Promoting Successful Restoration through

Effective Monitoring in the Chesapeake Bay Watershed

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NON-TIDAL WETLANDS

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Introduction and Acknowledgements

The National Fish and Wildlife Foundation (NFWF) funds a variety of projects aimed at achieving restoration goals for the Chesapeake Bay and watershed. In order to use their restoration funds most cost-effectively, NFWF seeks scientifically-based criteria for identifying projects with the highest potential for success and monitoring successful outcomes. This chapter is one of many being developed to generate monitoring metrics for restoration and management projects that include: 1) tidal wetlands; 2) non-tidal wetlands; 3) streams; 4) "green" stormwater management (under the direction of Allen Davis, UMCP); 5) agricultural and forest management (under the direction of Brian Benham and Gene Yagow, VA Tech); and 6) stewardship and social marketing (under the direction of Gene Yagow and Erin Ling, VA Tech).

Web-based reviews were conducted to seek expert feedback on the literature review, metrics and recommendations provided in this report. We are grateful to the experts who were generous with their time in the review process: Kristen Hychka (US EPA), Mary Kentula (US EPA), Jeffrey Matthews (Illinois Natural History Survey), Amanda Nahlik (US EPA), Karen Prestegaard (University of Maryland), Raymond Semlitsch (University of Missouri – Columbia), Joy Zedler (University of Wisconsin). We thank Mandy Chesnutt (NFWF), Ben Hillier (Chesapeake Research Consortium, Inc.) and the University of Maryland Center for Environmental Science for their assistance in arranging the web-based reviews.

Non-Tidal Wetlands – Restoration Project Implementation, Monitoring and Recommended Metrics

This document provides a summary of evidence-based metrics for verifying project implementation and outcomes in freshwater (non-tidal) wetlands. The selected metrics were selected to fulfill the goals of: 1) demonstrating potential benefits from restoration activities, 2) promoting adaptive management, and eventually 3) enhancing understanding of effective restoration techniques. The monitoring metrics were derived from a literature review of studies that measured meaningful ecological or environmental outcomes, such as those that document improvement in desirable ecosystem processes and functions (e.g. nutrient cycling or protection of species of concern). The functional assessments reported here appear to be the best indicators of a system's ability to support beneficial outcomes (e.g., enhanced fish habitat, water quality improvements), and to maintain them into the future.

How to use this report:

Grantees may use this guidance for: 1) Identifying a project type, 2) Setting goals for a specific wetland restoration project, 3) Selecting reference sites or reference conditions, 4) Selecting key metrics for monitoring, and 5) Verifying the implementation of key project elements prior to monitoring. Given that project goals are set for a three-year period, a list of priority metrics has been generated as guidance for both NFWF and their grantees. The metrics described range from the physical, structural and biological, and are comprehensive in scope with both basic and advanced protocols that represent either direct measures or proxies for key structural features and wetland functions. It is recognized that not all projects will incorporate all the metrics within a single project, however, it is important that grantees understand the full range of metrics available. Practitioners are encouraged to select metrics in consultation with experts and to focus on only those metrics that can generate *meaningful* data that clearly demonstrate if wetland functions approach restoration goals.

To assist grantees in preparing a restoration plan, this report is organized as follows:

1) Project Types
2) Metric Selection to Support Project Goals
3) The Use of Reference Conditions to Assess and Define Project Goals
4) Site Selection Considerations
5) Project Implementation Verification Metrics
6) Monitoring Metrics
7) Appendix A: Scientific Evidence That Supports Monitoring Metrics

Metric Selection to Support Project Goals

A key factor in planning for restoration is the selection of a monitoring metrics and these metrics will vary greatly among projects depending on the project type and specific goals. Metrics are divided into three main categories: Hydrology and Geomorphology, Biota and Physico-Chemistry (Table 1). Recommended Monitoring Metrics identified in the literature are also shown to correspond with NFWF project goals (Table 2). Following guidance on other key components in planning for restoration and setting goals (i.e., the use of reference criteria, site selection and project implementation verification), we summarize where the use of each metric has been useful in assessing improvements to wetland features and processes, and the ecological elements that should be emphasized in restoration efforts.

Table 1. Performance metrics reviewed for monitoring success of non-tidal wetlands restoration projects

Hydrology and Geomorphology	Biota	Physico-Chemistry
• Surface water area, depth and duration of inundation • Connectivity to adjacent wetlands and streams • Microtopographic relief and bank slope • Presence of large woody debris	• Vegetative composition • Vegetative complexity • % non-native species cover • Presence of species of high conservative value • Bioassessment (i.e., biodiversity, species lists)	• Physicochemical characteristics of surface water • Soil characteristics • Denitrification potential • Sedimentation rates

Table 2. Recommended Monitoring Metrics that corresponds to NFWF priorities

Category	Metric	Water Quality	Vital Habitat
Hydrology	**Flooding regime**	**X**	**X**
	Hydrologic connectivity	**X**	**X**
Geomorphology	**Topographic variability**	**X**	
	Spatial complexity (microhabitats)	**X**	**X**
	Sedimentation rates	**X**	**X**
Biota	**Vegetation cover & density**	**X**	**X**
	Vegetation species richness & abundance		**X**
	Invasive Species Cover	**X**	**X**
	Canopy complexity & % Cover		**X**
	Species lists		**X**
	Reproductive breeding success		**X**
Physico-Chemistry	**Water quality**	**X**	**X**
	Denitrification potential	**X (N only)**	
	Soil characteristics	**X**	**X**

(NFWF priority 'Protecting Shorelines' is not included in this table. For a full list of metrics reviewed and evidence for their effectiveness, please see Table 4)

Project Types

Wetlands are complex aquatic systems with varying physical, chemical and biological conditions, often characterized by varying hydrologic regimes, saturated sediments that contribute to anaerobic conditions, and aquatic plants or animals that occur only in the wetland (Cowardin et al. 1979). Restoration projects, therefore, also vary in type and scope in order to meet pre-determined goals of creation, restoration and enhancement.

