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Wetland Assessment: Beyond the Traditional Water Quality Perspective

Mary E. Kentula, Amanda M. Nahlik, Steven G. Paulsen and Teresa K. Magee

Abstract

Use of water chemistry or water quality data as the sole indicator to determine if aquatic ecosystems meet restoration objectives or Clean Water Act criteria is not possible for wetland resources because surface water presence varies across wetland types. The 2011, National Wetland Condition Assessment (NWCA) assessed 967 sites representing 25,153,681 ha of wetland across the conterminous US. Surface water could be collected at 537 sites representing only 41% of the wetland population area and under-representing particular wetland types. These results motivated the authors to introduce the concept of *aquatic resource quality*, the condition of an ecosystem based on the integrated assessment of physical, chemical, and biological indicators, as the goal of monitoring and assessment of aquatic systems. The NWCA is an example of the use of *aquatic resource quality*. The survey successfully reported on wetland condition using a biotic indicator (the vegetation multimetric index) and the relative extent and relative risk of stressors using 10 physical, chemical, and biological indicators to report on *aquatic resource quality*. The NWCA demonstrated that *aquatic resource quality* can be consistently evaluated regardless of surface water presence. Consequently, we recommend *aquatic resource quality* as the goal of aquatic ecosystem monitoring and assessment.

Keywords: wetlands, monitoring and assessment, National Wetland Condition Assessment, aquatic resource quality, National Aquatic Resource Surveys, water chemistry, water quality

1. A new paradigm: *Aquatic resource quality*

For many, the terms water quality and water chemistry are synonymous, but others (e.g., Eriksson [1]) recognize a subtle yet important distinction between the terms. While the term water chemistry refers to the chemical composition of the water; water quality implies a value judgment on the suitability of the composition of the water for a specific use. Typically, the composition of the water is defined by chemical characteristics (as in Eriksson [1]), but sometimes physical or biological aspects of the water, such as turbidity, color, or odor, are used. Making a distinction between the definitions of water chemistry and water quality is essential for clear communication. To further avoid the ambiguities surrounding the use these terms,

we introduce the concept of *aquatic resource quality* for reporting based on the physical, chemical, and biological integrity of aquatic resources as outlined in the goals of the Clean Water Act (CWA) [2].

Aquatic resource quality is defined herein as the condition of an aquatic eco-system. Evaluating *aquatic resource quality* requires the integrated use of physical, chemical, and biological indicators to describe the condition of the resource and identify factors negatively affecting the condition [3]. Wetlands are an excellent test case for examining the application of the *aquatic resource quality* concept because traditional use of only water chemistry or water quality to determine whether rivers, streams, and lakes meet CWA criteria is not consistently possible for wetlands. Wetlands do not always have surface water. This is because the surface water in wetlands varies on seasonal and annual time scales, with regimes ranging from permanently flooded to saturated (i.e., substrate is saturated to the surface for extended periods, but surface water is seldom present) to intermittently flooded (i.e., weeks, months, or years may intervene between periods of inundation) [4]. Furthermore, certain wetland types, like fens, are groundwater-driven and rarely have surface water. Because sampling surface water for determination of chemistry is not always possible in wetlands, the adoption of the *aquatic resource quality* concept is required to holistically characterize the wetland resource.

Wetlands are a critical part of the Nation's aquatic resources and are protected under the CWA. Because of this, there is an obligation to include wetlands in monitoring programs for reporting under the CWA—despite the challenges associated with sampling wetlands. Fortunately, there is ample evidence that the wetland resource can be successfully assessed at large scales based on the *aquatic resource quality* concept (e.g., [5–7]). This early research helped inform the development of the National Wetland Condition Assessment (NWCA), which was first conducted in 2011 by the US Environmental Protection Agency (USEPA) to fulfill the objective of determining a baseline for *wetland resource quality* in the conterminous US. The goals of the NWCA were to:

- "produce a national report describing the 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" [8].

In this chapter, we present a summary of the 2011 NWCA design and methods, and then use national-scale data to report on patterns in the distribution of the wetlands represented by surface water chemistry. Finally, we examine how the NWCA fulfills the more comprehensive objective of reporting on *wetland resource quality* in accordance with the CWA requirements to consider the physical, chemical, and biological integrity of the wetland resource.

2. Data collection for the 2011 NWCA

The following subsections provide a brief overview of the design and field sampling methods used in the NWCA. For details see the 2011 NWCA Site Evaluation

Guidelines [9], Field Operations Manual [10], Laboratory Methods Manual [11], and Technical Report [12]. These documents are available on the NWCA website (https://www.epa.gov/national-aquatic-resource-surveys/nwca).

2.1 2011 NWCA survey design

The target population, that is, the specific portion of the wetlands of the conterminous United States (US) to be assessed in the 2011 NWCA was composed of tidal and nontidal wetlands with rooted vegetation and, when present, open water less than 1 m deep, and includes farmed wetlands not in crop production at the time of the survey [8]. The target population was comprised of seven of the wetland classes used in the US Fish and Wildlife Service's (USFWS) Wetlands Status and Trends (S&T) reporting [13]: Estuarine Intertidal Emergent (E2EM), Estuarine Intertidal Forested/Scrub Shrub (E2SS), Palustrine Emergent (PEM), Palustrine Farmed (Pf), Palustrine Forested (PFO), Palustrine Scrub Shrub (PSS), and Palustrine Unconsolidated Bottom/Aquatic Bed (PUBPAB). These classes are an adaptation of those defined by Cowardin et al. [4] and used in USFWS National Wetland Inventory (NWI) mapping.

