Rhode Island DEM Freshwater Wetland Monitoring and Assessment

DEVELOPING FLORISTIC QUALITY ASSESSMENT METHODS FOR EVALUATING FRESHWATER WETLAND CONDITION

Final Report

Prepared for
Rhode Island Department of Environmental Management
Office of Water Resources

Thomas E. Kutcher
April 2013

RHODE ISLAND
NATURAL HISTORY SURVEY
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Executive Summary

Floristic quality assessment (FQA) is a biological assessment approach that has been gaining recognition by wetlands managers as an indicator of wetland condition. FQA relies on plant inventory data to indicate the ecological quality of a given area by the aggregate conservatism (or sensitivity to human disturbances) of the plant species observed per site. A key component of FQA is the coefficient of conservatism (CC), which is a numeric value ranging from 0 to 10, assigned to each vascular plant species to indicate its relative sensitivity to disturbance. The CCs are aggregated, by one of several formula variants, to generate a floristic quality index. In a recent regional effort by the New England Biological Assessment of Wetlands Working Group and the New England Interstate Pollution Control Commission, CCs were assigned to all known vascular flora for Northeast-Region states, including Rhode Island. This study tested these Rhode Island-specific CCs, applied to several known variants of the FQA formula, against three previously-tested measures of wetland condition, to evaluate the utility of FQA for the assessment of freshwater wetland condition in Rhode Island.

The State of Rhode Island Department of Environmental Management (DEM) and the Rhode Island Natural History Survey have been working to develop methods to characterize freshwater wetland condition pursuant to the *Rhode Island Freshwater Wetland Monitoring and Assessment Plan* with support and guidance from the United States Environmental Protection Agency (EPA). These efforts have produced and tested indicators of wetland condition representing three distinct levels of wetland monitoring and assessment endorsed by EPA; these include a landscape-level (Level 1) indicator based on the proportion of impervious surface area surrounding wetlands (ISA); a rapid assessment method (L2) based on the additive stresses and impacts observed at a wetland (RIRAM); and an intensive (L3) biological indicator, based on the aggregate conservatism (sensitivity) of Odonata (dragonfly and damselfly) species observed per site (OIWI). This current study used these three existing measures to analyze the capacity of FQA to indicate freshwater wetland condition. Additionally, this study tested the utility of FQA, OIWI, and RIRAM for evaluating wetland restoration condition. The specific objectives of this study can be summarized as follows:

1. Test the efficacy of the RI-specific plant CCs in freshwater wetlands
2. Compare the effectiveness and functionality of various FQA formulas
3. Develop and test practical methods of FQA implementation
4. Use FQA to further validate existing wetland assessment methods
5. Demonstrate FQA applicability to the assessment of restoration condition

Methods

FQA methods development relied on a *reference sample* (n = 20), which was drawn from a larger sample of freshwater wetland assessment units, identified in prior DEM/RINHS efforts that had produced OIWI, RIRAM, and ISA values for each unit. New vegetation data were collected at the reference units to generate several FQA index values (based on various tested and theoretical models) for each unit. The new FQA index values were compared against OIWI, RIRAM, and ISA values to determine the best-fit (i.e. most effective) FQA models, based on index agreement, using correlation and box-plot analyses. Additionally, FQA index values generated from reduced-effort vegetation data were tested to determine the loss of effectiveness with reduced sampling effort.

Demonstrating FQA, OIWI, and RIRAM capability in the evaluation of restoration condition required the reference sample and an additional *restoration sample* (n = 10) of previously restored wetlands, which was selected largely from DEM Office of Compliance and Inspection records. New vegetation, Odonata, and rapid assessment data were collected at the restoration units to generate FQA, OIWI, and RIRAM values for each unit. These values were compared against the reference-sample values, directly and in the context of surrounding land use, to indicate the condition of the restoration units relative to the un-restored reference units.

Results and Discussion

The FQA variants that disregard species richness and incorporate the proportion of exotic species were strongly correlated with (i.e. best fit) the three existing measures, whereas those variants incorporating species richness were not significantly correlated with the measures. Incorporating broad cover-class information for each species further improved FQA metric performance, and additionally, improved resistance to loss of effectiveness with reduced sampling effort. The proportion of native species per site was also strongly correlated with the existing measures, but was particularly sensitive to a reduction in the number of plant species identified per site. The best-fit floristic measures were also strongly correlated with multiple aspects of wetland condition as represented by RIRAM metrics. Best-fit floristic and OIWI index values were lower among restoration units than among least-disturbed and intermediately-disturbed reference wetlands and were roughly equivalent with values from most-disturbed wetlands. Additionally, floristic index values among restoration units were lower than expected in the context of surrounding land use, but this was not the case with OIWI values. RIRAM did not agree with the bioindicators in evaluating relative restoration condition; this discrepancy may be due to limitations of RIRAM in objectively characterizing certain constructive manipulations.

These results suggest that the best-fit FQA measures can predictably indicate general freshwater wetland condition across a broad range of wetland types, and may be useful for indicating the condition of restoration wetlands. Full-effort vegetation sampling methods applied in this study could be practical for DEM implementation of FQA. Additionally, reducing the number of species identified by using only species occupying at least 10% total cover could be a viable alternative to full-effort sampling in non-critical applications, and could reduce botanical expertise limitations considerably.