Wetland creation – The creation of wetlands achieved by altering pre-existing hydrologic conditions via the modification of topography or water inflows / outflows. This is often developed jointly with upstream sedimentation basins. This category also includes *floating wetlands* in which wetland plants are established on a floating raft.

Wetland restoration – The re-establishment of wetland vegetation (through plantings) or hydrologic conditions (e.g., by removing drainage devices) on former wetland sites; Riverine wetland restoration is sometimes accompanied by stream bank stabilization or re-establishment of floodplain hydrologic connectivity by altering water inflows and outflows (e.g., filling ditches or removing berms).

Wetland enhancement – Improving conditions within existing wetlands through invasive species control and/or plantings of native vegetation; sometimes accompanied by stream bank stabilization.

The Use of Reference Conditions to Assess and Define Project Goals

The aim of most restoration projects is to repair, rehabilitate or restore a disturbed wetland to pre-disturbance or target conditions. The guidance provided here emphasizes that a critical component in *defining* project goals and *assessing* success is the identification of reference criteria (also referred to as baseline or target criteria) against which metrics can be compared. Reference criteria are essential when trying to understand the extent of spatial and temporal variation experienced at the site (White and Walker 1997) and to determine whether the restoration goal is being met. For some projects, the first year following the establishment of a constructed wetland may be regarded as an "acclimation period" after the introduction of a restoration element, followed by sampling in the early years post-restoration. Therefore, early metric results may be viewed in the context of a longer-term trajectory of improvement that may include high variability.

Determining restorative success has been shown most convincingly through the use of statistical tests and models of reference sites as a standard for comparison. Because success in restoration projects is a relative term that may refer to compliance or ecological or landscape success (Kentula 2000), users will need to set site-specific goals. Key to the success of any wetland restoration project is **to screen potential restoration sites using monitoring data and to adapt the restoration design, if necessary, to reflect landscape constraints.** Ideally, restoration sampling design must follow scientific methods to plan observations, measurements or models that can be used to test specific hypotheses (Grayson et al. 1999) or develop response curves indicating the range in wetland function that will be the target of restoration (Kentula et al. 1992).

One approach to determining if restoration success is to incorporate hypothesis testing based on ecological first principles (Zedler 2000) and/or model building in an adaptive management framework in consultation with experts (Kentula 2000). These approaches have challenged traditional approaches of once- or twice-annually conducted surveys over a period of a few short years. For example, when establishing or collecting reference or monitoring datasets, approaches that include sampling by transect, using several, replicated sampling plots, or both can be applied. Sampling frequency must be sufficient to capture changes through time by covering multiple seasons and years with replicated sampling over a range of conditions, particularly across seasons and water level fluctuations. This ensures that the life stages of most biota are incorporated, and measured relative to changing hydrologic conditions within the system. Frequent sampling at multiple locations within the wetland ensures that baseline conditions are accurate, and that the full range of ecological functions are measured. **To be effective, restoration projects should identify reference conditions that include both biological and abiotic metrics. Reference conditions should be considered both at the design stage and when assessing goals.** Success may be determined through changes in the chosen metrics over time and also in comparison to the reference conditions.

Site Selection Considerations

The selection of a wetland site for restoration is an important decision that may determine what is possible in terms of a project goal, and may also ensure the success of a project. Site selection is a critical step in planning a restoration project and can ultimately influence the metrics chosen. Grantees are recommended to consider the common factors described in Table 3 prior to choosing a site for restoration.

Table 3. Site considerations for non-tidal wetland restoration projects

Site Consideration	**Description**
Adjacent land use cover / Buffer condition / Proximity to other wetland patches	*Adjacent land-use, adjacent forest cover and connectivity to other wetlands can influence project success, in particular, the provision of vital refugia, foraging areas and dispersal corridors available for biota. Connectivity to other wetlands or forested areas is ideal for promoting many habitat goals, however isolated wetlands can still provide key habitat. In urban areas, wetland patches may provide habitats to migratory species. In agricultural areas, hydrologic connectivity between the landscape and wetlands may support key biogeochemical processes. Depending on the project goals, unsuitable sites will have adjacent areas without natural land cover, and high land conversion rates from forested to agricultural or urban.*
Invasive species (flora and fauna)	*Invasive species can include both flora and fauna. Plant invasion is a particularly common threat in non-tidal wetlands. For example, a local measure of invasive plant dominance during site screening can be used as an indicator of potential habitat restoration success.*
Drainage area loads / Tile drain interception	*The flow of nutrients entering the wetland can enhance the effectiveness of functions to sequester nutrients but may also serve as a constraint on achieving other goals. Area and intensity of agricultural activity that drains to the site, and, location relative to outflow points for agricultural tile drains can be used to assess opportunities and constraints.*

Soil conditions and topographic setting	*Multiple functions are promoted by using areas of former wetlands for restoration (e.g., areas of tile drains) since hydrologic position and regime is more likely to be favorable. Topographic depressions and saturated conditions promote nutrient and sediment reduction goals. Generally, areas with steep grades should be avoided as they can lead to rapid overland runoff of stormwater, limiting infiltration and retention capacities.*
Restorable area and buffer in upland area	*Parcel size and topography will limit the wetland size and functions related to size, such as habitat, and should be considered during site screening. Small ephemeral wetlands are among the most difficult to restore.*

Monitoring Metrics

Once project goals have been identified, a site has been chosen and appropriate reference criteria are selected, the careful selection of monitoring metrics should occur. This section highlights the evidence for monitoring metrics that may represent where and when ecological processes and functions of a site have been restored. **Practitioners are encouraged to select only those metrics that can be appropriately measured (i.e., sufficient spatial and temporal coverage) and those that adequately address the project goals.** The guidance provided is intended to be of assistance before, during and after project implementation and emphasizes that reference sites are necessary when deciding on which metrics to implement in a given project. It is recommended that metric selection, planning and decisions on sampling design occur in consultation with experts and appropriate professionals.

