0.03	0.06
Interior Plains W	**[-0.49]**	-0.13	**0.33**	-0.17	**0.44**	-0.02	0.00	**0.37**
West H	-0.19	0.16	**0.45**	-0.27	**0.32**	**0.44**	**0.57**	**0.46**
West W	0.14	0.19	0.07	-0.21	0.04	0.20	**0.32**	0.09

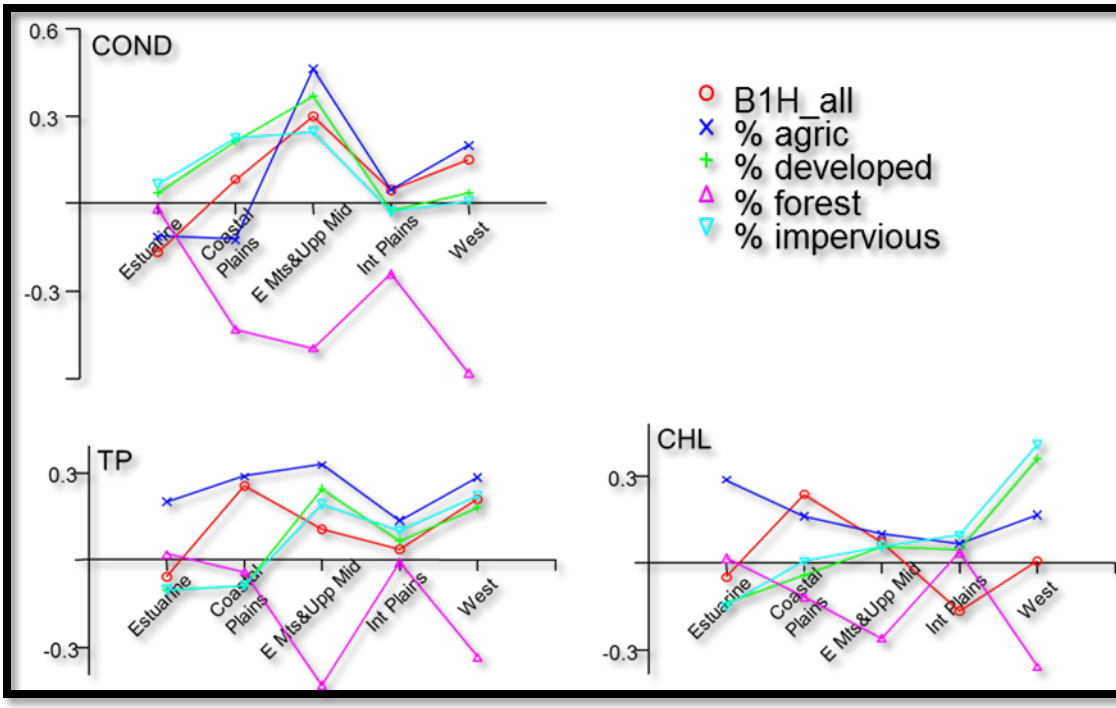

Figure 11-9. Plots showing Pearson strength of correlation between water chemistry and five anthropogenic stressor variables for five geographic reporting units (woody and herbaceous combined). Note that the vertical axis is scaled the same in all 3 graphs but does not extend as far for TP and CHLA as it does for COND. Plots exclude 10 sites with unusual conductivity.

Across all sites, % forested area was negatively correlated with all four analytes (magnitude > 0.30, strongest for COND), while % agriculture was positively correlated with TN and TP. Within site groupings, % forested remained a predictor (negative sign) for water chemistry in all non-estuarine geographically-based reporting units and for most non-estuarine reporting units x vegetation type combinations, while % agriculture remained a predictor (positive sign) for all water chemistry analytes except CHLA. In general, correlation coefficients were higher in magnitude for % forested than for %agriculture; however % agriculture had higher correlation coefficients than did % forested in estuarine woody sites. Correlation coefficients were generally lower for CHLA than the other three analytes examined. Percent forested and % agriculture generally trade off in NLCD-based assessments (i.e., increases in one tend to lead to decreases in the other) but because land formerly in forest can also be converted to urban land-uses and because land can be in a natural state yet not be forested (e.g., in grassland or in wetland) the relationship is not exactly inverse – hence it of interest to examine which is the better predictor where.

There were no correlations >0.3 in magnitude for population density, road density, B1H_ALL, or % developed across all sites, nor across estuarine vs. non-estuarine reporting unit site groupings. However each of these stressor variables was at times a significant predictor of water chemistry within reporting units x vegetation type site groupings. For example, % developed land, population density, and road density all were predictors (positive sign) for COND, TN, and TP in the Eastern Mountains & Upper Midwest and the West. B1H_ALL was a negative predictor for TN and TP in some reporting units (e.g., the Interior Plains) but a positive predictor for TP and CHLA in other (e.g., the Coastal Plains) making it somewhat hard to interpret. Other predictors also had unexpected signs sometimes, but usually these were accompanied by low correlation magnitudes.

Water chemistry, in general, was not well predicted from landuse-landcover variables in estuarine sites. Within estuaries the herbaceous sites have no correlations >0.30 for any stressor variables and any water chemistry analytes, and the woody sites have relationships whose direction is often counterintuitive (e.g., lower analyte levels with higher population density, road density, and percentages in developed or impervious land); only % agriculture shows the expected positive relationship to TN, TP, and CHLA. In contrast, water chemistry was much better predicted from landuse-landcover variables in non-estuarine sites, with many more correlations >0.3 in magnitude and the direction of the relationship (positive or negative) usually as expected. Water chemistry was more poorly predicted in the Interior Plains reporting unit than in other non-estuarine site types (**Figure 11-9**). No predictors with correlation magnitude >0.3 were found for the herbaceous Interior Plains site for any of the four water chemistry analytes. At the other extreme, the North-Central east reporting unit is one where nutrients and conductivity was strongly predicted from stressor variables (however this was not the case for CHLA).

Patterns of which predictors were strong were fairly consistent between COND, TN, and TP but often quite different for CHLA. For example, there were no correlations >0.3 for CHLA in the North-Central east despite many such correlations for the other three analytes, and notably fewer significant correlations for CHLA than the other analytes in West woody sites. CHLA was negatively correlated with % forested across all sites and across all non-Estuarine groups but had no correlations above 0.3 for any of the finer NWCA Reporting Group categories. Percent agriculture and/or developed land were predictors of CHLA in estuarine woody sites (where they also had been predictors of TN and TP), but also in Interior Plains woody and West herbaceous sites (where they had not been predictors of TN or TP). Population density and road density were predictors of CHLA in the West but not in the Eastern Mountains & Upper Midwest – in fact there were no significant predictors of CHLA in the Eastern Mountains & Upper Midwest even though both TN and TP were related to landuse/landcover there, suggesting that primary productivity responses are not being channeled to planktonic algae.

Differences in which landuse/landcover variables are correlated with water chemistry in which site groups are not necessarily because these predictors differ regionally in their *ability* to affect water chemistry, but rather that there are differences among regions in whether they have sufficiently high range that their effects are detectible. This is illustrated by box plots showing the range in landuse/landcover within site types. The one non-estuarine site type where declining percent forested was never a predictor for increasing COND was Interior Plains-Herbaceous, where forest levels are low (naturally) anyway (**Figure 11-10**, bottom). Population density was most consistently a predictor for water chemistry in the Eastern Mountains & Upper Midwest, which (aside from the Estuaries) is also where wetlands have the highest median and range in population density (**Figure 11-10**, middle). Agriculture levels are highest in the Interior Plains (**Figure 11-10**, top) leading one to wonder why % agriculture was not a predictor variable for water chemistry there; however this reporting unit covers not only much of the US cornbelt but also the prairies, meaning “agriculture” characterized broadly ranges from nutrient-intensive row-crop cultivation to much less intensive hay and pasture use; we suspect that landuse/landcover classifications examined here are insufficient to resolve these or that finer spatial categorization is necessary.

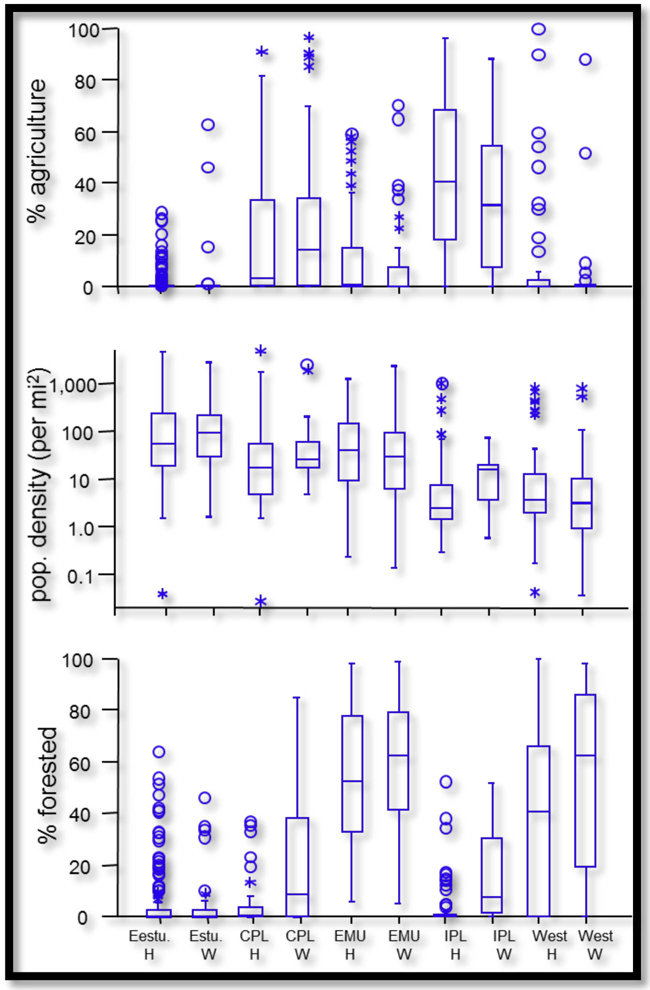

Figure 11-10. Box plots showing distribution of three anthropogenic stressor variables within geographic reporting unit & vegetation type combinations ("H" and "W" refer to herbaceous and woody, respectively).