A spatially balanced probability survey design [14–16] was developed using plots from the USFWS S&T Program as a basis for a sample of site locations for the NWCA. The USFWS S&T plots were mapped using 2005 aerial photography. The S&T Program mapped additional plots on the Pacific Coast at the request of the NWCA to assure sites would be selected for sampling along the coast due to the lower frequency of wetland occurrence in the Western US than in other parts of the country (**Figure 1**). The NWCA design allocated site locations by state and wetland class, generating 1800 potential site locations to ensure approximately 900 sites meeting target criteria would be available for sampling [12, 17]. Nine-hundred sites allow evaluation of different wetland types in the conterminous US and five major ecoregions. Ultimately, 967 sites from the probability design were sampled (**Figure 1**).
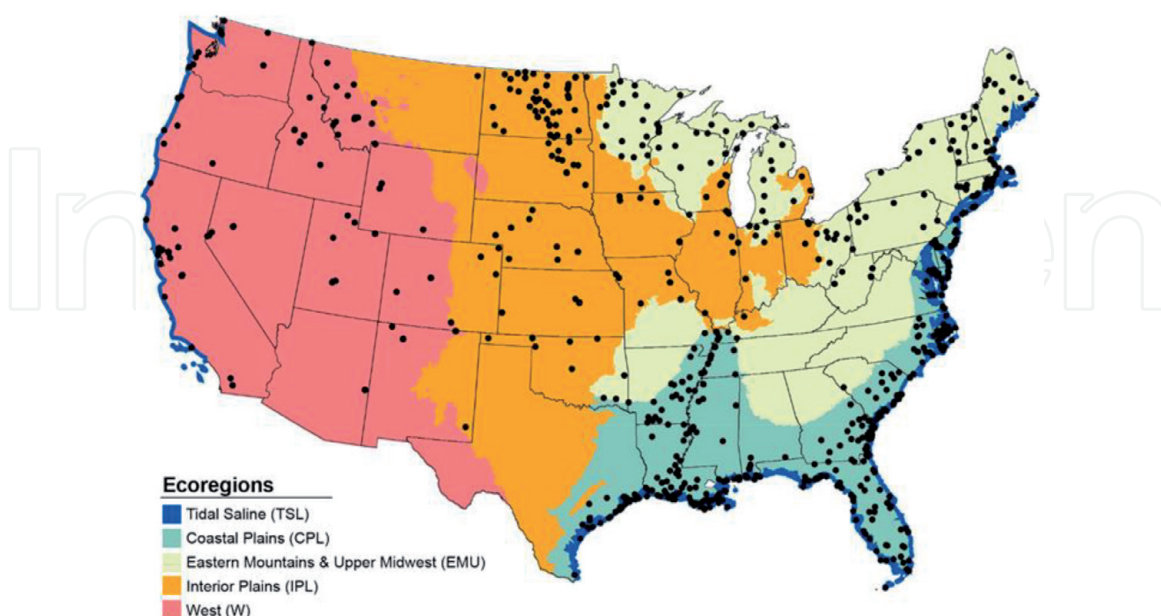

Figure 1.
Map of the 967 site locations sampled in the 2011 National Wetland Condition Assessment by five Ecoregions: Tidal Saline (TSL), Coastal Plains (CPL), Eastern Mountains & Upper Midwest (EMU), Interior Plains (IPL), and West (W). Note that CPL, EMU, IPL, and W exclusively include freshwater wetlands. The pattern of site locations reflects the distribution of wetlands across the conterminous United States with most wetland areas in the East and Southeast and the least in the Midwest and West.

As part of the design process, weights were assigned to each of the 1800 potential site locations that indicate the wetland area (i.e., the number of hectares) of the NWCA target population represented by the site (Olsen et al. [17]). After the 967 sites were visited, the weights were adjusted to account for the inability to sample sites, for example, due to denial of access, a site being inaccessible (i.e., safety issues), or a site failing to meet the target criteria (i.e., non-target). Finally, the adjusted weights were used to calculate the extent estimates of the wetland resource, expressed as hectares or percent of the wetland area, for different groupings (or subpopulations) of wetlands. The subpopulations presented in the 2011 NWCA final report (USEPA [8]) were ecoregion and wetland type. For a more detailed description of how this was done, see Diaz-Ramos et al. [18], Kincaid and Olsen [19], and Olsen et al. [17].

2.2 Field sampling for the 2011 NWCA

NWCA protocols for sampling each site were designed to be completed by a four-person field crew during a single day during peak growing season when most plants are in flower or fruit to optimize species identification and characterization of species abundance. This typically occurs between April and September depending on the status of the vegetation for sampling at the location of the site [10, 20]. The standard assessment area (AA) was a 0.5-ha circular plot with a 40-m radius, centered on the site location from the design (**Figure 2**). A buffer extended 100 m from the edge of the AA. If the wetland size and shape made the standard, circular
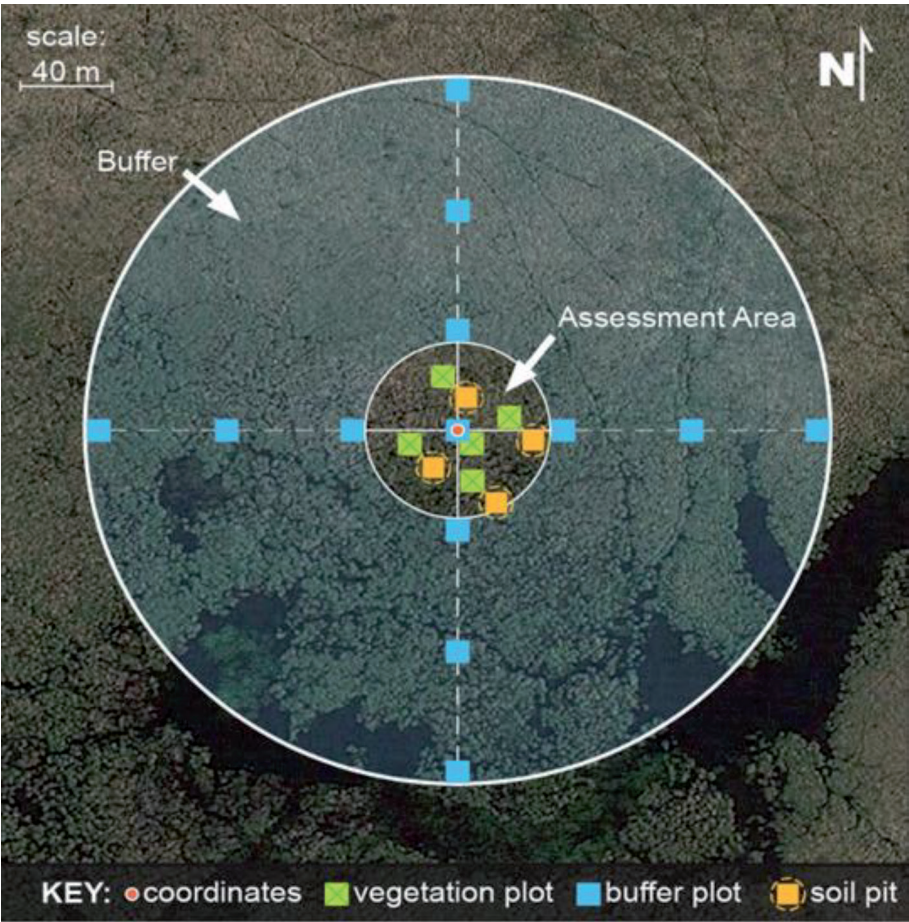