The metrics in Table 4 are divided into three categories: Hydrologic and Geomorphic Metrics, Biota and Physico-Chemistry, all of which require specific monitoring approaches. From this list, a priority list of metrics has been generated as being likely to support the core structural and functional elements in wetlands (Table 6). All restoration projects should include all metrics in the Primary list and add the relevant secondary metrics depending on the project goals.

Table 4. Non-Tidal Wetlands Monitoring Metrics

Category	Metric	Measured variables	Timing & Frequency	Main functions or processes supported	Performance Measures	Adaptive Mgmt / Considerations
Hydrology & Topography	Hydrologic Regime I: Water depth	- Surface water depth - Flow direction and variability	- Pre-restoration & as soon as construction is completed (within days); 1 year post-restoration - Monthly - Seasonally (if monitoring for bird populations or nutrient dynamics) - Early spring if monitoring for presence of seeds & at peak vegetation if sampling for plant communities	- Habitat: Birds, plants, fish, amphibians - Nutrient cycling - Food web support - Water stabilization & support	- Depth and flow variability match reference conditions - Native waterfowl diversity increases over time - Decrease in invasive plant species; Increase in native plant species - Nitrogen: increased denitrification rates following flooding event & increased water residence time	
	Hydrologic Regime II: Hydrologic connectivity & Spatially variable hydroperiods (where appropriate)	- Presence of surface water and/or overland flowpaths - Hydroperiod length in different patches within wetland	> 1 year post-restoration Continued monitoring over time	- Habitat: Birds, fish & Invertebrates - Water stabilization & support	- Given expected variation seasonally, connectivity is maintained over time	- Monitor invertebrate and bird density and diversity over time as indicators of habitat connectivity
	Hydrologic Regime III: Discharge (if hydrologically connected to surface streams)	- Presence of surface water and/or overland flowpaths - Outflow monitoring	- Pre-restoration & as soon as construction is completed (within days); 1 year post-restoration & continued monitoring over time	- Water quality - Water stabilization & support	- Given expected variation throughout the year, connectivity is maintained over time	- Monitor invertebrate and bird density and diversity over time as indicators of habitat connectivity
	Hydrologic Regime IV: Sources of water	- Water levels in piezometers installed around a wetland	- Pre-restoration & as soon as construction is completed (within days); monthly to seasonally 1 year post-restoration to determine temporal and spatial variability in water sources	- Water stabilization & support - Food web support - Nutrient cycling	- Matches reference conditions	
	Hydrologic Regime V: Surface water inundation	- Number of days of continuous surface water - Probability of annual inundation - Depth to groundwater table	- Pre-restoration & as soon as construction is completed (within days); 1 year post-restoration	- Water stabilization & support - Food web support - Nutrient cycling	- Matches reference conditions	
	Hydrologic Regime VI: % Time saturation in upper 30 cm of sediment (i.e., root zone of plants)	- Median depth to water table	- Pre-restoration, as soon as construction is complete, then seasonally post-restoration	- Water stabilzation & support - Vital habitat - Nutrient cycling	- Median water table depth approaches reference conditions - Water tables are deep in natural or reference wetlands. Water tables should decline during summer and fall seasons, typically going dry	
	Presence of large woody debris (LWD) (may only apply to stream-wetland complexes or riverine wetlands)	- Presence and number of floating and submerged wood	- >1 year post restoration, annually to assess persistence of LWD over time - Annually (late-spring/ summer) for invertebrate sampling	- Habitat: Invertebrates	- Increased invertebrate richness and biomass associated with LWD compared to reference conditions	- Indicator species may be associated with LWD (amphibian, bog turtle, terrestrial mice)
	Local meteorological conditions	- Record of local weather patterns (e.g., rainfall, number of drought days)	- Ongoing	- Water stabilization & support - Vital habitat	- Departure from normal conditions	
Geomorphic	Geomorphic assessment	- Visual classification of wetland type: riverine, depressional, slope, mineral soil flat, organic soil flat, esturine fringe, lacustrine fringe - landscape composition - GIS	- Once, typically as an initial survey used to classify wetlands and identify potential reference sites	- Water stabilization & support - Vital habitat	- Similar to reference conditions	
	Topographic variability (at varying spatial scales)	- Visual inspection and photo-documentation (e.g., presence of hummocks, hollows, ridges, furrows and floats; Number and depths of 'hummocks' and 'hollows' within wetland; sediment plumes after storm events) - bank slope measurements - survey for elevation - description of landscape context and composition	- Once, typically as an initial survey used to classify wetlands and identify potential reference sites - Annually to assess change over time	- Habitat - Food web support	- Variability approaches reference conditions and is maintained or increases over time	- Avian diversity increases with increased number of microhabitats - Low shallow bank slope provides key amphibian habitat - Isolated wetland patches required for successful amphibian breeding