11.3.5 Water Chemistry Patterns at Regional and National Scale – Scaling Up to Wetland Population

NARS reports typically summarize water body condition and stressor data into categories (e.g., good/fair/poor) constructed by using percentiles of the reference-site distribution for preselected reporting units (the NWCA Reporting Groups in the case of 2011 NWCA). Because water samples could not be collected at all sites as noted earlier, this resulted in even fewer number of least disturbed sites in each reporting group with water chemistry data. This confounded efforts to use this reference condition based approach to report on water chemistry parameters. We will continue to explore the development of meaningful condition or stressor metrics derived from the water chemistry data collected in NWCA that can be used for national and regional population estimates.

11.4 Discussion

In addition to being the first ever nationwide survey of the condition of the nation's wetlands, this survey also served as the first national-scale survey of wetland surface water chemistry. Questions of interest in analyzing these data included evaluating patterns in the water chemistry data, evaluating success in and barriers to obtaining water chemistry, and developing recommendations for future sampling protocols. Despite the challenges of the more limited water chemistry dataset for the NWCA, the data were valuable to the survey as a whole in understanding broad water chemistry patterns in across reporting units and in understanding potential stressors. As has been seen in other NARS, we also found that water chemistry results taken at Visit 1 were relatively stable with results taken at the revisit.

We had wondered whether the more complicated and diverse hydrology of wetlands relative to other waterbody types (lakes, streams, estuaries) might make wetland water chemistry patterns more difficult to interpret. We found a very large, multiple orders of magnitude range in TN, TP, CHLA, and nutrient ratios across wetlands, but also a corroboration of patterns seen in broad surveys of other water body types including increased nutrient and chlorophyll levels with increasingly agricultural and urbanized landuse/landcover. Despite the expectation that wetlands would be generally productive environments, the water chemistry data shows they can span a range from what would qualify as oligotrophic in lakes and streams to extremely eutrophic.

The geographic reporting units explored in this analyses did not explain variability patterns, suggesting that other geographic and hydrologic units ought to be examined. Further assessment of water chemistry predictors including other types and scales of landuse/landcover data and more refined analyses of field-collected stressor data is also needed. One intriguing finding from this data analysis is that across geographic reporting units, wetlands dominated by woody rather than herbaceous vegetation consistently had lower TN, TP, and CHLA – is this because wetlands in different vegetation types process nutrients differently, is it because landscape changes that increase nutrient loading also tend to change wetland vegetation types, or is it related to some other interaction? Water chemistry data from this and future NWCA surveys will enable us to uncover and explore such questions.

The inclusion of water chemistry parameters within the NWCA also provided valuable information to the survey overall. Water chemistry metrics served as a screening tool to identify sites impacted by potential stressors that may not have otherwise been detected through other indicators or observed during the on-site field evaluations. By identifying sites with measures on the extreme ends of the sample distribution, the Analysis Team was able to investigate those sites further and identify potential stresses acting on the system that may not have been visible at the time of the site visit. For example, surface water collected from a non-estuarine site in New Jersey with higher than expected COND value was determined to have experienced overwash from the coastal surge associated with Hurricane Irene in August 2011. The water chemistry from this site thus served as a diagnostic tool to identify reasons why the vegetation community metrics observed deviated from those expected for the wetland type.

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Chapter 12: Research Feature – USA-Rapid Assessment Method (USA-RAM)

12.1 Background Information

The increasing pressure that human activities are having on wetland ecosystems (Brinson and Malvarez 2002; Kentula et al. 2004) has generated considerable interest in developing methods designed to assess the ecological condition or integrity of wetlands. The assessment of wetlands can be approached both with quantitative biological methods, such as multimetric indexes of ecological condition (MMIs; Karr and Chu 1999) and by using semi-quantitative, rapid assessment methods (RAMs; e.g., Collins et al. 2008). Rapid methods have benefits such as requiring less time in the field and less taxonomic expertise than more quantitative methods, leading to cost savings and potentially larger sample sizes. For these reasons, RAMs have a key role in the implementation of wetland monitoring and assessment programs and the effective management of the resource (USEPA 2003; Fennessy et al. 2007).

The USA-Rapid Assessment Method (USA-RAM) was developed as an integral component of the suite of methods used in the 2011 National Wetland Condition Assessment (NWCA). The three primary objectives of the NWCA are to: (1) report the ecological condition of the nation's wetlands, (2) build state and tribal capacity for wetland monitoring and assessment, and (3) advance the science of wetland assessment. USA-RAM helps meet the first objective by providing relatively less expensive, semi-quantitative measures of overall wetland health that complement the more quantitative and expensive NWCA methods for assessing particular aspects of wetland condition or stress. USA-RAM helps meet the second objective by serving as a RAM template for consideration by States and Tribes that do not have RAMs at this time. To help meet the third objective, USA-RAM provide data that can support an exploration of the statistical relationships between stress and condition of wetland areas as mediated by their buffers (**Figure 12-1**). Buffers are crucial elements that protect wetlands from the effects of human activities in the landscape context (Lopez and Fennessy 2002).

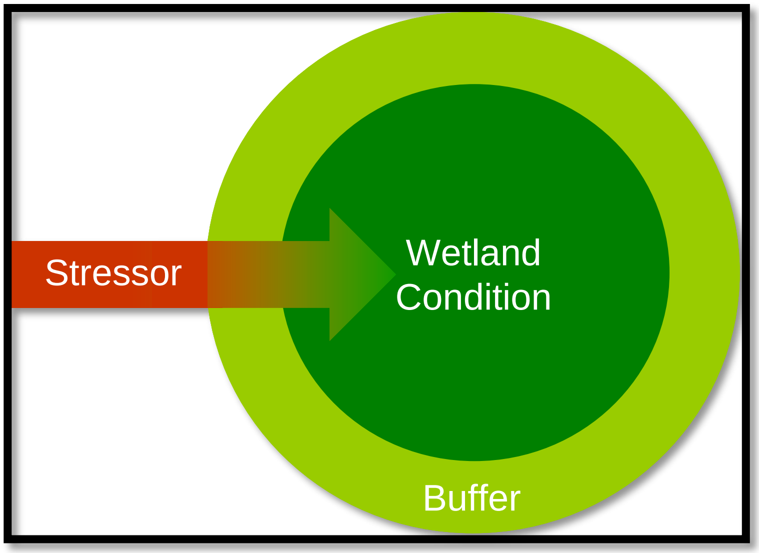


Figure 12-1. Conceptual diagram showing the relationship between stressors, buffers and condition. The effect of a stressor that originates outside a wetland is diminished as it passes through the buffer area that adjoins it.

12.1.1 *Tenets of USA-RAM*

USA-RAM was designed through a series of regional field tests involving experts in wetland assessment from across the conterminous 48 states. An iterative process of field trials and revisions was conducted over the course of two field seasons based on the following set of ten key guiding principles or tenets.

1) Condition, as assessed using USA-RAM, means the potential of a wetland area to provide high levels of its intrinsic ecosystem services;
2) Stress, as assessed using USA-RAM, means the combined measures of the abundance, diversity, and magnitude of common stressors evident within a wetland area or its buffer;
3) Wetland health, as assessed using USA-RAM, means the aggregate assessment of condition and stress within a wetland area and its buffer;
4) For any wetland class, the condition of a wetland area increases as the physical and biological structural complexity of the area and its buffer increases, and as the stress in the area and its buffer decreases, relative to best achievable or least-impacted wetland areas and their buffers;
5) There should be one version of USA-RAM that reflects the full range of form, structure and stress for all wetland classes and regions throughout the 2011 NWCA, and that can be applied consistently by all 2011 NWCA field crews;
6) USA-RAM should be based on easily recognized visible indicators of Metrics of condition and stress that represent universal Attributes of wetland health, namely buffer, hydrology, physical structure, and biological structure (Fennessy et al. 2007);
7) Rapid means that 2-3 trained practitioners require fewer than 2 hours elapsed time to successfully apply the entire method in the field to achieve a measure of overall wetland health;
8) Condition and stress should be assessed separately within each wetland area and within its surrounding buffer;
9) There should be no numerical weighting of any USA-RAM Metrics, Attributes, or Indices of condition or stress; and,

10) Any re-scaling of Metric scores for condition or stress, relative to regional differences, should be done as a post-survey analysis.

12.1.2 *Structure of USA-RAM*

USA-RAM is designed to assess the overall of a 0.5-ha Assessment Area (AA) and its buffer zone. The buffer zone is defined as the area within 100m distance from the perimeter of the AA. Ultimately, Metrics that assess condition and stressor within a wetland area were used to determine its overall health, as mediated by its buffer. In essence, the effects of a stressor that originate outside a wetland area are diminished as the stress passes through the buffer, lessening its impact.
USA-RAM recognizes four Attributes of condition and stress: buffer, hydrology, physical structure, and biological structure (**Table 12-1**). Each Attribute is assessed using two Metrics, except for the hydrology Attribute, which is only assessed in terms of its stressors. Hydrological condition was not assessed directly for three reasons:

1) Since all aspects of wetland condition are affected by hydrology, its condition is represented by the condition of the other Attributes, such that assessing hydrology directly would essentially be adding emphasis to the hydrology Attribute in violation of tenet 8 above;

2) A survey of how hydrology is treated in other RAMs revealed that it is usually assessed as the amount of departure from natural hydrological conditions due to stress, such that it could be well-represented by stressor indicators; and

3) Early efforts to develop USA-RAM Metrics of hydrological condition concluded with the recognition that the natural variability of hydrology across wetland classes and regions of the US was too great to be reasonably represented by a single version of USA-RAM, as stipulated by tenet 5 above.

An assessment of hydrological stressors is critical, however, to account for human activities that alter hydrology, and to be better able to interpret the results of the condition assessment.

Table 12-1. USA-RAM Attributes and Metrics of wetland condition and stress.

Attributes	Condition Metrics	Stress Metrics
Buffer	Percent of AA Having Buffer Buffer Width	Stress to the Buffer Zone
Hydrology	None	Alterations to Hydroperiod Stress to Water chemistry
Physical Structure	Topographic Complexity Patch Mosaic Complexity	Habitat/Substrate Alterations
Biological Structure	Vertical Complexity Plant Community Complexity	Percent Cover of Invasive Plants Vegetation Disturbance

USA-RAM is designed to be rapid, taking a crew of 2 or 3 trained practitioners 1 to 1.5 hours to prepare for a field visit, and another 1.5 to 2 hours to conduct the field assessment.