Figure 2.
Diagram of a standard layout for a 0.5-ha assessment area and surrounding 100-m buffer (adapted from USEPA [10]). Locations of the coordinates for the site location generated by the survey design, of vegetation and buffer plots, and of soil pits are indicated.

AA unfeasible, alternate configurations of the AA and buffer were established using a rule-based system [10]. Sample plots were established in the AA and buffer according to standardized protocol to collect observational data and samples associated with physical, chemical, and biological aspects of each site.

Physical aspects of the site were characterized by evidence of human activities in the AA and buffer. Using a standardized checklist of 52 predefined human activities, field crews collected observational data associated with anthropogenic disturbance from thirteen 100-m^2 plots (one in the center of the AA; 12 in the buffer), and on hydrologic alterations throughout the entire AA (**Figure 2**) [10, 21].

Chemical aspects of the site were characterized using nutrient and heavy metal data associated with soil and surface water samples. To collect soil samples, field crews first excavated four soil pits (**Figure 2**), describing each soil horizon to a depth of 60 cm [10]. Crews chose the pit that best reflected the soils on the site based on the descriptions of the soil horizons and expanded it to 125 cm, collecting soil samples for each horizon. Soil samples were analyzed for heavy metals and phosphorus, among other analytes, by the US Department of Agriculture, Natural Resource Conservation Service, Kellogg Soil Survey Laboratory, Lincoln, Nebraska, using standard procedures [11, 22]. Surface water samples were collected as close to the center of the AA as possible at sites where adequate (≥15 cm deep) surface water was present in the AA and prior to conducting other sampling activities to avoid disturbance of the water and substrate, and before 1100 h to avoid diurnal changes in the chemistry [10]. The characteristics of the location from which the water sample was collected were recorded, including the stage of tide for tidal sites.

Biological aspects of the site were characterized using vegetation data. Field crews recorded plant species identity and abundance data in five, systematically placed, 100-m^2 vegetation plots within the AA (**Figure 2**) [10, 11, 23, 24]. A variety of information describing attributes of vegetation structure was also collected within each plot.

3. Understanding what *wetland water chemistry* represents

The value of the probability design used in the NWCA is that the wetland sites sampled represent the larger population of wetlands that meet the target definition. In other words, data that were collected at the 967 wetland sites sampled in 2011 can be inferred to 25,153,681 ha of wetland area across the conterminous US.

Most kinds of data were collected at all wetland sites; however only a portion of the sites had surface water during the 2011 field visits, so water chemistry samples could be collected from just 537 sites of the 967 sampled sites. Factoring in the design weights from the sites with water samples, only 41%, or 10,408,004 ha of the 25,153,681 ha of total sampled population was represented by surface water chemistry. In addition, the 10,408,004 ha represented by water chemistry data do not represent the total sampled population. This is most evident in the proportion of wetland area with water chemistry data in each of the five ecoregions (**Figure 3a**). Surface water chemistry was most commonly sampled in the Tidal Saline (TSL) and Interior Plains (IPL) regions, and represented 72 and 62%, respectively, of the total sampled awetland area. Water chemistry data for the Coastal Plains (CPL), Eastern Mountains and Upper Midwest (EMU), and West (W) represented, respectively, 33, 34, and 47% of the estimated wetland area in each of these ecoregional subpopulations. The proportion of wetlands with surface water in each ecoregion is driven by climatic differences [25], and by characteristics of the landscape [26–29].