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Category	Metric	Measured variables	Timing & Frequency	Main functions or processes supported	Performance Measures	Adaptive Mgmt / Considerations
Biota (It is recommended that destructive sampling or removal of plant and animal species from the restoration sites be kept to an absolute minimum)	Vegetative cover, quality & complexity	- Native plant cover, % obligate and facultative wetland plants, and diversity	- Annually, at peak-vegetation (seasonally, if possible)	- Primary production - Habitat: Plants	- Increasing native plant diversity over time - Approaches references conditions	- May support other plants (i.e., non-native species) with increases in diversity over time
		- % Non-native plant cover	- Annually, at peak vegetation (seasonally, if possible)	- Habitat: Plants - Nutrient cycling	- Decreasing non-native cover over time, compared to reference conditions	'- Harvest invasive plants annually to slow invasion and establishment of seed banks
		- Plant density, richness and cover	- Annually, at peak-vegetation	- Primary production - Food web support	- Measured variables approaches reference conditions - Inceased nutrient removal rates in zones with high stem density, species richness and percent cover	
		- Species Lists May be used in regional assessments or in a database. Use species lists to calculate a coefficient of conservatism (CC), multi-metric indices such as FQAI, VIBI or in combination (e.g., Index of Wetland Condition, IWC - which incorporates IBI & HGM)	- Annually, for at least 3-5 years after restoration	- Habitat: Plants, Nekton - Primary production	- Higher quality scores over time, indicative improving or less-degraded habitat quality, compared to reference conditions or multiple sites - Mean coefficient of conservatism values approaching 10 (indicating low tolerance to anthropogenic factors, low or zero CC values indicate nonnative taxa or species tolerant of anthropogenic activity)	
		- Structural diversity / layering (Canopy complexity)	- Annually, at peak vegetation (seasonally, if possible)	- Habitat: Plants & animals		
	Mammal diversity	- Species Lists	- Seasonal surveys (timing dependent upon species)	- Habitat: mammals - Food web support	- Approaches reference conditions	- Protection for vegetation if potentially detrimental mammals are present (nutria, muskrat)
	Bird diversity	- Bird diversity and abundance	- Seasonally to include observations during breeding, migration and wintering periods	- Habitat: birds - Food web support	- Bird diversity and abundance approaches reference conditions	- Healthy waterfowl populations may indicate that trophic levels are intact (I.e., invertebrates, organic matter, plant materials which serve as food sources) - Bird diversity may change over time as successional development of wetland and/or lanscape changes
	Bird breeding success	- Number of breeding and nesting sites (e.g., typically found among specific wetland microhabitats depending on species)	- Annual surveys during peak of breeding season, or annual surveys done at the same time each year	- Habitat: birds	- Increasing number of breeding and nesting sites compared to reference conditions - Diverse plant and food availability for waterfowl compared to reference conditions	

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Biota (It is recommended that destructive sampling or removal of plant and animal species from the restoration sites be kept to an absolute minimum)	Presence of species of high conservative value (Birds)	- Presence/absence of successful breeding bird populations	- Annually, during peak of breeding season	- Habitat: birds - Food web support	- Presence of species of interest - Increasing over time and/or approaches reference conditions	- Species of concern present
	Amphibian and reptile diversity	- Presence / absence of amphibians and reptiles	- In disturbed landscapes, monitor soon post-construction to capture short-term response to disturbance - Seasonal surveys	- Habitat: amphibians and reptiles	- Increasing number of individuals, populations and/or species over time - Approaches reference conditions	- Species of concern targeted for restoration, if appropriate
	Amphibian breeding success	- Larval amphibian abundances and/or larval egg masses	- Seasonal surveys following breeding season	- Habitat: amphibians	- Increased counts over time - Approaches reference conditions	- Species-specific responses to flooding duration in wetlands: Presence of wood frog associated with shorter hydroperiod; Green frog supported by longer hydroperiod
	Bioassessments	- Metrics for fish, macroinvertebrate (e.g. %EPT), diatom diversity	- Seasonally	- Habitat: Nekton - Food web support	- Approaches reference conditions - Does not exceed tolerance limits for sensitive taxa	

Table 4. Non-Tidal Wetlands Monitoring Metrics

Category	Metric	Measured variables	Timing & Frequency	Main functions or processes supported	Performance Measures	Adaptive Mgmt / Considerations
Physico-Chemistry	Surface water quality	- Temperature, salinity, DO, turbidity, TSS	- Regular intervals throughout the year (e.g., monthly, seasonally)	- Nutrient cycling - Food web support	- Conditions match with reference conditions - Meets or does not exceed maximum limits for specific constituents	- High DO levels may be accurate predictors of taxon richness and distribution in wetland
	Porewater / sub-surface water chemistry	- Conductivity, N, P, DO, pH, Fe and other indicators of redox conditions			- Water chemistry approaches reference conditions or pre-identified levels	
	Surface water chemistry	-N & P (organic & inorganic) - Bacterial counts	- Regular intervals throughout the year (e.g., monthly, seasonally, quarterly)	- Nutrient cycling - Food web support	- Conditions approach reference conditions - Meets or exceeds tolerance limits	
	Soil & sediment properties	- Soil organic matter: C, N, P	- Replicated sampling at the beginning of restoration, and annually post-restoration	- Nutrient cycling	- OM increases over time and approaches references conditions	- Consider nutrient storage in sediments vs. release/export
		- Sediment grain size	- Replicated sampling at the beginning of restoration, and annually post-restoration	- Nutrient cycling - Vital habitat	- Approaches to reference conditions	
		- Bulk density	- Replicated sampling at the beginning of restoration, and annually post-restoration	- Food web support - Vital habitat	- Approaches reference conditions	
		- Denitrification potential in sediments using Denitrification Enzyme Assays (DEAs)	- Replicated sampling at the beginning of restoration, and annually (or seasonally) post-restoration	- Nutrient cycling: Nitrogen	- Denitrification potential increase over time, approaches reference conditions - Spatial variability in rates indicative of soil heterogeneity	
	Sediment accretion	- Accumulation of sediment above a fixed point in the wetland	- Regular intervals throughout the year (e.g. monthly, seasonally) - After storm events	- Erosion control & sediment retention - Food web support	- Approaches reference conditions	