USA-RAM provides separate scores for stress and condition for each AA and its associated buffer zone. The Metric scores are derived from standardized “scoring tables” that are used to assign one of four scores to each Metric of condition or stress. In total, USA-RAM is made up of 12 Metrics, three to assess the buffer zone, four to assess condition of the AA, and five to assess stress in the AA. Each Metric consists of a checklist of visible indicators of field conditions, based on reference sites. Narrative descriptions are provided for each indicator, allowing rapid scoring in the field. The data for each Metric were used to develop metric scores for the AAs and their buffer zones, and an overall ecological condition score for each AA (also referred to as the site index score or USA-RAM score).

Stressors are an important component of an assessment because of their effect on condition. Knowledge of the stressors present in and around a wetland is valuable in determining how condition might be improved through management actions. All stressor Metrics are scored based on the number of stressors that are observed (i.e., visibly evident at the time of the assessment), as well as a ranking of their severity. The severity of a stressor was characterized based on the portion of the zone or AA that was obviously influenced by the stressor, as indicated in **Table 12-2**. The total number of stressors (i.e., a stressor count), regardless of their severity, was also tabulated.

Table 12-2. Guidelines for Assessing Stressor Severity.

Description of Stressor Prevalence	Stressor Severity Score
Less than one-third of the buffer or AA is influenced by the stressor	1 (not severe)
Between one-third and two thirds of the buffer	2 (moderately severe)
More than two-thirds of the buffer or AA is influenced by the stressor	3 (severe)

12.1.2.1 *Section A: Assessment of Condition and Stress in the Buffer Zone*

There are three Metrics designed to evaluate the extent and condition of the buffer zone, as well as the kinds and severity of the stressors to which it is subject. In the USA-RAM we define the buffer as the land immediately adjacent to the AA that is mostly covered with natural vegetation and lacks evidence of intrusive human activity. The buffer has a maximum width of 100m. It is assumed that the buffer helps protect the AA by mitigating external stress, including deleterious effects of nearby or adjacent human land uses. The three buffer Metrics are described in the following subsections.

12.1.2.1.1 Metric 1: Percent of AA Having Buffer

The land area adjacent to the AA only qualifies as buffer if it consists of a land cover type that is capable of “buffering” the AA by protecting it from stress originating in the landscape outside of the buffer. This Metric tallies the percent of the AA perimeter that adjoins a qualifying “buffer land cover” as defined in **Table 12-3** and **Table 12-4**. For the NWCA, land covers that might provide limited buffering under special circumstances, such as pasture and land managed for ecological functions were not considered to be buffers because adequate knowledge of such localized circumstances could not be assured.

Metric 1 is completed in two steps. The first is a desktop evaluation at the time of AA planning (USEPA 2010) to determine the land use surrounding each survey point used to locate an AA. The NWCA sample point imagery was used in this effort, although other sources of data such as Google Earth could be used. Once the AA was established, the land area within 100m of the AA boundary was defined as the buffer zone. For the sake of USA-RAM, this is the maximum area that has the potential to serve as buffer, depending on its land use. The second step is a field verification of the data derived from the aerial imagery. The field reconnaissance is used to evaluate the perimeter of the AA and to estimate the percent of the distance along the perimeter of the AA that adjoins buffer land covers, based on **Table 12-3** and **Table 12-4**.

Table 12-3. Buffer Land Cover Criteria. To qualify as buffer, a land cover must meet all four of the listed criteria.

Buffer Land Cover Criteria
1. Is on the list of “buffer land covers” in Table 2
2. Is at least 5m wide
3. Extends at least 10m along the AA boundary as a contiguous cover patch
4. Is not separated from the AA by a non-buffer cover that is ≥ 5m wide

Table 12-4. List of land covers classes and whether they count as buffer land cover or are non-buffer land covers. Land cover classes based on the Anderson Land Cover Class system.

Buffer Land Covers	Non-Buffer Land Covers
▪ Open water surfaces of lakes, bays, ponds, rivers, etc. with <5% plant cover ▪ Wetlands ▪ Natural vegetation (areas with ≥ 5% cover of mostly non-impacted vegetation, including herbaceous, forest, or old fields undergoing succession, ▪ Permanent ice or snow (year round snow or ice surfaces with <5% plant cover) ▪ Natural, non-vegetated earth surfaces (natural rock outcrops, sand, gravel, etc. with <5% plant cover) ▪ Trails (foot trails, equestrian trails, single-track bicycle trails, etc.)	▪ Built structures (houses, factories, schools, etc.) ▪ Urban and suburban lawns, including recreational lawns, sports fields, etc.) ▪ Any active agriculture (orchards, vineyards, row crops, hay or grain fields, sod farms, feedlots, recently **clear-cut** or otherwise severely impacted forest lands, etc. Includes fallow agricultural fields) ▪ Artificial, non-vegetated land surfaces (parking lots, feed lots, etc. that support <5% plant cover) ▪ Active mining areas (quarries, strip mines, gravel pits, etc.) ▪ Any recently burned lands ▪ Roads (including railroads, streets, highways, etc.) ▪ ATV trails

12.1.2.1.2 Metric 2: Buffer Width

The ability of an area to buffer a wetland from external stressors depends on the width of the buffer that is present. Minimum effective buffer widths can vary depending on the type of stressors present. However, it is assumed that buffers do not usually need to be wider than 100m. A width of 100m has become a common definition for the sake of assessment in many programs, and land use in the 100m buffer has been found to be correlated with wetland condition.

To complete this Metric, four transect lines, each 100m long, are drawn from the AA perimeter on the site imagery in the four cardinal directions (N, S, E, W). Another four lines are drawn outward from the AA perimeter in the ordinal directions (NE, SE, SW, NW). Lines are numbered clockwise with North as “1” as shown. Starting at the AA perimeter, the following procedure is followed.

- On each of the eight (8) transect lines, estimate the distance (in increments of 5m) between the AA perimeter and the point at which the line first intercepts any type of non-buffer land cover (see **Table 12-4** above). This distance equals the buffer width for that transect line.
- Ignore any non-buffer areas that do not cover at least 5m of a line.

To ensure the best possible estimate of buffer width, the buffer area should be ground-checked to ensure the accuracy of the aerial imagery in the field. If there is a substantial difference between buffer zone land cover as evident in the aerial imagery and what is observed in the field, the data to indicate buffer width based on the imagery will have to be corrected, based on the field observations.

12.1.2.1.3 Metric 3: Stressor to the Buffer Zone

This metric is designed to tabulate and characterize the types and severity of stressors that occur within the 100m buffer zone that can act to reduce the effectiveness of the buffer in protecting the AA from human activity in the surrounding landscape. For the sake of this Metric, the buffer zone is considered to be the entire 100m area around the AA, regardless of land use. Stressors that occur in any land use type, whether or not they count as buffers, have the potential to directly impact the AA. Therefore, stressors that occur in any land use within 100m of the AA will be tallied using a stressor checklist.

12.1.2.2 *Section B: Assessment of Wetland Condition in the AA*

12.1.2.2.1 Metric 4: Topographic Complexity

Natural wetlands develop topographic relief due to variations in sediment production or deposition, erosion or oxidation of sediments, variations in hydroperiod, wildlife activity, etc. Increases in both *micro*- and *macro-relief* represent increases in the surface area of a wetland and therefore can lead to increased biological and geo-chemical processes at the sediment-water or sediment-air interface. It can also represent an increase in habitat quantity and diversity through an increase in habitat heterogeneity.

12.1.2.2.2 Metric 5: Patch Mosaic Complexity

This Metric assesses the horizontal structural complexity of the AA (as viewed from above), a characteristic that is sometimes referred to as *interspersion*. When viewed from above, most wetlands are mosaics of different patches of substrate or plant cover. The complexity of the mosaic is made up of the diversity of the component patches and the degree to which they are interspersed. Within a given wetland class, the diversity and levels of ecological function of a wetland mosaic are expected to increase with its overall complexity.

12.1.2.2.3 Metric 6: Vertical Complexity

Metric 6 addresses the vertical structure of the plant community in terms of its component number of *plant strata*. Different strata provide different physical and ecological services. For instance, tall vegetation tends to be more efficient at intercepting and holding rainwater, serving as a source of allochthonous inputs, and moderating air temperature. Low stature vegetation can shield soils from intense rainfall while serving as forage for herbivorous game animals. The basic assumption is that more strata provide a greater amount of niche space and broader ranges in habitat condition, as well as more kinds and higher levels of material and energy transformations for the wetland as a whole.

12.1.2.2.4 Metric 7: Plant Community Complexity

This metric evaluates the diversity of plant species that dominate the plant strata. Since different species tend to have different growth patterns and morphometry, an increase in species diversity within a stratum tends to increase its internal architectural complexity. Within a wetland class, the diversity and levels of ecological function of a wetland are expected to increase with the number and abundance of different plant species. The basic assumption is that a greater diversity of co-dominant species translates into a wider variety and higher levels of wetland functions.

12.1.2.3 *Section C: Assessment of Stress in the AA*

The following Metrics were used to assess stressors within the AA. In general, the effects of stressors on wetland condition tend to increase as their number, variety, and severity increases, regardless of wetland type or vegetation community. The severity of a stressor depends on its duration, intensity, frequency, and proximity. The field indicators of stress tend to integrate across these parameters, such that they are not assessed independently. In this case, by observing whether the stressor indicators were obvious and pervasive, or characterized as more moderate, each stressor was evaluated to determine whether it had a high, medium, or low degree of severity, as indicated in the previous **Table 12-2**. The total number of stressors, regardless of their severity, was also tabulated. Ultimately data on stressors offer a diagnostic tool by documenting causes of degradation within the AA. All available information was used to identify stressors including direct observation of the AA, aerial photos, and maps.

12.1.2.3.1 Metric 8: Stressors to Water Chemistry

Hydrology has been called the "master variable" that determines the structure, function and ecosystem services provided by wetlands. In USA-RAM, Hydrology is represented by a Metric for water chemistry (Metric 8) and quantity (Metric 9). Human activities that degrade water chemistry include discharge from point sources and watershed activities that result in high sediment loads, nutrient runoff, mine drainage, excess salts, etc. As stressors accumulate at a site, services such as biodiversity support and biogeochemical cycling are compromised and downstream aquatic systems can become impaired.