Characteristics of the landscape that drive wetland structure and function are embodied in the hydrogeomorphic (HGM) classification [30, 31]. HGM wetland
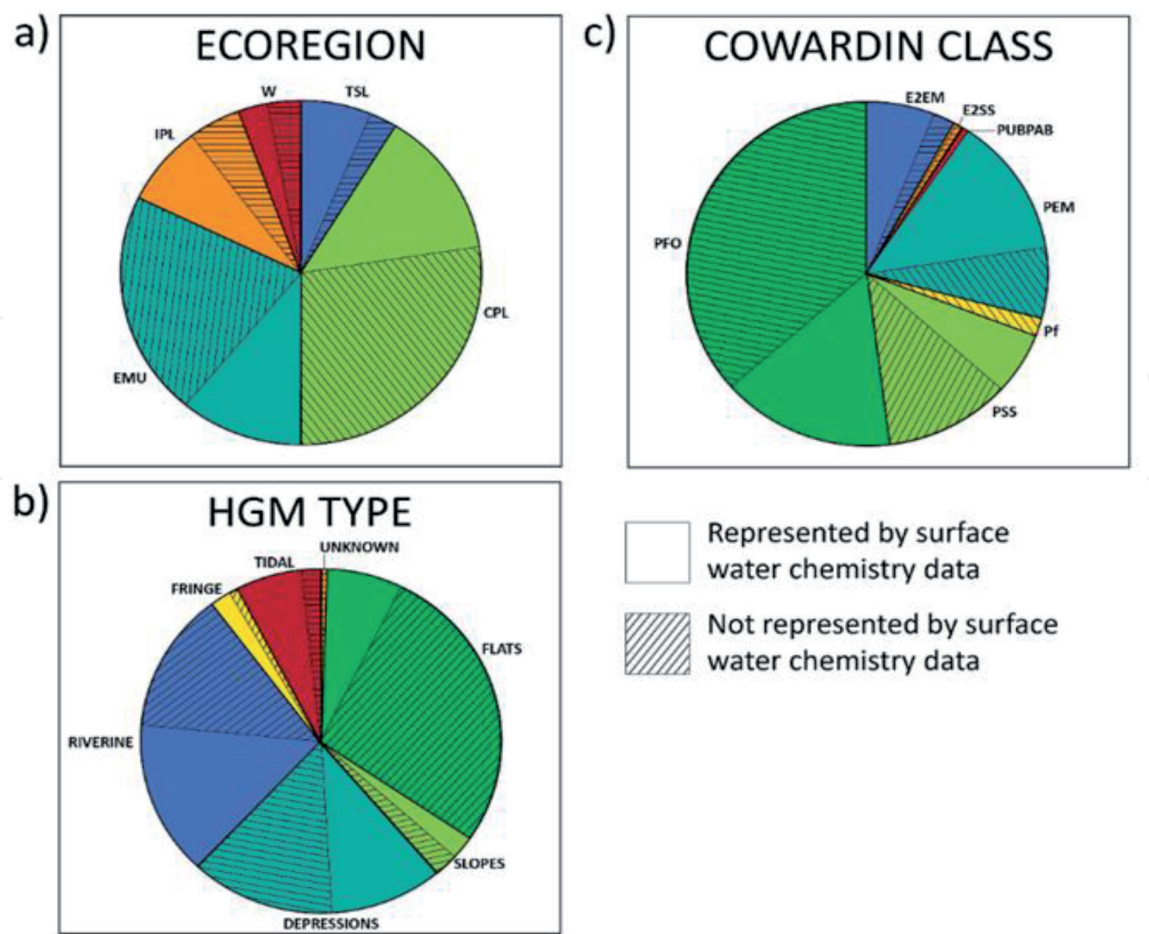
Figure 3.
Proportional area of the 2011 National Wetland condition assessment (NWCA) sampled wetland population represented (solid wedges) and not represented (hatched wedges) by surface water chemistry data. The sampled wetland population is presented using three different wetland groupings: (a) Ecoregion (TSL = Tidal Saline, CPL = Coastal Plains, EMU = Eastern Mountains and Upper Midwest, IPL = Interior Plains, and W = West), (b) hydrogeomorphic (HGM) type, and (c) Cowardin Class (E2EM = Estuarine Intertidal Emergent, E2SS = Estuarine Intertidal Forested/Scrub Shrub, PUBPAB = Palustrine Unconsolidated Bottom/ Aquatic Bed, PEM = Palustrine Emergent, Pf = Palustrine Farmed, PSS = Palustrine Scrub Shrub, and PFO = Palustrine Forested). For HGM type, unknown represents wetland area that was unable to be classified by the field crews. Note that solid and hatched wedges within the same color together represent 100% of the sampled wetland area within the subpopulation.

types are flats, slopes, depressions, riverine, fringe, and tidal [30–33]. These types are arranged along a hydrologic gradient from the least to the most surface water in **Figure 4**. Perhaps, unsurprisingly given that flats have the least surface water, water chemistry data only represented 20% of the total area of flats in the sampled population (**Figure 3b**). Conversely, tidal and fringe HGM types, which tend to have the most surface water throughout the year, had water chemistry data for 77 and 71% of their sampled wetland area, respectively. Slopes, depressions, and riverine wetlands encompass a wide range of varying hydrologic regimes; about half of the wetland area each of these HGM types were represented by water chemistry data (51, 44, and 52%, respectively).