Table 4. Non-Tidal Wetlands Monitoring Metrics

Category	Metric	Measured variables	Basic Measurement Protocols	Additional and/or advanced measurement protocols
Hydrology & Topography	Hydrologic Regime I: Water depth	- Surface water depth - Flow direction and variability	- Measure monthly water level with float pulley, water-level monitors with data loggers, supplemented with staff/crest gauges.	- If temporal detail is required, pressure transducers may be employed - See: Shaffer et al. 2000. Wetlands.
	Hydrologic Regime II: Hydrologic connectivity & Spatially variable hydroperiods (where appropriate)	- Presence of surface water and/or overland flowpaths - Hydroperiod length in different patches within wetland	- Use mapping or GIS analysis. For example protocol, see: Collins et al, 2008, p 43 to 45. http://www.cramwetlands.org/documents/2008-09-30_CRAM%205.0.2.pdf - Use conventional surveying techniques.	
	Hydrologic Regime III: Discharge (if hydrologically connected to surface streams)	- Presence of surface water and/or overland flowpaths - Outflow monitoring	- Use mapping or GIS analysis. For example protocol, see: Collins et al, 2008, p 43 to 45. http://www.cramwetlands.org/documents/2008-09-30_CRAM%205.0.2.pdf - Use conventional surveying techniques.	
	Hydrologic Regime IV: Sources of water	- Water levels in piezometers installed around a wetland	- Minipiezometers installed in soft sediments around wetland edge, driven to a depth of 1.5m - Measure water level using water level logger or gage	
	Hydrologic Regime V: Surface water inundation	- Number of days of continuous surface water - Probability of annual inundation - Depth to groundwater table		
	Hydrologic Regime VI: % Time saturation in upper 30 cm of sediment (i.e., root zone of plants)	- Median depth to water table	- Pressure transducers or water level recorder installed at specific depths around wetland edge - Use staff gages, water level logger and pre-installed wells at several locations around wetland edge, along a transect through wetland	- For an example of a detailed study comparing reference and re-created wetlands, see Cole and Brooks. 2000. Ecological Engineering.
	Presence of large woody debris (LWD) (may only apply to stream-wetland complexes or riverine wetlands)	- Presence and number of floating and submerged wood	- Count number and relative size of LWD during site visits	
	Local meteorological conditions	- Record of local weather patterns (e.g., rainfall, number of drought days)	- For national hydrologic conditions, see the Palmer Hydrologic Drought Index: http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought/phdiimage.html in combination with simple precipitation observations: http://water.weather.gov/precip/about.php	
Geomorphic	Geomorphic assessment	- Visual classification of wetland type: riverine, depressional, slope, mineral soil flat, organic soil flat, esturine fringe, lacustrine fringe - landscape composition - GIS	- Use the HGM classification system described in: Smith et al, 1995, p 10 to 22. http://el.erdc.usace.army.mil/wetlands/pdfs/wrpde9.pdf	
	Topographic variability (at varying spatial scales)	- Visual inspection and photo-documentation (e.g., presence of hummocks, hollows, ridges, furrows and floats; Number and depths of 'hummocks' and 'hollows' within wetland; sediment plumes after storm events) - bank slope measurements - survey for elevation - description of landscape context and composition	- Visual assessment. For example protocol, see: Collins et al, 2008, p 71 to 74. http://www.cramwetlands.org/documents/2008-09-30_CRAM%205.0.2.pdf - Photographs of sediment plumes after storm events	- Conventional surveying techniques offer a more quantitative assessment. For a detailed example, see: Moser et al, 2007. http://mason.gmu.edu/~cahn/Publication/Moser%20and%20Ahn-MTvege%202007.pdf -Can also be assessed using GIS analysis, as in: Diefenderfer et al, 2008, p 345.