12.1.2.3.2 Metric 9: Stressors to Hydroperiod

The hydroperiod, or the pattern of water level change over time, affects wetland vegetation community composition and productivity, controls the provision of spawning and nursery grounds for fish and amphibians, affects migratory waterfowl habitat, and biogeochemical processes. Functions such as floodwater storage and flood peak reduction are reflected in the hydroperiods of wetlands.

12.1.2.3.3 Metric 10: Stressors to Habitat/Substrate

Some human activities such as grading, cattle grazing, off-road vehicle use, and vegetation control can severely alter wetland substrates and other parameters of wetland habitats. Some urban wetlands are severely impacted by dumping of yard debris and other trash. Substrate alterations can cause changes in soil quality and drainage that subsequently alter wetland plant communities. Severe alterations of wetland substrates often lead to invasions by non-native vegetation.

12.1.2.3.4 Metric 11: The Cover of Invasive Species

Wetland plants are particularly useful as indicators because they are an easily observed, universal component of wetland ecosystems, and they integrate across other aspects of wetland condition or stress that vary more rapidly over time. Plant community composition, including the occurrence of invasive species, provides clear and robust signals of human disturbance. This Metric is assessed based on field observations of the percent cover of invasive species in each of the plant strata within the AA. Local invasive plant species lists or resource agencies were consulted to determine the plant species within a region of the NWCA that are considered invasive in wetlands.

12.1.2.3.5 Metric 12: Stressors to the Vegetation Community

This metric accounts for human activities that directly alter the plant community in the AA. Vegetation is an easily observed component of wetlands that responds predictably to disturbance. As vegetation communities respond to stressors, important wetland services, such as biodiversity support and water chemistry improvement, may be affected. Common stressors might include mowing within the AA, excess herbivory, or various management practices to suppress the risk of wildfires.

12.2 Data Preparation

As described in Chapter 2, all field data, including data for USA-RAM, were collected during field visits conducted in the 2011 growing season. The USA-RAM was developed by Collins and Fennessy (2011) based on their experience with other rapid assessment approaches for wetlands (Fennessy et al. 1997; Mack 2001; Fennessy et al. 2007; Collins et al. 2008), and discussions with regional teams working on the NWCA. A field manual was written for use by field crews, which included the rationale for each metric and instructions for completing the field data forms (USEPA 2011).

At each site where the Level 3 intensive data were collected on vegetation, soils, algae, etc., data for the USA-RAM were also collected. Field crews recorded data using the USA-RAM field data sheets, but did not score the Metrics during the site visits. The methods and breakpoints used to score the Metrics and to combine them into the final USA-RAM scores were developed as part of the subsequent NWCA data analysis effort.

The USA-RAM data were exported for analysis both in a summary form, in which the Metric scores were compiled, and using the raw data for each indicator that comprised a metric. Both data sets were used in data analysis.

Data were prepared for analysis using the approach shown in **Figure 12-2**. Field data were entered by scanning the field data forms, and the scanned data were validated according to NWCA protocols as described in **Chapter 2**. Once all the data were compiled, several quality assurance reviews were conducted:

- The field data for all AAs were reviewed to ensure that they were complete and had been compiled accurately. We found only one data value for one AA had been miscalculated;
- 15 AAs were selected for intensive review. The sites were selected because of suspect combinations of Metric data; for example, one site that was designated as a reference site also had a high number of stressors. All data recorded on the forms were checked against the corresponding data in the scanned data files. We found no errors in the scanned data; all field data had been recorded correctly.

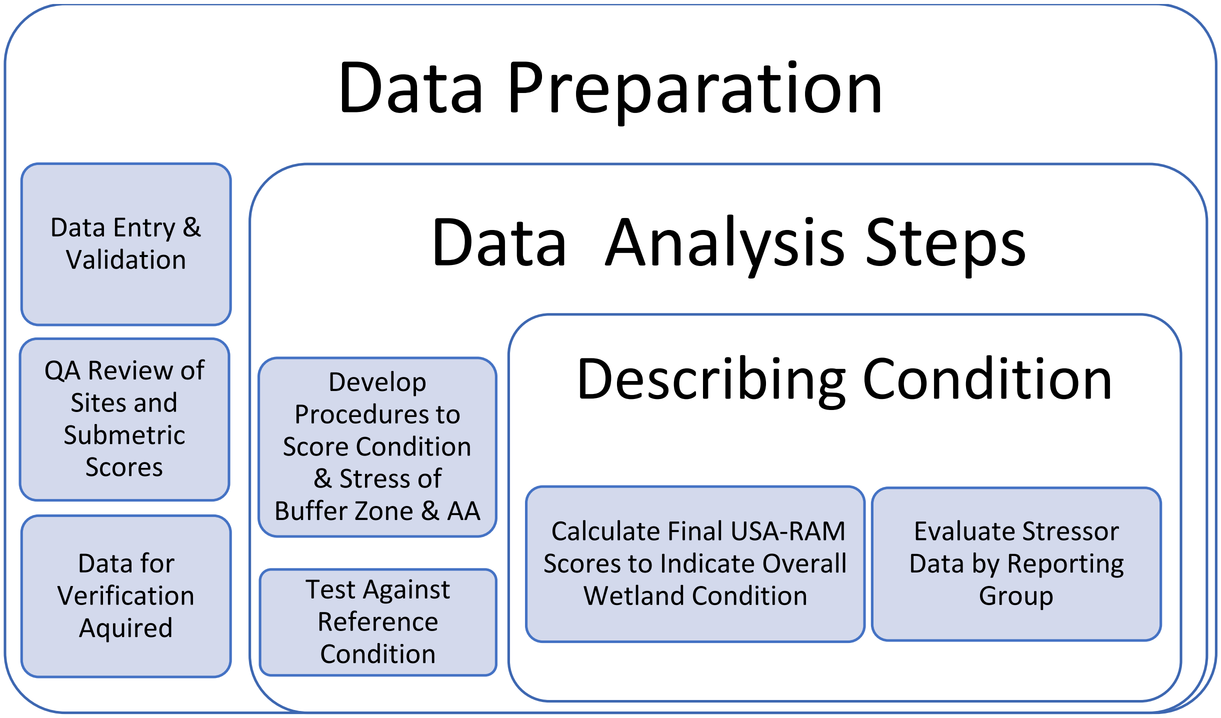


Figure 12-2. Overview of data preparation and analysis steps to describe condition and stress based on USA-RAM.

In order to prepare the data to score Metric 7 (Plant Community Complexity), the dominant species recorded in each plant stratum at an AA were compiled into a single list, with each species appearing only once, regardless of the number of strata in which the species occurred. Species lists were compiled and the total species count for each site was used in scoring the Metric. Compiling the species list revealed that 97 sites were missing plant data for Metric 7, despite the fact that these sites had plant data recorded in other data tables. A map of these sites showed that a large number of them were concentrated along the Gulf Coast, specifically in Louisiana, Mississippi, and Alabama (**Figure 12-3**). Because of their missing data, these 97 sites were eliminated from the analysis. An additional 18 sites were dropped; six due to other missing data, and 12 sites because they were outliers (defined as data beyond the 95th and 5th percentiles of the distribution of their respective Metric scores), leaving a total of 1,119 AAs included in the USA-RAM analysis.

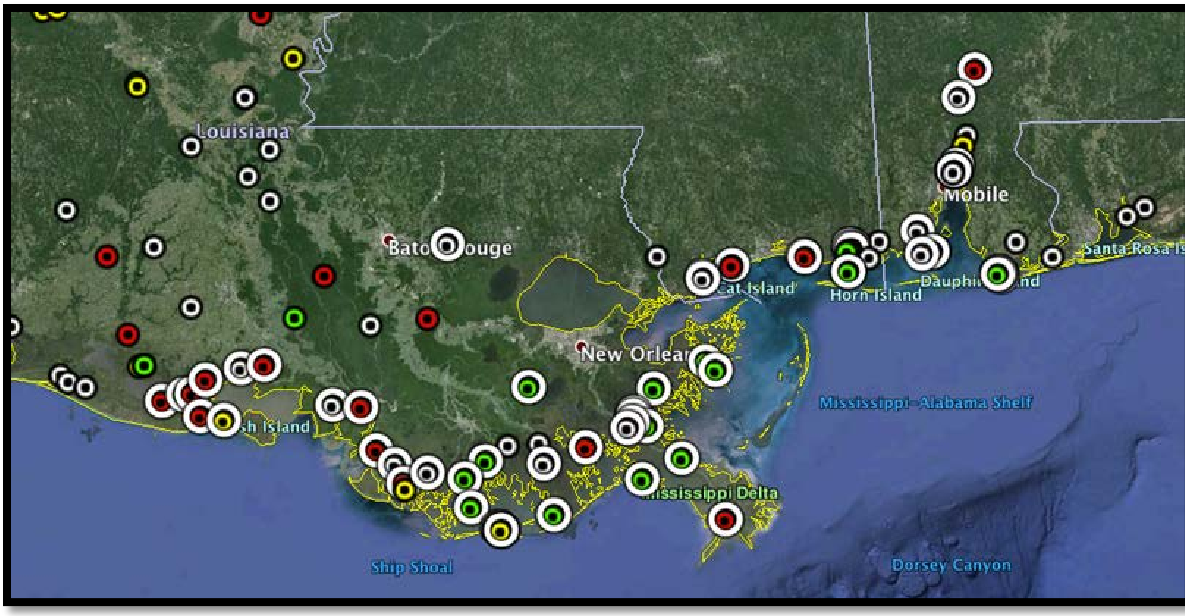


Figure 12-3. Map NWCA sites in portions of Louisiana, Mississippi and Alabama. Sites marked with an outer white circle were missing plant data for Metric 7 (not all 65 of these sites are distinguishable in this figure due to overlapping markers). Least disturbed sites are green; intermediate disturbed sites are white, and the sites designated by NCWA as most disturbed are red.