While HGM classifies wetlands based on a hydrologic gradient, Cowardin wetland classes [4], used in the NWCA design, characterizes wetlands by the type of dominant vegetation. Again, the water chemistry does not equally represent the total sampled wetland area associated with each class. Wetland classes dominated by floating and rooted submerged vegetation (PUBPAB) and emergent herbaceous vegetation (E2EM, PEM) are better represented by the water chemistry data than are wetland classes dominated by forest (PFO) and shrub scrub (E2SS, PSS).
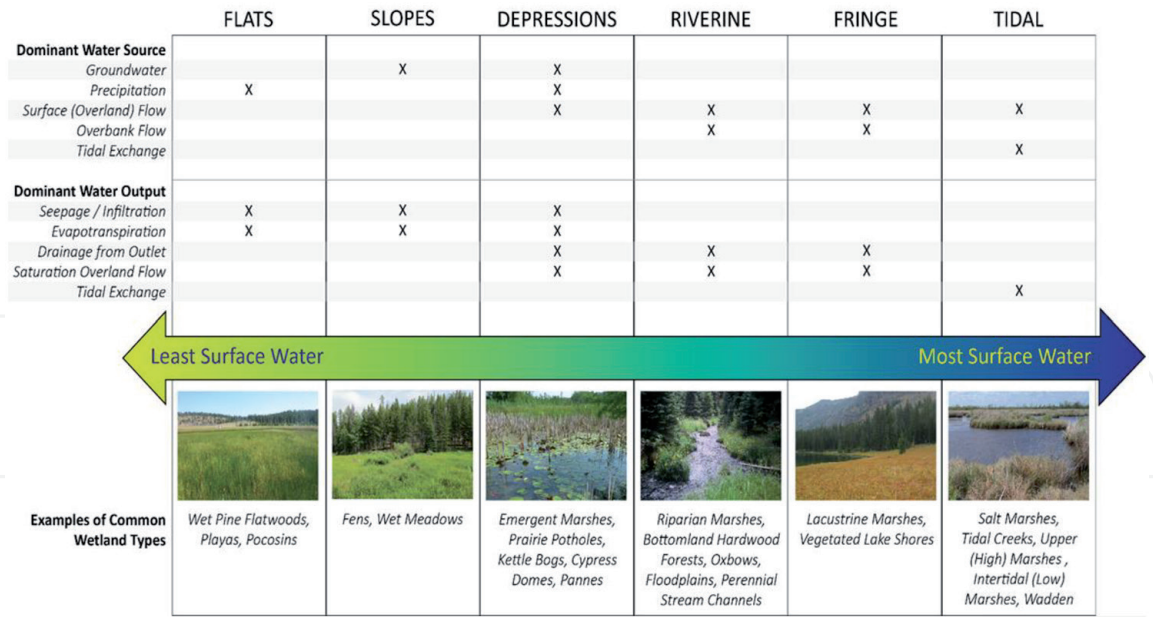
	FLATS	SLOPES	DEPRESSIONS	RIVERINE	FRINGE	TIDAL
Dominant Water Source						
Groundwater		X	X			
Precipitation	X		X			
Surface (Overland) Flow			X	X	X	X
Overbank Flow				X	X	
Tidal Exchange						X
Dominant Water Output						
Seepage / Infiltration	X	X	X			
Evapotranspiration	X	X	X			
Drainage from Outlet			X	X	X	
Saturation Overland Flow			X	X	X	
Tidal Exchange						X

Least Surface Water → Most Surface Water

| Examples of Common Wetland Types | Wet Pine Flatwoods, Playas, Pocosins | Fens, Wet Meadows | Emergent Marshes, Prairie Potholes, Kettle Bogs, Cypress Domes, Pannes | Riparian Marshes, Bottomland Hardwood Forests, Oxbows, Floodplains, Perennial Stream Channels | Lacustrine Marshes, Vegetated Lake Shores | Salt Marshes, Tidal Creeks, Upper (High) Marshes, Intertidal (Low) Marshes, Wadden |

Figure 4.
The gradient of hydrologic conditions associated with hydrogeomorphic (HGM) wetland types as characterized by their dominant water sources and water outputs. Photos exemplifying each HGM wetland type were taken by the NWCA field crews.

Figure 3c shows that 94% of PUBPAB, 76% of E2EM, 66% of PEM wetland area was represented by surface water chemistry data, while only 30% of PFO, 33% of E2SS, and 34% of PSS wetland area were represented by surface water chemistry data.

Our results from the NWCA show that using water chemistry to determine whether the wetland resource meets CWA criteria poses a number of issues. Wetland water chemistry data are biased relative to ecoregions, HGM wetland types, and Cowardin wetland classes [4]. This is because water chemistry data tend to capture wetlands that are permanently flooded, clearly under-representing precipitation- and groundwater-driven wetlands and wetland types that drawdown during the summer (i.e., when sites were sampled). Wetlands dominated by herbaceous vegetation were better, but far from completely, represented by the 2011 water chemistry data, compared to wetlands dominated by woody vegetation where only a third of the area was represented. Water chemistry is often seen as a fundamental component for monitoring and evaluating aquatic systems; however, in the case of the majority of wetlands (where the presence of surface water is highly variable) interpreting what water chemistry results represent and what they signify is problematic.

4. Measuring *wetland resource quality* through the 2011 NWCA

Surface water chemistry as an indicator of chemical integrity is limited to wetland types that have permanent or recurrent surface water or require continuous monitoring throughout the year to capture wetland types that have ephemeral or infrequent surface water. Collecting surface water samples from some wetland types that rarely have surface water, like flats and slopes (**Figure 4**), may be unfeasible. Water chemistry is not a consistently available, readily interpretable, indicator for wetlands across the nation.

Fortunately, there are physical, chemical, and biological indicators of integrity that can be measured consistently and are easily interpreted. Using a suite of

physical, chemical, and biological indicators to describe condition also directly addresses the recommendations in the CWA. The 2011 NWCA illustrates how physical, chemical, and biological indicators were employed as the basis for assessing condition.

4.1 Use of condition to report on the state of *wetland resource quality*

Condition of an ecosystem can be expressed in different ways—ecological, or by individual components (biological, chemical, physical). Biological condition of the wetland resource at national and regional scales in the 2011 NWCA was used to report on the state of *wetland resource quality*. To evaluate the biological condition of wetlands, a multimetric index was developed based on plant species and trait data collected as part of the NWCA [12, 23]. Although the Vegetation Multimetric Index (VMMI) is biological in nature, it is calibrated using physical, chemical, and biological data that reflect the level of anthropogenic disturbance at a site.

Physical, chemical, and biological data resulting from information collected in the field were used to construct 10 measures of anthropogenic disturbance [10, 34]. Eight indices utilized observational data to describe physical disturbance [21]; one index used concentrations of heavy metals in the wetland soils to describe chemical disturbance [22]; and one metric for relative cover of alien plant species was used to describe biological disturbance. For each of the 10 measures, thresholds were established to reflect the degree of human impact to the site. A screening approach was used to categorize sites as least disturbed, moderately disturbed, or most disturbed based on the frequency at which thresholds were exceeded [12, 34]. Least disturbed sites, which represented the best attainable conditions given the state of the landscape [35], were used as a measure of physical, chemical, and biological reference condition in developing the VMMI.