Table 4. Non-Tidal Wetlands Monitoring Metrics

Category	Metric	Measured variables	Basic Measurement Protocols	Additional and/or advanced measurement protocols
Biota (It is recommended that destructive sampling or removal of plant and animal species from the restoration sites be kept to an absolute minimum)		- Native plant cover, % obligate and facultative wetland plants, and diversity	- Appropriate field methods depend on complexity of site and project goals. For basic example protocols, see: - Carlisle et al, 1998, p 4-1 to 4-2. http://www.mass.gov/czm/wetlandecologicalintegrity.pdf - Collins et al, 2008, p 74 to 82. http://www.cramwetlands.org/documents/2008-09-30_CRAM%205.0.2.pdf	- For a discussion of vegetation sampling method design, see: U.S. EPA, 2002a. http://water.epa.gov/type/wetlands/upload/2008_12_23_criteria_wetlands_10Vegetation.pdf -For a more advanced sampling methodolgy, see: Mack, 2007. http://www.epa.state.oh.us/portals/35/wetlands/Part9_field_manual_v1_4rev4sept07.pdf
	Vegetative cover, quality & complexity			
		- % Non-native plant cover		
		- Plant density, richness and cover	- See methods listed under "Native Plant Cover and Diversity" (above) - For estimating biomass, see method in Mack, 2007, p 10. http://www.epa.state.oh.us/portals/35/wetlands/Part9_field_manual_v1_4rev4sept07.pdf	
		- Species Lists May be used in regional assessments or in a database. Use species lists to calculate a coefficient of conservatism (CC), multi-metric indices such as FQAI, VIBI or in combination (e.g., Index of Wetland Condition, IWC - which incorporates IBI & HGM)	- For a protocol on vegetation sampling in wetlands: http://water.epa.gov/type/wetlands/upload/2008_12_23_criteria_wetlands_10Vegetation.pdf - For an explanation of FQAI, see: Andreas et al, 2004, p 1 to 12. http://www.cedarville.edu/personal/silvius/research/floristicquality.pdf	- Using species lists, assign coefficients of conservatism to individual species by consulting a group of expert botanists & determine a mean CC for the vegetative assemblage in the system. Consider calculating a FQAI as a product of the site mean CC score and the square root of the total number of species (excluding exotics; See Cohen et al. 2004. Ecol Apps) - For a detailed example of sampling for and calculating VIBI, see: Mack, 2007. http://www.epa.state.oh.us/portals/35/wetlands/Part9_field_manual_v1_4rev4sept07.pdf - For an example of Floristic Quality Assessment Index (FQAI), see: Andreas and Lichvar, 1995. http://el.erdc.usace.army.mil/wetlands/pdfs/wrpde8.pdf -For an example of calculating IWC, see: Jacobs et al, 2010. - Schulse et al. 2009, 2011
		- Structural diversity / layering (Canopy complexity)		
	Mammal diversity	- Species Lists	-For general mammal survey methodologies, see: U.S. EPA, 1990. http://water.epa.gov/type/wetlands/assessment/mamm.cfm -For information on detrimental mammals, see: Thayer et al, 2005, p 10.57 to 10.58. http://coastalscience.noaa.gov/documents/rmv2/WholeDocument.pdf	
	Bird diversity	- Bird diversity and abundance	- For a basic example of observation protocol and data analysis, see Carlisle et al, 2002. http://www.mass.gov/czm/smchapter7.pdf - For another simple example protocol, see: Niedowski, 2000, p 61. http://www.edc.uri.edu/restoration/html/resource/nymarsh.pdf.	- If secretive or rare birds are present, experts can use broadcast call surveys, as in: Conway, 2009. http://www.cals.arizona.edu/research/azfwru/NationalMarshBird/index.htm - Aerial surveys can be used, as in: Erwin et al, 1991.
	Bird breeding success	- Number of breeding and nesting sites (e.g., typically found among specific wetland microhabitats depending on species)	- Count nests, breeding pairs, and/or offspring during bird monitoring.	- For examples of advanced methods, see: Erwin and Beck, 2007. http://www.pwrc.usgs.gov/prodabs/pubpdfs/6904_Erwin.pdf

Table 4. Non-Tidal Wetlands Monitoring Metrics

Category	Metric	Measured variables	Basic Measurement Protocols	Additional and/or advanced measurement protocols
Biota (It is recommended that destructive sampling or removal of plant and animal species from the restoration sites be kept to an absolute minimum)	Presence of species of high conservative value (Birds)	- Presence/absence of successful breeding bird populations	- See methods listed under "Bird Diversity" (above)	- Marsh birds may be secretive and rare birds may be especially hard to observe; experts should ideally use broadcast call surveys, as in: Conway, 2009. http://www.cals.arizona.edu/research/azfwru/NationalMarshBird/index.htm
	Amphibian and reptile diversity	- Presence / absence of amphibians and reptiles	- Appropriate methods depend on species present - Prefer non-destructive sampling (i.e., do NOT remove species from site) - For general information, see: Thayer et al, 2005, p 10.55 to 10.57. http://coastalscience.noaa.gov/documents/rmv2/WholeDocument.pdf - For example amphibian protocol, see: Micacchion, 2011. http://www.epa.state.oh.us/portals/35/wetlands/AmphIBI_Field_Manual.pdf	- For comprehensive discussions of amphibian sampling options, see: U.S. EPA, 2002. http://water.epa.gov/type/wetlands/upload/2008_12_23_criteria_wetlands_12Amphibians.pdf - For amphibian and reptile sampling options, see: Hutchens and DePerno, 2009.
	Amphibian breeding success	- Larval amphibian abundances and/or larval egg masses	- Prefer non-destructive sampling (i.e., do NOT remove species from site) - For example protocol, see: U.S. EPA, 2003, p 20 to 21. http://water.epa.gov/type/wetlands/upload/2008_12_23_criteria_wetlands_14Casestudies.pdf - Amphibian IBI may be used	- For information on egg sampling, see: U.S. EPA, 2002, p 15 to 18. http://water.epa.gov/type/wetlands/upload/2008_12_23_criteria_wetlands_12Amphibians.pdf
	Bioassessments	- Metrics for fish, macroinvertebrate (e.g. %EPT), diatom diversity	- For general information on bioassessments, see: U.S. EPA, 2010. http://water.epa.gov/type/wetlands/assessment/biobasic.cfm - For examples of bioassessment field sampling protocols across the U.S., see: U.S. EPA, 2000. http://water.epa.gov/type/wetlands/assessment/case.cfm	- For comprehensive information on designing and implementing a bioassessment program, see: Rader et al, 2001. - For information on fish bioassessments, see: U.S. EPA, 1990. http://water.epa.gov/type/wetlands/assessment/fish.cfm - For comprehensive information on macroinvertebrate bioassessments, see: U.S. EPA, 2002b. http://water.epa.gov/type/wetlands/upload/2008_12_23_criteria_wetlands_9Invertebrate.pdf - For information on algae bioassessment, see: U.S. EPA, 2002c. http://water.epa.gov/type/wetlands/upload/2008_12_23_criteria_wetlands_11Algae.pdf - For examples of diatom bioassessment, see: Dixit and Smoll, 1994; and Weilhoefer and Pan, 2006. http://web.pdx.edu/~pany/homework/clw_wetlands06.pdf