12.3 Data Analysis

12.3.1 *Overview*

The data for each Metric were separated into four categories of condition or stress, and the four categories were assigned values of 3, 6, 9, and 12, with the high values representing increases in condition or stress. Each AA was therefore given one of these values for each Metric, termed the Metric score. The values for the AA Condition Index, AA Stressor Index, and Buffer Index were calculated as the simple sum of their respective Metric scores, scaled to a maximum of 100 points. The Site Index is a combination of these three other indices, as explained in **Section 12.3.2.3**.

12.3.2 *Data Analysis Steps*

12.3.2.1 *Distribution of Metric Data*

A frequency histogram was calculated for all the data of each Metric. The histogram for all but one Metric indicated that the data were reasonably distributed across the full range of condition represented by all the AAs. However, the data for Metric 1, the percent of the AA perimeter adjoining a buffer land cover, were very heavily skewed toward high scores. Ninety-two percent of all the AAs had more than 75% of their perimeter buffered, while only 2% of the AAs had less than 25% of their perimeter buffered. This indicates that the condition of the AA buffer zones was essentially the same with regard to Metric 1, which was therefore excluded from further analyses of the USA-RAM data. For a discussion of the likely causes of the poor performance of this Metric, see **Section 12.4**.

12.3.2.2 *Scoring USA-RAM Metrics*

As stated above, the data for each Metric were separated into four categories of condition or stress. For most Metrics, the data were categorized in the field, based on the field indicators of the Metrics. Data for the other Metrics were not initially categorical. For these Metrics, the four categories corresponded to either the quartiles of the frequency distributions of the data, or to natural breaks in the frequency distributions (**Table 12-5**). The four categories were assigned values of 3, 6, 9, and 12, with the high values representing increases in condition or stress. Each AA was therefore given one of these values for each Metric, termed the Metric score.

12.3.2.3 *Procedures to Calculate the AA Condition Index, AA Stressor Index, Buffer Index, and Site Index*

For each AA, the Buffer Index, AA Condition Index, and AA Stressor Index are each calculated as the sum of its component Metric scores, which is then divided by its maximum possible sum. The value of each of these indices for each AA therefore represents the proportion of its maximum possible value. This value is then scaled to a maximum of 100 points, such that each of these indices has a minimum possible value of 25 and a maximum possible value of 100. Thus, an index score of 25 indicates that each component Metrics had the lowest score possible (3 points), while an index score of 100 indicates that each component Metric had the highest score possible (12 points). This scoring approach ensures that the index scores are weighted equally, regardless of the number of their component Metrics, as stipulated in the guiding tenets (**Section 12.1.1**). The formulas for these three indices are given below:

Buffer Index: ((Metric 2+Metric 3)/24)*100.

Scores for the two Metrics are summed, then divided by the maximum possible sum (i.e., 2 Metrics at 12 maximum points each = 24), then multiplied by 100; the full range of possible index values is therefore 25 to 100.

AA Condition Index: (Metric 4 + Metric 5 + Metric 6 + Metric 7)/48)*100.

Scores for the four Metrics are summed, then divided by the maximum possible sum (i.e., 4 Metrics at 12 maximum points each = 48), then multiplied by 100; the full range of possible index values is therefore 25-100.

AA Stressor Index: (Metric 8 + Metric 9 + Metric 10 + Metric 11 + Metric 12)/60)*100.

Scores for the five Metrics are summed, then divided by the maximum possible sum (i.e., 5 Metrics at 12 maximum points each = 60, then multiplied by 100; the full range of possible index values is therefore 25-100.

The overall Site Index or Wetland Health Index is calculated by summing the Buffer and AA Condition Indices (since in both cases high Index values indicate good condition), then subtracting a modified AA Stressor Index (for which high index values are correlated to poor condition), as follows:

Site Index = (Buffer Index + AA Condition Index) + (50 – AA Stressor Index).

The Stressor Index is subtracted from 50 to ensure that the Site Index is positive. Without this adjustment, AAs having very low values for both the Buffer Index and the AA Condition Index, but having high values for the AA Stressor Index could have negative values for the Site Index. With this adjustment, the possible values for the Site Index range from 0 to 225. An overview of the procedure to calculate USA-RAM scores is shown in **Table 12-5**.

Table 12-5. The upper and lower sections of the table show data thresholds separating the four categories of condition or stress for each Metric. Higher scores for the stressor Metrics indicate greater stress, except for Metric 3, for which higher scores indicate lesser stress; this was done to facilitate calculation of the Buffer Index (see text for details).

Condition Category	Score	Buffer Condition	Buffer Condition	AA Condition	AA Condition	AA Condition	AA Condition
		Metric 1 % AA Perimeter Adjoining Buffer	Metric 2 Buffer Width	Metric 4 Topographic Complexity	Metric 5 Patch Complexity	Metric 6 Vertical Complexity	Metric 7 Plant Community Complexity
Good	12	>75	>75	≥5	Row 4	≥4	>6
Moderately Good	9	51-75	51-75	3-4	Row 3	3	5-6
Moderately Poor	6	26-50	26-50	2	Row 2	2	3-4
Poor	3	≤25	≤25	<2	Row 1	<2	≤2

Stressor Category	Score	Buffer Stressor	AA Stressor	AA Stressor	AA Stressor	AA Stressor	AA Stressor
		Metric 3 Buffer Stressors (reversed scale)	Metric 8 Water chemistry Stressors	Metric 9 Hydroperiod Stressors	Metric 10 Substrate Stressors	Metric 11 Invasive Species Cover	Metric 12 Vegetation Stressors
Very High Stress	12	<2 (low stress)	≥3	≥3	≥3	26-75% and >75%	≥3
High Stress	9	2	2	2	2	5-25%	2
Moderate Stress	6	3-4	1	1	1	<5%	1
Low Stress	3	≥5 (high stress)	0	0	0	Absent	0

12.3.2.4 *Reporting Groups*

Many factors affect stress and condition for wetlands across the conterminous US. It is assumed that these factors vary more between wetland classes and ecoregions than within them. Based on this assumption the NWCA Analysis Team adopted the following reporting groups for the USA-RAM analysis (**Table 12-7**). The NWCA Analysis Team also identified the least-disturbed sites (i.e., reference sites) and the most-disturbed sites, based on a NCWA screening procedure (**Chapter 4**).

Table 12-6. A summary of the method for calculating USA-RAM scores.

1. Calculate Metric Score	Convert the Metric field data to the corresponding numerical scores (i.e., 3, 6, 9, or 12) as indicated on **Table 12-5**.
2. Calculate Buffer and AA Indices	Calculate each Index using its component Metrics: • Buffer index: ((Metric 2+Metric 3)/24)*100 • AA Condition Index: (Metric 4 + Metric 5 + Metric 6 + Metric 7)/48)*100 • AA Stressor Index: (Metric 8 + Metric 9 + Metric 10 + Metric 11 + Metric 12)/60)*100
3. Calculate Site Index	Calculate the Site Index: (Buffer Index Score + Condition Index Score) + (50 - Stressor Index Score)

Table 12-7. Summary of Reporting Regions to Aggregated Ecoregions and wetland types.

Aggregated Ecoregions	Aggregated Wetland Types
CPL *(Coastal Plains)*	EH *(Estuarine Herbaceous)*
EMU: *(Eastern Mountains & Upper Midwest)*	EW *(Estuarine Woody Shrub or Forest)*
IPL *(Interior Plains)*	PRLH *(denoted PH, Palustrine, Riverine, Lacustrine Herbaceous)*
W *(West)*	PRLW *(denoted PW, Palustrine, Riverine, Lacustrine Woody)*

Reporting Regions	
EH	*Estuarine Herbaceous*
EW	*Estuarine Woody*
CPL-PH	*Coastal Plain - Palustrine, Riverine, and Lacustrine Herbaceous*
CPL-PW	*Coastal Plain - Palustrine, Riverine, and Lacustrine Woody*
EMU-PH	*Eastern Mountains & Upper Midwest - Palustrine, Riverine, and Lacustrine Herbaceous*
EMU-PW	*Eastern Mountains & Upper Midwest - Palustrine, Riverine, and Lacustrine Woody*
IPL-PH	*Interior Plains - Palustrine, Riverine, and Lacustrine Herbaceous*
IPL-PW	*Interior Plains - Palustrine, Riverine, and Lacustrine Woody*
W-PH	*West - Palustrine, Riverine, and Lacustrine Herbaceous*
W-PW	*West- Palustrine, Riverine, and Lacustrine Woody*

12.3.2.5 *Testing USA-RAM Performance*

The Metric scores, Buffer Index, AA Condition Index, AA Stressor Index, and Site Index were calculated for each of the ten NWCA Reporting Groups. The data analysis packages JMP 11.0 (SAS Institute) and R were used to generate box plots of the indices for the populations of least-disturbed and most-disturbed sites, as defined by the NWCA Analysis Team. The efficacy of USA-RAM was assessed based on its ability to distinguish between these two populations of sites.

12.4 Results and Discussion

12.4.1 *Overview*

USA-RAM provides a rapid means to evaluate a wetland's overall health, based on visible indicators used to score common Metrics of stress and condition for standard Assessment Areas (AAs) and their buffer zones. Stressor Metrics provide details on specific human activities that tend to degrade wetlands. The condition Metrics reflect wetland form and structure, the complexity of which is linked to the capacity of wetlands to sustain high levels of their intrinsic ecosystem services, particularly wildlife and biodiversity support. The Metric scores are used to calculate four components of USA-RAM: the AA Condition Index, the AA Stressor Index, the Buffer Index, and the total USA-RAM Site Index score of overall ecological health. Here we report on the performance of USA-RAM in describing the status of the Nation's wetlands.

12.4.2 *Efficacy of the Site Index*

The Efficacy of the USA-RAM Site Index was evaluated based on its ability to distinguish between the least-disturbed AAs and most disturbed AAs for each of the 10 NWCA Reporting Groups. In each case, the efficacy of the USA-RAM Site Index was high, as indicated in **Figure 12-4**. For example, for the CPL-PW, where the interquartile range (25^{th}-75^{th} percentiles) for the least-disturbed sites is well above the range for the most-disturbed sites. Palustrine herbaceous wetlands in the Interior Plains (IPL-PH) showed the least difference in Site Index, indicating a narrow range of overall ecological condition for this group. This ecoregion is one of the most modified by human activities, and herbaceous wetlands are subject to some of the greatest amount of stressors. This is reflected by the relatively low median Site Index values (i.e., median values were 135 and 115 for least- and most-disturbed AAs, respectively). However, in every case, the differences in mean Site Index values were highly significant ($p < 0.001$; except for IPL-PH with $p <0.002$).