Development of the VMMI is described in detail in Magee et al. [23] and began with calculation of 405 candidate metrics describing different vegetation properties with probable relationships to biological condition. The potential efficacy of each metric in reflecting biological condition was evaluated using a variety of objective screening tests with cut-offs appropriate to wetland data including: (1) sufficient range in values to allow detection of signals in response to disturbance; (2) repeatability, quantified using a signal to noise ratio (S:N) based on repeat sampling of a subset of sites (see Magee et al. [23] for a discussion of S:N); and (3) responsiveness, that is, how well a metric distinguished least disturbed from most disturbed wetland sites sampled in the NWCA. Candidate metrics that passed the screening criteria were examined for utility as components of potential VMMIs. Many thousands of potential VMMIs combining from 4 to 10 individual metrics were calculated and evaluated using approaches similar to Van Sickle [36] and Stoddard et al. [37], but adapted for wetlands, to identify the VMMIs with the best performance and with limited redundancy (correlation) among metrics included in a particular VMMI [23]. The final national-scale VMMI for the 2011 NWCA was based on the combination of four metrics, all broadly applicable across major classes of wetlands (**Table 1**). The VMMI is scaled from 0 to 100, with higher values representing better biological condition. To translate the continuous VMMI scores to condition categories, thresholds for delineating "good," "fair," and "poor" condition were determined based on the distribution of VMMI values in least-disturbed sites [23] using the percentile approach described in Paulsen et al. [38].

Biological condition of wetlands, reported as "good," "fair," and "poor" by the 2011 NWCA, reflects the state of the *wetland resource quality* as measured at all 967 sampled wetland probability sites, representing 25,153,681 ha of wetlands across

Metric name	Metric description	Calculation
Floristic Quality Assessment Index (FQAI)	Based on all species observed	**FQAI = Σ CC*ij*/ √N*j*** where CC$_{ij}$ = coefficient of conservatism for each unique species *i* at site *j* N = number of species at site *j*
Relative importance of native species	Combines relative cover and relative frequency for native taxa at each site	**((Σ Absolute Cover native species$_i$/Σ Absolute Cover all species$_i$) × 100 + (Σ Frequency native species$_i$/Σ Frequency all species$_i$) × 100)/2** where for each unique species *i*: absolute cover = 0–100%, frequency = 0–100% calculated as the percent of plots in which it occurred
Richness of disturbance-tolerant species	Tolerance to disturbance defined as coefficient of conservatism (C-value) ≤ 4	**Number of taxa with C-value ≤ 4 occurring at a site**
Relative cover of native monocots	Relative cover of native monocot species at each site	**(Σ Absolute Cover native monocot species$_i$/Σ Absolute Cover all species$_i$) × 100**

Table 1.
The four metrics, and equations for their calculation at each sampled site, that were included in the 2011 National Wetland Condition Assessment (NWCA) vegetation multimetric index (VMMI) as described in Magee et al. [23].

the conterminous US. Specifically, results from the survey showed that 48% of the target sampled wetland area in the nation was in good condition, 20% was in fair condition, and 32% was in poor condition (**Figure 5**) [8].

4.2 Evaluation of *wetland resource quality* using indicators of stress

While condition describes the state of *wetland resource quality*, it is equally important to understand factors that negatively affect *wetland resource quality* in making policy and resource management decisions. This requires an evaluation using physical, chemical, and biological stressor data [3]. The concepts of relative extent and relative risk were used to report the magnitude of six physical indicators of stress [21], two chemical indicators of stress [22], and one biological indicator of stress across wetlands of the US [24] to evaluate the impact of the chemical and physical stressors on the state of the *wetland resource quality* [39].

Using observational data collected in the buffer and in the assessment area (AA), an Anthropogenic Stress Index (ASI) was developed for six physical stressor categories: vegetation removal, vegetation replacement, damming, ditching, hardening, and filling/erosion (**Table 2**). Thresholds that indicate the degree of physical stress associated with each physical stressor were established [12, 21]. Each site was assigned to either low, moderate, or high stressor levels for each of the six stressor categories based on its ASI score.

Soil chemistry data were examined to identify chemical indicators of stress. Ultimately, only heavy metals and total phosphorus concentrations were used in the NWCA analysis (**Table 2**). Twelve heavy metals, each (1) with high signal-to-noise ratios [40], (2) a close relation to anthropogenic impacts, and (3) occurring in consistently measurable quantities, were used to develop a Heavy Metals Index (HMI) [12, 22]. The metals were: silver, cadmium, cobalt, chromium, copper, nickel, lead, antimony, tin, vanadium, tungsten, and zinc. The HMI is the sum of the number of metals present in the uppermost layer of the soil with concentrations above expected natural background levels. Background levels were based on published values primarily from Alloway [41] and used directly or slightly modified.
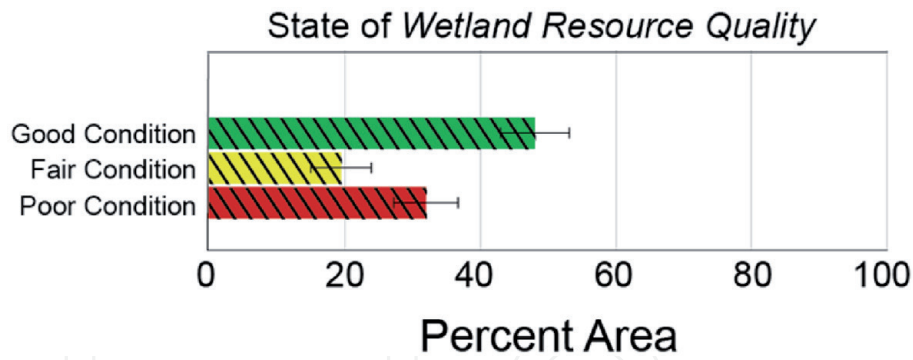
Figure 5.
State of the wetland resource quality *as indicated by the vegetation multimetric index (VMMI) for the 2011 National Wetland Condition Assessment (NWCA). Condition classes are reported as the percent area of the sampled wetland population. Error bars are 95% confidence intervals (figure adapted from USEPA [8]).*