Table 4. Non-Tidal Wetlands Monitoring Metrics

Category	Metric	Measured variables	Basic Measurement Protocols	Additional and/or advanced measurement protocols
Physico-Chemistry	Surface water quality	- Temperature, salinity, DO, turbidity, TSS	- Measuring the following metrics are all described in: U.S. EPA, 2006. http://water.epa.gov/type/oceb/nep/upload/2007_04_09_estuaries_monitoruments_manual.pdf - For dissolved oxygen, see: p 9.1 to 9.13. Note that titrations should only be done by trained professionals. - For turbidity, see: p 15.1 to 15.11. - For temperature, see p 13.1 to 13.5. -chlorophyll-a must be measured in a lab. Use standard water sampling techniques to collect sample (for example, as described in chapters 6 and 7).	
	Porewater / sub-surface water chemistry	- Conductivity, N, P, DO, pH, Fe and other indicators of redox conditions		
	Surface water chemistry	-N & P (organic & inorganic) - Bacterial counts	- These metrics should be analyzed in a lab. For proper sample collection techniques, see: U.S. EPA, 2006, chapters 6, 7, 10, and 17. http://water.epa.gov/type/oceb/nep/upload/2007_04_09_estuaries_monitoruments_manual.pdf	
	Soil & sediment properties	- Soil organic matter: C, N, P	- For general soil sampling guidelines, see U.S. EPA, 2008, p 15 to 17. http://water.epa.gov/type/wetlands/upload/2008_12_23_criteria_wetlands_18Biogeochemical.pdf - Soil organic matter should be analyzed by a lab. See example collection protocol in Niedowski, 2000, p 60. http://www.edc.uri.edu/restoration/html/resource/nymarsh.pdf	- For a comprehensive review of soil sampling techniques, see: U.S. Army Corps, 2009, chapter 7. http://www.evergladesplan.org/pm/pm_docs/qasr/qasr_2009/qasr_2009_chap_07.pdf
		- Sediment grain size	- For general soil sampling guidelines, see U.S. EPA, 2008, p 15 to 17. http://water.epa.gov/type/wetlands/upload/2008_12_23_criteria_wetlands_18Biogeochemical.pdf	
		- Bulk density	- For general soil sampling guidelines, see U.S. EPA, 2008, p 15 to 17. http://water.epa.gov/type/wetlands/upload/2008_12_23_criteria_wetlands_18Biogeochemical.pdf	'- For a comprehensive review of soil sampling techniques, see: U.S. Army Corps, 2009, chapter 7. http://www.evergladesplan.org/pm/pm_docs/qasr/qasr_2009/qasr_2009_chap_07.pdf
		- Denitrification potential in sediments using Denitrification Enzyme Assays (DEAs)		- Soil collection should be done by experts, and assay must be done in laboratory. - For example sampling method and discussion, see Bruland et al, 2006. http://www.ctahr.hawaii.edu/brulandg/publications/Bruland06Wetlands.pdf -For laboratory methods, see Groffman, 1999.
	Sediment accretion	- Accumulation of sediment above a fixed point in the wetland	- Feldspar markers or sediment traps - Total suspended sediments should be analyzed in a lab. For proper sample collection techniques and information, see: U.S. EPA, 2006, p 15-10. http://water.epa.gov/type/oceb/nep/upload/2007_04_09_estuaries_monitoruments_manual.pdf	- GIS analysis to calculate soil volume and/or mass

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Hydrologic and Geomorphic Metrics

The maintenance of a characteristic hydrologic regime (e.g., hydroperiod, fluctuations in water levels and sources) and topographic variability are key factors in promoting multiple wetland functions. Hydrologic metrics apply to surface water, saturated sediments, and the variety of water sources entering a wetland and hydrologic connections across the landscape. For example, hydrologic connectivity of a wetland to groundwater sources, nearby wetlands and proximate streams has been shown to promote increased biodiversity (native and non-native species) and allow for the exchange of nutrients and material transport. Moreover, connected wetlands can have higher net primary productivity rates than isolated wetlands. Biological responses to changes in both hydrology and geomorphology can vary widely depending on species due to specific life stage requirements and the presence of features such as large woody debris in riverine wetlands can in turn influence both the physical and biological components of a wetland. Geomorphic features, especially topographic variability – the presence of furrows, flats, ridges, hollows, and bank slope – is an important habitat feature for biota and is also necessary for supporting nutrient cycling. Specific metrics associated with monitoring hydrologic regimes and geomorphologic characteristics should approach reference conditions in order to encourage increased rates nutrient and sediment removal.

Biota

Various metrics may be employed in a given restoration project and will vary depending on whether the goal is to maintain a vital habitat, protect a species of concern or support key nutrient processes. Plant biomass levels that approach reference conditions, high species richness and percent cover, for example, can be positively correlated with nutrient removal. Increased uptake rates have been shown to occur in densely vegetated areas composed of multiple species. Moreover, canopy complexity supports several key ecological functions and processes in wetlands. Invasive, non-native species represent key biological metrics when applied to restoration projects related to forecasting possible effects of climate change and multiple stressors. Other evidence has demonstrated the vegetative indices are not adequate indicators of faunal community establishment (e.g., fish, waterfowl, amphibians or invertebrates). However, guiding principles in ecology support the restoration of diverse plant communities that match reference conditions in the absence of specific conservation targets.

Observations of bird and amphibian breeding success post-restoration over several years (i.e., >5 years) are critical to determining if a restored wetland has remained a vital habitat for specific species. Moreover, species and communities can be expected to change as the features and processes within a restored wetland develop over time. Biotic indices used to evaluate the restoration of habitat-supporting functions are often the most cost-effective approach to assessing restoration progress. In some projects, such as among constructed wetlands, or when targeting a species of concern, a combination of restoration and monitoring metrics have been shown to support successful faunal communities of interest (e.g., presence or absence of predators, wetland landscape placement, canopy cover and land-use).