The USA-RAM Site Index scores were very high for the least-disturbed woody wetlands in the Coastal Plains (CPL-PW) and for Estuarine woody wetlands (EW), which had median Site Index values of 189 and 185, respectively. The lowest mean USA-RAM Site Index scores were seen in the palustrine herbaceous wetlands of the Interior Plains (IPL-PH) and the West (W-PH), which had median values of 135 and 150. In all of the Aggregated Ecoregions, woody wetlands tended to have greater Site Index values than herbaceous wetlands (i.e., see the right hand panels in each row of **Figure 12-4**. This may be due to the structural characteristics of woody vegetation; woody species are longer lived with more permanent structure than are herbaceous species, which probably tends to increase their Metric scores for physical and biological structure, while also increasing the performance of the buffer zone.

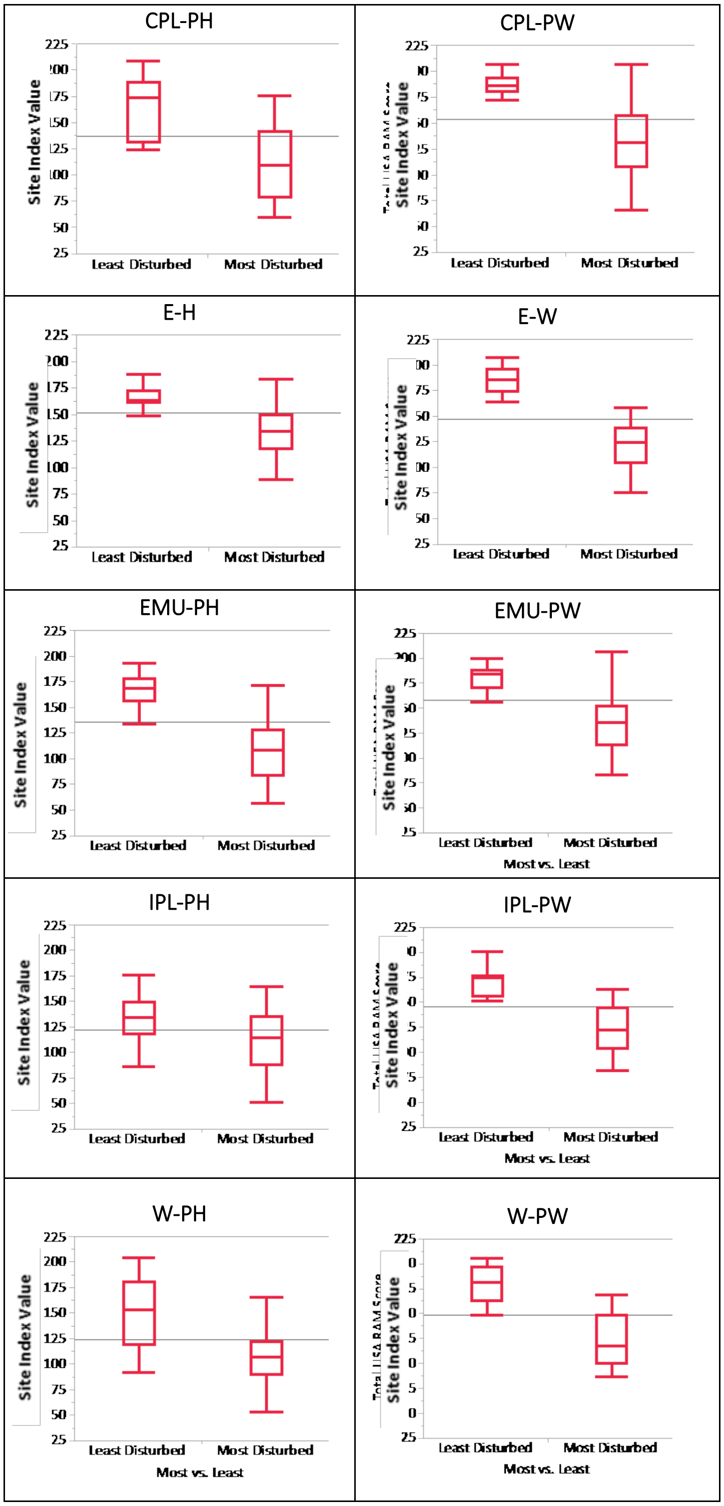


Figure 12-4. Box-plots of the USA-RAM Site Index scores for the least-disturbed and most-disturbed AAs (as independently defined by the NCWA Analysis Team) for the 10 NWCA Reporting Groups.

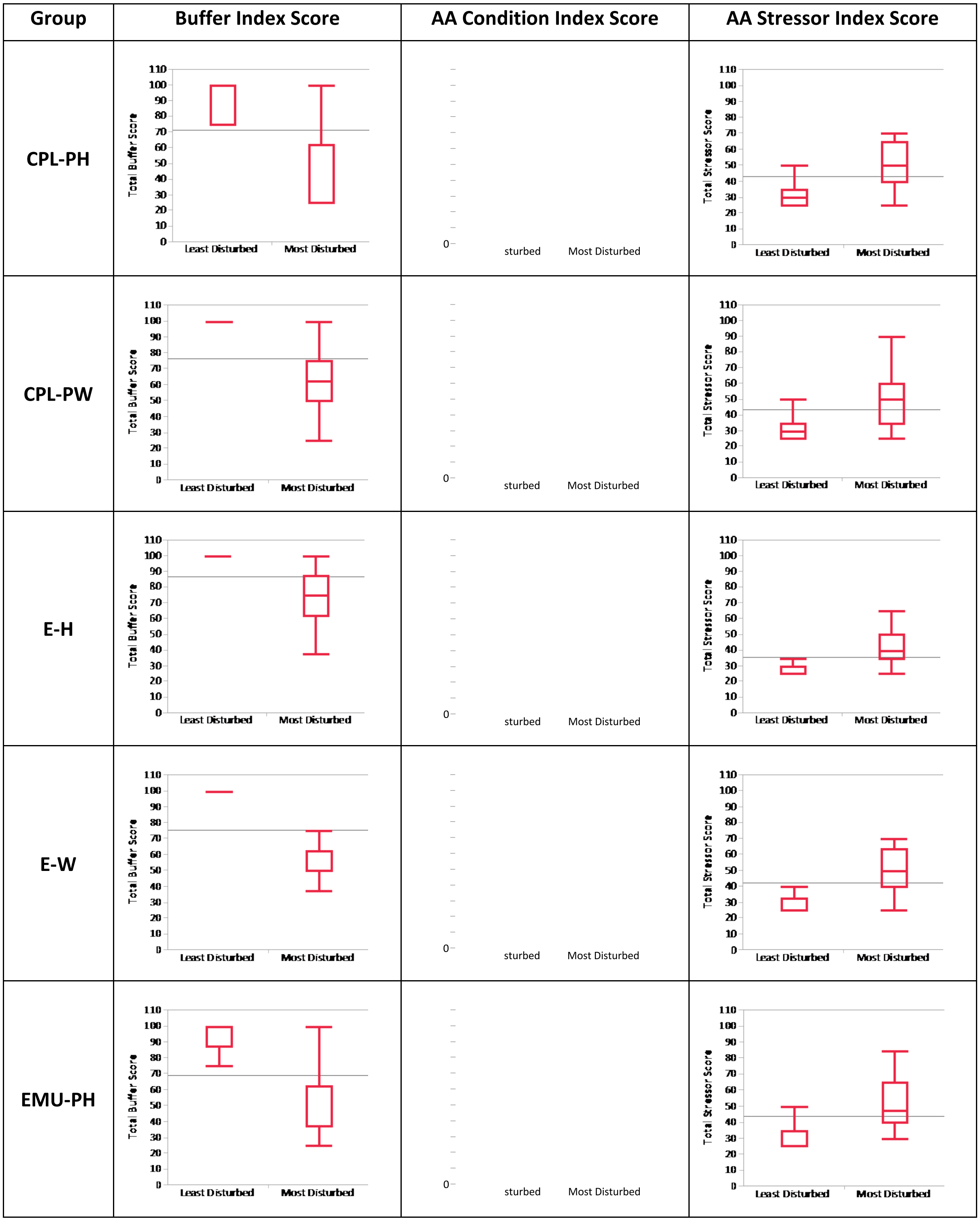
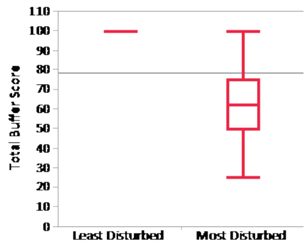
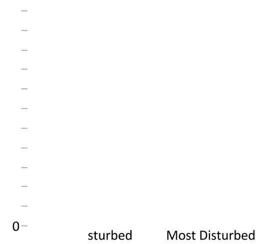
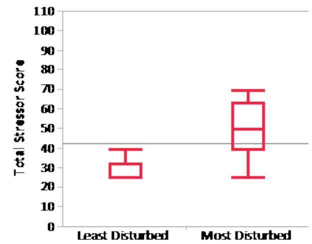
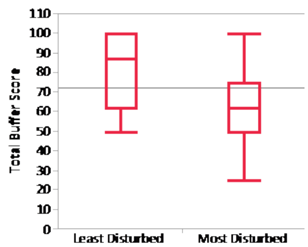
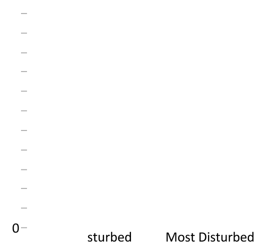
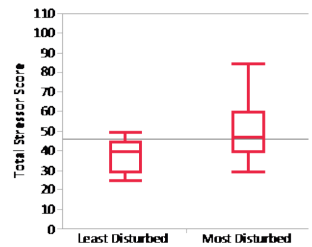
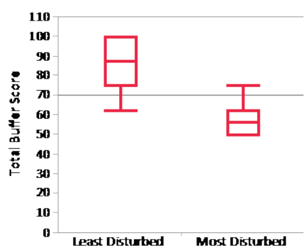
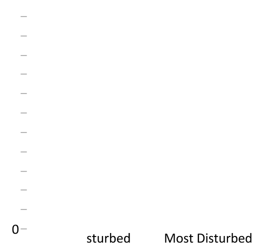
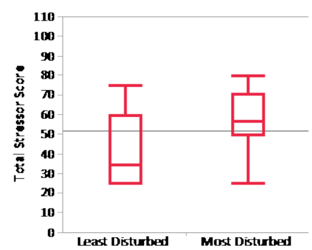
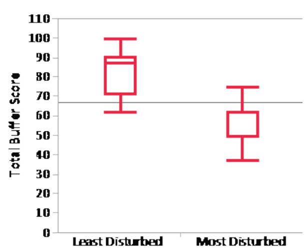
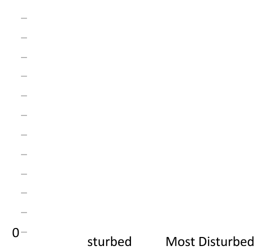
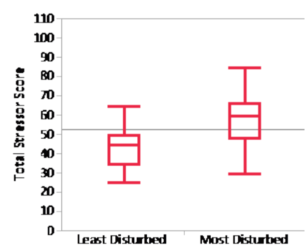
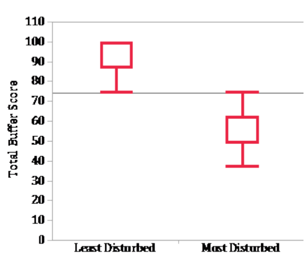
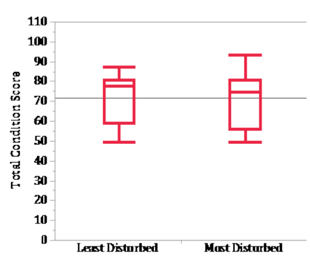
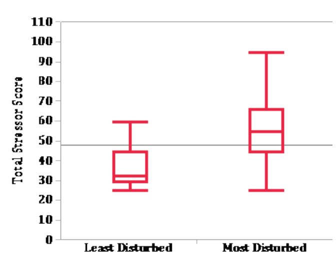