Because no published thresholds for anthropogenic impacts to wetlands were available, thresholds for chemical stressor levels were set based on the background concentrations from Alloway [12, 22, 41]. The threshold for the low HMI stressor level required that all metals were less than or equal to background concentrations, and the threshold for the high HMI stressor levels was ≥3 metals above background. All values falling between the high and low stressor levels were termed moderate. In the case of phosphorus, concentration of total phosphorus in the uppermost layer with soil chemistry was used as a chemical indicator of stress. The thresholds for low and high phosphorus stressor levels were set using the 75th and 95th percentiles observed in least-disturbed sites [42, 43].

The Nonnative Plant Indicator (NNPI) was developed as a biological indicator of stress [12, 24]. Nonnative plants are widely recognized as (1) indicators of stress (e.g., their presence is often associated with human-mediated disturbances that negatively affect biological condition), or as (2) direct stressors to the condition of wetlands and other ecosystems (e.g., by inducing structural changes in vegetation, competing with native plant species, altering species interactions, community composition, or ecosystem properties); see Magee et al. [24] and citations therein. The NNPI is a categorical indicator based on three metrics describing different pathways of potential effects from the collective set of nonnative taxa occurring at each site (**Table 2**). The three NNPI metrics (nonnative relative cover, nonnative richness, and nonnative relative frequency) were used together in a decision matrix to assign each sampled site to a stressor-level category (low, moderate, or high) based on exceedance values for each metric [12, 24]. Note, that the high stressor-level category presented here combines the high and very-high stressor levels defined in Magee et al. [24].

Relative extent describes the frequency at which indicators of stress occur in wetlands and can be used to identify the most common indicators of stress occurring at high levels likely affecting wetland resource quality. Using the low, moderate, and high stressor-level thresholds for each of the indicators of stress, the wetland area associated with each stressor level and indicator was determined using the weights from the sampled sites [39]. Relative extent is reported as the proportion of wetland area sampled with high stressor levels for each of the indicators of stress (**Figure 6**). The most frequently encountered indicators of stress at high stressor levels were associated with physical indicators and include vegetation removal, hardening, and ditching, at 27, 27, and 23% of the sampled wetland area, respectively. The NNPI had 19% area associated with the high stressor level, while the chemical indicators, soil phosphorus, and heavy metals, had 6 and 2% of the sampled wetland area associated with the high stressor level.

Relative risk can be used to evaluate the proportional effect of factors that have an impact on wetland resource quality and is defined as the probability of having

Indicators	Description	Observations/measurements included
Physical indicators		
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*
Vegetation replacement	Any field observation of altered vegetation within the site due to anthropogenic activities	*Golf course, lawn/park, row crops in small amounts in the Assessment Area, row crops in the buffer, fallow field, nursery, orchard, tree plantation*
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 outfalls*
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, off road 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*
Chemical indicators		
Heavy Metal Index	Heavy metals with concentrations above background concentrations in soil samples	*Antimony, cadmium, chromium, cobalt, copper, lead, nickel, silver, tin, tungsten, vanadium, zinc concentrations from the uppermost layer with soil chemistry*
Soil phosphorus concentration	Soil phosphorus concentrations relative to reference sites	*Phosphorus concentration from the uppermost layer within 10 cm of the soil surface with soil chemistry*
Biological indicator		
Nonnative Plant Indicator (NNPI)	A categorical indicator based on three metrics that describe different avenues of potential impact to biological condition	*Relative cover of nonnative species, richness of nonnative species, relative frequency of nonnative species*

Table 2.
Description and components of the biological, physical, and chemical indicators of stress (adapted from USEPA [12]).

poor condition when stressor levels are high relative to when stressor levels are low [12, 39, 44–46]. Relative risk was calculated for the six physical and two chemical indicators of stress. Because condition of wetlands is based on vegetation data (i.e., the VMMI) and the biological indicator of stress (i.e., the NNPI) also uses the vegetation data, relative risk is not reported for the NNPI (see [12] for details). **Figure 6** shows the relative risk for the physical and chemical stressors. The likelihood of poor condition (compared to good condition) was 1.8 times higher when
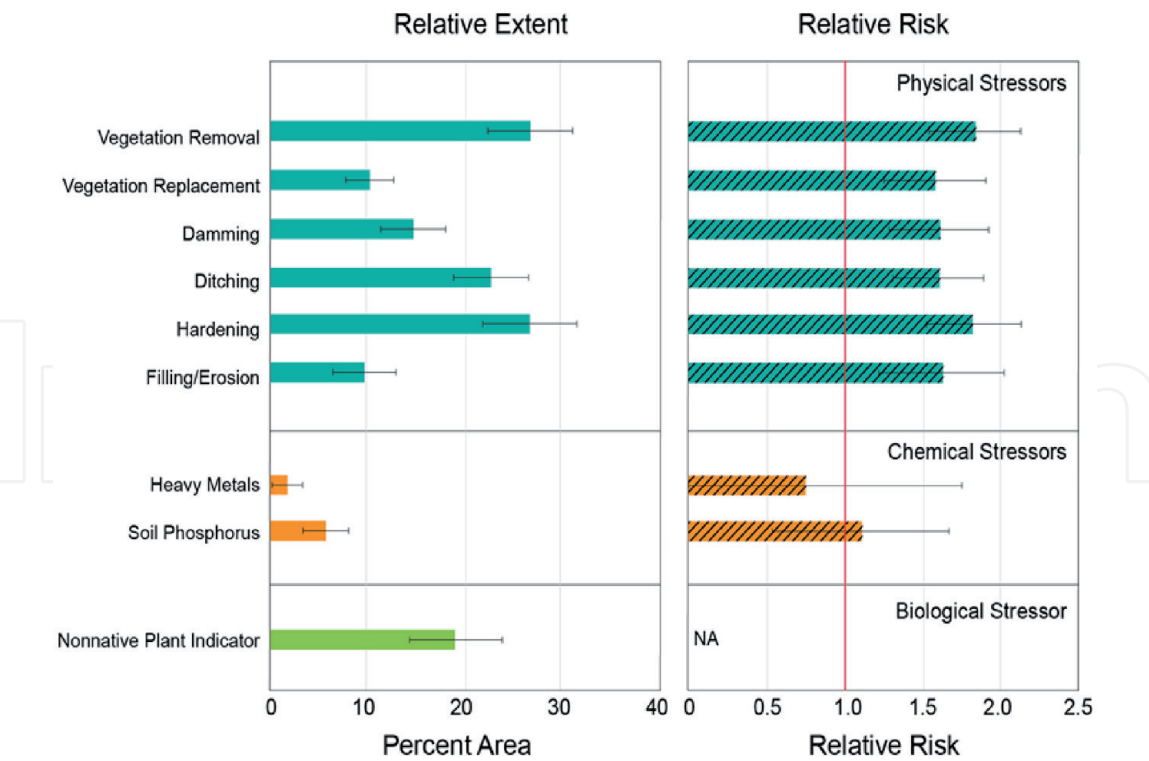
Figure 6.
Evaluation of the factors that affect wetland resource quality as indicated by relative extent (percent area of the wetland resource) and relative risk from chemical, physical, and biological indicators of stress for the 2011 National Wetland Condition Assessment (NWCA). NA indicates "not applicable" for relative risk of the nonnative plan indicator to avoid circularity (see text for details). Error bars are 95% confidence intervals (figure adapted from USEPA [8]).