Multi-metric indices – such as floristic quality assessment indices (FQAIs) or vegetation indices of biological integrity (VIBIs) – are commonly employed, yet the evidence that supports in use assessing restoration success among individual projects remains unclear. Comparisons of existing vegetation indices have been shown to over-estimate wetland performance, particularly in the first 5 years after restoration. Scores generated using IBIs for plants may suggest that communities are not approaching project goals or restoration targets immediately after implementation. However, in reality, practitioners are reminded that the score will not reflect successional changes towards stable, healthy communities over time, often after the length of a project's monitoring schedule. To be sure, project monitoring, often years after restoration implementation, is recommended. More critical than IBIs are individual species lists over multiple years, including several years after project implementation. Multi-metric indices are thought to be more useful for before and after project implementation comparisons, and particularly for broad-scale (i.e., regional) comparisons and assessments.

Physico-Chemistry

Surface water quality and soil composition and nutrient processing rates have been shown to correlate with local hydrodynamics, regional factors, and habitat suitability for several plant and animal taxa. However, as tempting as it may be to use these metrics as indicators of a restoration, synoptic surveys that often include point measurements do not capture the full range of variation experienced at a site. Water quality metrics in particular are primarily useful in adaptive management for examining whether water conditions are preventing development of desirable outcomes, or when sampling intervals encompass both spatial and temporal variability. Saturated soils that alternate between oxic and anoxic conditions can facilitate denitrification, along with sources of organic matter and nitrate levels. When carbon levels and oxic conditions are comparable, there appears to be little difference between restored and created wetlands. Restoring wetlands for denitrification capacity will require extensive pre-restoration denitrification data and a combination of several soil metrics that are carefully planned in consultation with or conducted by experts. Individual soil measurements alone are insufficient in demonstrating if ecological functions have been restored within a wetland.

Project Implementation Verification Metrics

Implementation verification metrics confirm that the main project elements were successfully completed and also help determine if the proposed project goals and monitoring metrics are still reasonable (Table 5). Implementation verification is necessary because this work is typically carried out by sub-contractors, and can vary widely across projects from structural to non-structural components. Implementation verification is often viewed as a comparison between original and realized project plans. The resulting "as built" plan provides practitioners with qualitative and quantitative information on wetland features at the beginning of the project. If the implementation of the project has varied from the original design, practitioners can revise project goals and metrics, as required and in consultation with experts.

Table 5. Examples of Implementation Verification Metrics

Metric Category	Metric	Description / Explanation
Structural	Built features (during construction)	Built elements, such as a rock layers (header and footer rock); document design elements using photos or site inspections to ensure that the design was carried out accordingly (e.g., appropriate depth was excavated, filter cloth was installed).
	Built features (post-construction)	Built elements match design in extent, placement, and type of material. Installed wells equipped with water loggers and other features may be used to ensure water levels are maintained to sustain vegetation and habitat needs. For experimental or monitoring work within the wetland itself, platforms may be used to access plots and to minimize disturbance to the wetland
	Topography	Matches design
	Natural structures	Natural structural elements, such as large/coarse woody debris or surrounding vegetation, meet all design specifications
Non-Structural	Vegetative plantings	Verify that specified planting was conducted through photo documentation or on-site inspection
	Area of vegetated and non-vegetated areas	Measure/estimate area of all zones including non-vegetated areas. Use of GIS, GoogleMaps or other appropriate software is desirable for documenting vegetation cover and the locations of all project elements.

Prioritized Sets of Recommended Metrics

The list below represents a prioritization of metrics to be used in wetland restoration. The "Primary" set represents metrics that would address the most fundamental of wetland functions and processes. The "Secondary" set represents additional metrics that, depending on the project goal, would support multiple restoration goals, wetland processes and functions, and should be selected as needed depending on the goal and resources available.

Resources will limit total monitoring effort at a site and goals will suggest which metrics are most useful to measure. However, to promote data collection that allows restoration to be tracked and compared at multiple sites, we recommend a "primary" set of metrics that can be used to evaluate core system features and processes within and across sites. To supplement the primary metrics, a "secondary" set of metrics is proposed that provides options for measuring goal-driven outcomes, such as restoration of a particular species or ecosystems. Table 6 provides further description of the metrics including recommended measurement protocols, but some aspects of measurement and interpretation will need to be tailored to project design and goals. Many metrics are only useful if they can be sampled at a sufficient number of locations throughout the marsh and at sufficient frequency. Therefore, intensively sampling a few metrics, rather than superficially sampling many metrics is likely to be a preferred strategy for monitoring effectiveness, particularly for larger sites.

Table 6.
Primary Metrics (Required by all projects and represent core structure & functional elements in wetlands)

1. An "as built" plan[1]
2. Hydrologic regime
3. Hydrologic connectivity
4. Spatial heterogeneity (microhabitats)
5. Vegetative zones, structure and canopy cover
6. Soil characteristics (%OM, bulk density) in upper 30 cm
7. Species lists

Secondary Metrics – dependent on project goals

1. Canopy complexity
2. Invertebrate, bird, amphibian, fish assessments (e.g., IBIs for regional comparisons)
3. Vegetative species composition
4. % non-native species (plants) / % exotic species in urban settings
5. Sediment accretion
6. Microtopographic relief (quantitative)
7. Water chemistry (salinity, Temp, DO, Chl *a*, turbidity)
8. Surface and pore water salinity
9. Denitrification potential (DEA)
10. Surface water quality (contaminants, coliforms)
11. Soil characteristics (N, P, C)

[1] A quantitative and qualitative survey of the realized construction plans. An as-built plan should be carried out prior to the initiation of the restoration project, and compared with the original proposed design. Results of the as-built survey should also indicate whether the restored features were exactly as, more, or less than the original plan.

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