Figure 12-5. Box-plots for Buffer Index, AA Condition Index, AA Stressor Index scores for the least-disturbed and most-disturbed sites for the 10 NWCA Reporting Groups. Note high Stressor Index values indicate greater stress. This figure continues on the next page.

Figure 12-5 continued

Group	Buffer Index Score	AA Condition Index Score	AA Stressor Index Score
EMU-PW			
IPL-PH			
IPL-PW			
W-PH			
W-PW			

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12.4.3 *Efficacy of the Buffer Index, AA Condition Index, and AA Stressor Index*

The Efficacy of the Buffer Index, AA Condition Index, and AA Stressor Index was evaluated separately based on their ability to distinguish between the least-disturbed AAs and most disturbed AAs for each of the 10 NWCA Reporting Groups (**Table 12-5**). As described above, higher scores for the AA Stressor Index indicate more anthropogenic disturbance.

The efficacy of the Buffer Index and AA Stressor Index is high. For most of the Reporting Groups, the median values for these two indices are significantly different for the most-disturbed sites versus the least-disturbed AAs, and their interquartile ranges are clearly separate. The high efficacy of these two indices is likely due to their dependence on easily recognized visible indicators of common stressors that vary little between wetland types or ecoregions. For example, the evidence of ditching, vegetation control, and substrate disturbance is relatively obvious and very similar for all wetlands throughout the conterminous US. This means that many of the stressor indicators were universally applicable and could be consistently applied by the different ecoregion teams.

The AA Condition Index did not perform as well as the AA Stressor Index or the Buffer Index. The median values for the AA Condition Index were similar for the least-disturbed and most-disturbed AAs for most of the Reporting Groups. There are at least four likely reasons for this. First, while the USA-RAM Attributes and their component Metrics are universally applicable among wetland types and ecoregions of the US, the indicators of the Metrics are probably not. Based on the guiding principles or tenets of USA-RAM (see **Section 12.1.1**), it consists of a single set of field indicators that does not vary among all the ecoregions and wetland types of the conterminous 48 states. Other RAMs that consist of similar Attributes and Metrics either employ a single set of indicators for narrower range of wetland types (e.g., ORAM; Mack 2001), or different sets of indicators are employed for very different wetland types (e.g., CRAM; Collins et al 2008). The NWCA results suggest that the condition indicators of USA-RAM were not equally applicable among all the wetland types and ecoregions of the 2011 survey. Second, there is evidence that the reference conditions defined by the NCWA screening method (**Chapter 4**) may not pertain to the AA Condition Index of USA-RAM. The condition Metrics of USA-RAM are designed to assess the overall structural complexity of an AA, which does not have a clear relationship to the screening method. AAs defined as least-disturbed or most-disturbed by the screening method can be structurally very complex. Indeed, high values of the AA Condition Index were calculated across the range of condition as defined by the screening method (see following **Section 12.4.4.2** for further explanation). Third, linkages between some stressor Metrics and Condition Metrics can reduce the efficacy of the condition Metrics. Simply stated, some stressors in a wetland can increase its structural complexity, such that AAs having high values for the AA Stressor Index (indicating human disturbance) can also have high values for the AA Condition Index. Fourth, correct application of the condition metrics can require considerable interpretation subject to practitioner experience. To some degree, the relatively poor performance of the AA Condition Index was due to inconsistent application of the condition indicators among the assessment teams.

12.4.4 *Meaning of the Stressor Metrics*

The stressor metrics are based on easily observable field indicators of stress. They were grouped into different categories of stress based on the most closely associated aspects of wetland condition, namely water chemistry, hydroperiod, substrate and habitat, and vegetation.

As stated above, the USA-RAM stressor Metrics were able to differentiate among AAs across the range of condition as defined by then NCWA screening method. This is reflected in the calculations of the

Buffer Index and AA Stressor Index (**Figure 12-5**). All of the least-disturbed AAs in some Reporting Groups (e.g., CPL-PW, E-H, E-W, EMU-PW) had the maximum possible score (100) for the Buffer Index.

Information on stressors also provides a basis for identifying human activities that can be adjusted to reduce stress and thus improve condition. **Table 12-8** and **Table 12-9** show the total stressor counts (a sum of the number of stressor indicators checked in the field) for the least-disturbed and most-disturbed AAs for each Reporting Group. The sum of all stressors recorded in both the buffer zone and the AA are also shown. As expected, the total number of stressors recorded is substantially lower for the least-disturbed AAs than for the most-disturbed AAs, as defined by the NWCA screening method. For the buffer zone, the largest counts of stressors were recorded for the estuarine herbaceous wetlands (E-H). For AAs, the largest counts of stressors were recorded for the Coastal Plains palustrine woody (CPL-PW). The counts for Metric 10, Total Stressors to Substrate, received the highest counts in more than half of the Reporting Groups. This indicates that substrate disturbance was relatively common, particularly in the most-disturbed AAs (**Table 12-8**).

12.4.4.1 *Ranking Stressors*

To determine which stressors are most common to US wetlands, the stressor indicators (i.e., the individual stressors that make up each Metric) were ranked according to their frequency of observation by the assessment teams (**Table 12-10**). Ranks are shown for the three most common stressor indicators, which are assumed to have the greatest impact across the US, and the indicator selected least frequently, which is assumed to have the least impact. Invasive plant species was the most common stressor recorded in the buffer zone. For both the AAs and their buffer zone, the presence of ditches and dikes were among the most common stressor indicator noted, cumulatively affecting as much as 46% of the buffer zone of all wetlands, and 31% of all AAs. Thus, for the NWCA as a whole, the most widespread stressor indicators are due to activities that alter hydroperiods. It should be noted that for many AAs, the buffer zone was also wetland, so the presence of ditches and dikes in the buffer zones can directly impact the AAs. The most common cause of substrate disturbance was over-grazing, both by native and domestic animals.

Table 12-8. Total stressor counts recorded in the buffer and the AA for each NWCA Reporting Group, and the total stressors recorded for each of the individual stressor Metrics (M) in the AA for the ***Least-Disturbed*** AAs. Highlighted cells indicate the highest stressor count recorded for each Reporting Group. Because Metric 11, Cover of Invasive Species, is not based on a count of stressor indicators, it is not shown in this table.

Reporting Group	Sum of all Stressors in Buffer	Sum of all Stressors in AA	M8 Total Water chemistry Stressors in AA	M9 Total Hydroperiod Stressors in AA	M10 Total Substrate Stressors in AA	M12 Total Vegetation Stressors in AA
CPL-PH	11	18	1	2	8	7
CPL-PW	13	35	6	5	17	7
E-H	33	44	25	6	10	3
E-W	2	9	1	2	5	1
EMU-PH	19	7	1	2	1	3
EMU-PW	11	11	0	2	7	2
IPL-PH	46	36	14	6	7	9
IPL-PW	20	30	3	3	11	13
W-PH	44	40	7	9	15	9
W-PW	25	27	1	2	15	9

Table 12-9. Total stressor counts recorded in the buffer and the AA for each NWCA Reporting Group, and the total stressors recorded for each of the individual stressor Metrics (M) in the AA for the ***Most-Disturbed*** AAs. Highlighted cells indicate the highest stressor count recorded for each Reporting Group. Because Metric 11, Cover of Invasive Species, is not based on a count of stressor indicators, it is not shown in this table.

Reporting Group	Sum of all Stressors in Buffer	Sum of all Stressors in AA	M8 Total Water chemistry Stressors in AA	M9 Total Hydroperiod Stressors in AA	M10 Total Substrate Stressors in AA	M12 Total Vegetation Stressors in AA
CPL-PH	137	103	16	24	36	27
CPL-PW	282	229	43	65	75	46
E-H	337	172	44	88	32	8
E-W	112	62	9	25	18	10
EMU-PH	226	120	24	32	38	26
EMU-PW	182	96	19	24	32	21
IPL-PH	232	211	56	45	58	52
IPL-PW	64	65	29	16	14	6
W-PH	224	184	35	70	50	29
W-PW	120	80	15	17	29	19

Table 12-10. Ranking of the stressor indicators that were observed most frequently and least frequently, which are assumed to have the greatest and least impact, respectively, across the US. Metric 11, Cover of Invasive Species, is not included since it is not based on a count of stressor indicators.