vegetation removal and hardening are present at high stressor levels and 1.6 times higher when vegetation replacement, damming, ditching, and filling/erosion are present at high stressor levels. A relative risk of 1.0 indicates that there is no association or relationship between the indicator of stress and condition, and a relative risk less than 1.0, indicates a positive relationship between high stressor level of the indicator and good condition.

4.3 Summary of *wetland resource quality* in the conterminous US

The results of the 2011 NWCA indicates that the *wetland resource quality* across the conterminous US is good for about half of the wetland area, with the remainder divided between fair and poor *wetland resource quality* (**Figure 5**). Physical, chemical, and biological data collected in the field can also be used to evaluate factors that impact wetland resource quality. Review of the patterns in relative extent of the examined indicators of stress that were found at high stressor level, shows that specific physical stressors and the biological stressor were the most frequently encountered and may affect wetland resource quality, while chemical indicators of stress are less common at high stressor levels (**Figure 6**). The effect of stressors on *wetland resource quality* is illustrated by the relative risk results (**Figure 6**), which show that physical indicators of stress occurring at high stressor levels are likely to impact *wetland resource quality*.

5. Conclusions

We use the NWCA as an example of how physical, chemical, and biological data collected in the field can be synthesized to evaluate the state of *wetland resource*

quality (a specific type of *aquatic resource quality*). Furthermore, we illustrate that we can evaluate the factors affecting *wetland resource quality* on a national scale using relative extent and relative risk.

We believe that the concept of *aquatic resource quality* should be the basis for monitoring aquatic ecosystems. First, *aquatic resource quality* reflects condition, which is founded in physical, chemical, and biological data. Therefore, *aquatic resource quality* directly addresses the CWA goals for reporting on the physical, chemical, and biological integrity of water resources. Secondly, the concept of *aquatic resource quality* can be evaluated in all aquatic ecosystems, regardless of surface water availability (as in the case of precipitation-driven wetlands and ephemeral streams) or aquatic ecosystem type (e.g., wetlands versus streams). In fact, the data needed to evaluate *aquatic resource quality* in all aquatic ecosystems across the conterminous US are already being collected through the Environmental Protection Agency's (USEPA) National Aquatic Resource Surveys (NARS) program (https://www.epa.gov/national-aquatic-resource-surveys). Physical, chemical, and biological data are collected every year from one of four aquatic resources—rivers and streams, lakes, wetlands, and coasts—to assess the status of their condition. The NWCA, discussed extensively here, is the wetland component of NARS. Every 5 years, the entire water resource of the nation is assessed, allowing appraisal of trends and changes over time. In addition, because condition, relative risk, and relative extent are measured using comparable design, field protocols, and analysis methods for all aquatic resources assessed in NARS, the opportunity exists to evaluate and compare *aquatic resource quality* across ecosystem types on a national scale.

Another advantage of adopting *aquatic resource quality* as the basis for monitoring aquatic ecosystems is that the results are easily translatable to a non-scientific audience, in part because the concepts and terminology are unambiguous. In addition, information surrounding *aquatic resource quality* can be reported in a way that answers questions of interest to the public. These might include:

- What is the state of the *aquatic resource quality*?

- What factors are negatively affecting *aquatic resource quality*?

- How do the patterns in *aquatic resource quality* change over time?

Moreover, the questions can be addressed using tested and established NARS methods to gather data for reporting on *aquatic resource quality* using condition, relative extent, and relative risk. NARS field, laboratory, and analysis methods are publicly available and applicable to multiple scales. NARS methodology allows for the consideration of results beyond the context of individual sampled sites, thus increasing the power of the data. For example, (a) results can be compared to regional and national NARS datasets, or (b) results can be compared or combined with those from other data collected using the NARS methodology.

The example in this chapter was national in scale and evaluated wetlands; however, sampling physical, chemical, and biological indicators to characterize condition can also be applied to regional, state, and local aquatic ecosystems. *Aquatic resource quality* is broadly relevant and supports management and policy decisions across ecosystem types, spatial scales, and political entities.

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