Stressor Metric (M)	Rank of Stressor Indictor and % of NWCA AAs Affected							
	Most Common Indicator		2nd Most Common Indicator		3rd Most Common Indicator		Least Common Indicator	
M3 All Buffer Stressors	Invasive Species	31.7%	Ditches Present	26%	Dikes Present	20.3%	Mining	< 0.1%
M8 Water chemistry Stressors in AA	Algae	9.7%	Turbidity	8%	Sediment	7.2%	Septic Systems	0.3%
M9 Hydroperiod Stressors in AA	Dikes	16.2%	Ditches	15.0%	Upland Species	9.9%	Siphons	0.5%
M10 Substrate stressors in AA	Grazing by Native Species	19.2%	Grazing by Domestic Species	12.8%	Compaction	6.4%	Fire Lines	0.8%
M12 Vegetation Stressors in AA	Grazing	10%	Wildlife	7.6%	Mowing	5.5%	Fire	1%

12.4.4.2 *Links between Stressor Metrics and Condition Metrics*

As expected, there is a link between the scores for condition and stressor Metrics. For example, substrate disturbance (stressor Metric 8) can increase topographic complexity (condition Metric 4). Therefore, AAs having disturbed substrates (i.e., AAs for which stressor indicators for substrate disturbance were recorded) tended to have high scores for topographic complexity. For example, since over-grazing acts to increase micro-topographic relief, scores for topographic complexity were high for AAs where over-grazing was observed. Over-grazing was also the most common indicator of stress to substrates (see **Table 12-10**), and was a common stressor indicator among the most-impacted AAs. As a result of this linkage between over-grazing and micro-topographic relief, plus the association of over-grazing with the most-impacted AAs, many of these AAs had high scores for topographic complexity.

Such linkages between the stressor Metrics and condition Metrics contributed to the relative inability of the AA Condition Index to distinguish between the least-impacted and most-impacted AAs (see section 13.4.3).

12.4.5 *Sample Frame Effects*

Figure 12-6 shows a plot of the Cumulative Distribution Frequency (CDF) of the Site Index values for all AAs included in the NWCA. The range of possible Site Index values is 0 to 225. While the high end of the range is well represented, the low end of the range is not. There are almost no AAs with index values less than 50. Fully 100% of NWCA AAs had scores greater than 46, and 95% of sites had scores greater than 85. It should be noted that the CDF is based on the number of AAs, rather than wetland area. However, it is common that highly disturbed sites tend to be small and fragmented (Lopez and Fennessy 2002; Fennessy et al. 2007a). Therefore, had this CDF been plotted using wetland area, the under-representation of highly disturbed AAs may have been even more pronounced. A cursory examination of 30 AAs having low values for the AA Condition Index indicated that their encompassing wetlands were not especially small, relative to the size distribution of intensively mapped wetlands in some ecoregions.

The site selection process seems to have favored larger wetlands. One consequence of this was to greatly increase the abundance of AAs with intact buffers. This because an AA in a large wetland tends to be completely surrounded by other areas of the same wetland that qualify as buffer land cover (see **Table 12-4**). Nearly all AAs had the full extent of buffers possible; 92% of all AAs were assigned to the highest-scoring category (75% – 100% cover) for Metric 1 (percent of AA perimeter adjoining a buffer land cover), while only 2% of the AAs were assigned to the lowest-scoring category. The very low efficacy of this Metric resulted in its omission from the USA-RAM analysis. The data for Metric 2, mean buffer width, were similarly distributed, with over 50% of the AAs being assigned to the upper quartile of possible mean buffer widths, and only 3.5% being assigned to the lower quartile. The systematic bias of the sample frame against small wetlands clearly reduced the range of the Buffer Index, thus reducing its ability to differentiate among AAs across the gradient of their condition.

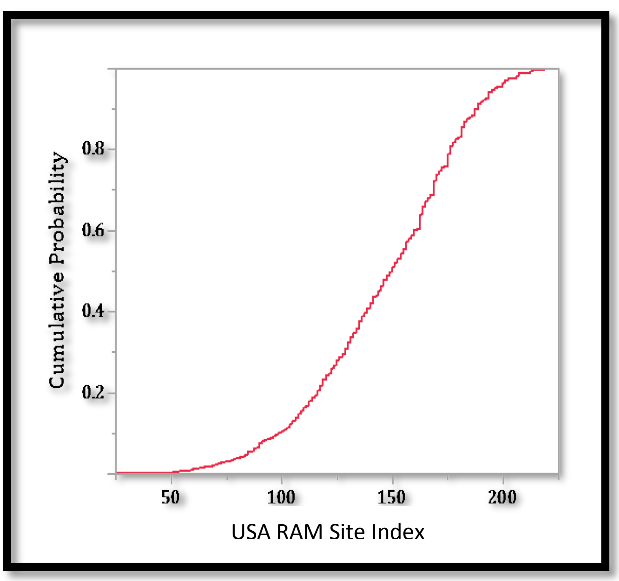

Figure 12-6. Cumulative frequency distribution of USA-RAM Site Index scores. The possible range of scores is 0-225. While sites at the top end of the condition gradient appear well represented, sites at the low end of the range (< 50) are lacking.

12.4.6 *Habitat Assessment with USA-RAM*

The condition Metrics in the USA-RAM were designed to evaluate the structural complexity of wetlands. The assumption underlying this design is that the capacity or potential of a wetland to sustain high levels of its intrinsic ecosystem services increases with its natural structural complexity. The structural complexity of wetlands has been correlated to a broad variety of their services, including peak flood reduction, pollutant filtration, chemical processing, biodiversity support, and especially overall habitat diversity and quality for wildlife (Fennessy et al. 2007; Collins et al. 2008; Stein et al. 2009; Faulkner et al. 2011; Steven and Gramling 2012). USA-RAM can therefore be especially useful for assessing wetlands as wildlife habitat. For example, the diversity of wetland dependent and riparian bird species has been linked to indicators of structural diversity metrics in the Ohio Rapid Assessment Method (ORAM), including those based on microtopography, vegetation communities, and modifications to hydrology (Stapanian et al. 2003). Many rapid assessment methods use the number of vegetation community types (including the extent of invasive species) as a proxy for overall community diversity (Mack 2001; Fennessy et al. 2007). The Montana Wetland Assessment Method is one example that rates structural diversity using the number of Cowardin vegetation classes present, and relates those to the provision of wildlife habitat. Food chain support has been assessed relative to vegetation cover and structural diversity (Burglund 1999). USA-RAM adds the assessment of wetlands as habitat to the NWCA, which extends the ecosystem services that are evaluated in the survey.

12.4.7 *Verification with Level 3 Vegetation Data*

USA-RAM provides measures of wetland stress and condition that complement the assessments provided by more intensive methods (i.e., Level 3 methods). It also provides measures of overall condition or health, and helps identify human actions that can be taken to reduce stress and otherwise improve conditions. The Level 3 methods focus on key biotic assemblages and other aspects of stress or condition, and are essential to quantify relationships between conditions and human actions.

Although USA-RAM and the Level 3 NWCA methods serve different, complementary purposes, some degree of correlations between their results is expected. Such correlations have two obvious applications. First, a high degree of correlation can justify replacing some relatively expensive Level 3 assessment with the less expensive USA-RAM. Combinations of rapid and Level 3 assessment can increase the overall geographic scope or density of assessment per unit of time or cost. Second, the correlations can be used to identify or verify the ecosystem services that are represented by USA-RAM. For example, knowing the degree to which USA-RAM correctly characterizes ecological condition as related to plant community metrics requires regressing the USA-RAM results on the more quantitative Level 3 measures of plant diversity as it relates to ecological condition. Establishing the relationship between USA-RAM and Level 3 NWCA data provides confidence on the reliability and defensibility of USA-RAM. However, caution should be exercised before using correlations between USA-RAM and Level 3 data to calibrate USA-RAM. That is, the correlations should usually not be used to adjust the USA-RAM Metrics, their indicators, or their scoring tables. The justification for this is that USA-RAM was designed to assess the overall potential or capacity of a wetland area to provide high levels of all or most of its intrinsic ecosystem services, and adjusting the method to increase the correlations of its results to any one or a few services may decrease its correlation to other services.

At the time of this analysis, several Level 3 plant metrics that will be part of the vegetation MMI development effort for the NWCA were made available for testing against the USA-RAM results. The Level 3 metrics are based on the Floristic Quality Assessment Index (FQAI) and its component Coefficients of Conservatism (C-values) (see **Chapter 5**). Both the FQAI and the mean C-values for wetlands have been shown to have a strong linear response to wetland disturbance (Fennessy et al. 1998; Lopez and Fennessy 2002). The FQAI is based on the concept that the ecological condition of a wetland can be objectively evaluated by examining the degree of conservatism (or tolerance) of the wetland's plant species. We found statistically significant positive correlations between values of the USA-RAM Site Index and the Levels 3 floristic metrics, with correlation coefficients ranging from 0.58 to 0.08. In eight cases, the correlation coefficient was greater than 0.4, and in four cases the coefficient was greater than 0.5 (**Table 12-11**). The weakest correlation was seen for estuarine herbaceous sites, which naturally tend to have very low plant diversity. The strongest correlation was seen for EMU-PH and W-PH. Considering the broad variability in plant species composition and richness among the broad range of wetland types and ecoregions included in the NWCA, the degree of correlation between the Level 3 plant metrics and the USA-RAM results strongly suggests that USA-RAM can be used to assess overall ecological condition and the ecosystem services associated with community structure of wetlands. Further verification will take place as the final Vegetation MMI data are available.

Table 12-11. Correlation coefficients for regression between USA-RAM Site Index values and the Level 3 NWCA Floristic Quality Assessment Index (FQAI) and mean Coefficients of Conservatism (Mean C) for each Reporting Group. Highlighted cells show correlations > 0.40.

NWCA Reporting Group	Correlation Coefficients (all with $p < 0.01$)	
	USA-RAM vs. FQAI	USA-RAM vs. Mean C
CPL-PH	0.225	0.504
CPL-PW	0.360	0.432
E-H	0.080	0.210
E-W	0.360	0.151
EMU-PH	0.580	0.470
EMU-PW	0.170	0.260
IPL-PH	0.273	0.270
IPL-PW	0.254	0.425
W-PH	0.414	0.381
W-PW	0.524	0.524

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