All best-fit measures and the OIWI agreed in indicating the general condition of DEM restoration units relative to the reference sample. Results suggested that the restoration units were slightly underperforming when compared to reference wetlands in similar landscape settings. The pervasiveness of invasive species certainly contributed to lower-than-expected condition among the restoration units. This outcome was not unexpected due to the limitations surrounding compliance restoration. However, the best-fit floristic measures could supply important information on restoration condition that could help restoration practitioners improve future restoration outcomes. Floristic assessment could provide complimentary information to *functions-and-values* assessment information to provide managers with a better-informed perspective for evaluating restoration outcomes. Specifically, whereas the functions-and-values assessment approach provides a direct qualitative measure of the functions the wetland possesses, FQA, and other reference-based assessment methods (such as OIWI), can assess the extent to which the restoration is functioning to its full ecological potential (i.e. indicate general ecological condition). When used in combination, these approaches could help managers more-confidently evaluate restoration success.

1. Introduction

1.1 Floristic Quality Assessment

Floristic quality assessment (FQA) is a biological assessment approach that has been gaining recognition as an effective indicator of wetland condition. FQA relies on plant species *conservatism*, which reflects the relative sensitivity of individual plant species to human disturbance (Swink and Wilhelm 1979). Typically, coefficients of conservatism (CCs) ranging from 0 to 10 to are assigned to species through the consensus of a panel of botanists applying best professional judgment. Higher CCs are assigned to plants with narrower environmental tolerances and higher sensitivity to disturbance; lower CCs are assigned to species with broad tolerance to disturbance; and a CC of 0 is usually assigned to exotic species. FQA theory predicts that CCs, aggregated in a simple model, can reflect the environmental quality of a given natural area by quantifying the relative prevalence of conservative versus tolerant species.

Although FQA was originally introduced as a means of utilizing existing plant inventory data to indicate the relative naturalness of broad conservation areas (Swink and Wilhelm 1979), recent work has demonstrated its effectiveness in the assessment of freshwater wetland condition and restoration success using targeted vegetation sampling (Lopez and Fennessy 2002; Cohen et al. 2004; Miller and Wardrop 2006; Matthews et al. 2009). Several variants of the original FQA metric have been empirically tested against independent measures of disturbance, but less attention has been given to comparing the functional and ecological significance of the variants. Consequently, there is a need to clarify the implications of the various FQA indices for practitioners, particularly for specifically indicating freshwater wetland condition. This study tests the various FQA indices to identify the most effective variants.

1.2 Evaluating Wetland Condition in Rhode Island

The Rhode Island Department of Environmental Management (DEM) and the Rhode Island Natural History Survey (RINHS) have been developing methods to characterize freshwater wetland condition in accordance with the Rhode Island Freshwater Wetland Monitoring and Assessment Plan (WMAP; NEIWPCC and DEM 2006), with support and guidance from the United States Environmental Protection Agency (EPA). The EPA endorses a three-level approach to wetland monitoring and assessment that integrates landscape (level 1), rapid (level 2), and intensive (level 3) assessment methods (U.S. EPA 2006).

The three-level assessment approach promotes program flexibility and defensibility. Landscape assessment provides a course-but-reliable indirect indicator of condition best suited for wide-scale characterization and analysis. Landscape assessments can often be automated for multiple wetlands using geospatial data, such as impervious or land use cover, and geographic information system technology. But since it generally relies on association with actual in-wetland condition, landscape assessment may not be appropriate for site-scale assessment (U.S. EPA 2006). Rapid assessment is a site-level method that generally aggregates observational data into a model characterizing cumulative wetland degradation. Rapid assessment can efficiently provide valuable information on wetland characteristics and on individual and cumulative anthropogenic stresses and impacts; such information can be directly applied to address a host of practical objectives. Intensive assessment (level 3), which typically relies on high resolution physical or biological indicators (or bioindicators), is considered to provide the most objective, reliable, and precise measure of condition (U.S. EPA 2006; Sifneos et al. 2010). Bioindicators

can act as continuous in-situ ecosystem monitors that may react predictably to multiple, cumulative or synergistic environmental factors and detect episodic events that periodic physical or chemical monitoring may not capture. Biological assessment (or bioassessment) is most appropriate for site-scale assessment, where a high degree of sampling and analysis effort is justified by a need for precision.

From 2006 to 2010, DEM and RINHS developed and demonstrated a Rhode Island-specific rapid assessment method, RIRAM, at more than 240 wetlands (Kutcher 2009; 2010a, b; 2011a, b, c). In 2010, RIRAM was compared with two independent measures of wetland condition, a level-3 bioindicator and a level-1 landscape indicator, at 51 wetlands throughout the State. That work validated RIRAM and represented a step toward expanding the wetland monitoring and assessment program to include effective new methods from the alternative assessment levels. This current study further pursued validation and program expansion by developing and testing vegetation-based bioindicators, based on FQA, against these existing indicators. Additionally, the FQA indicators were tested alongside the existing measures as indicators of wetland restoration condition.

1.3 Evaluating the Condition of Wetland Restorations

DEM is developing a voluntary wetland restoration plan, and researchers have advised that restoration of filled wetlands should be a priority because of the functional capacity that could be gained (Miller and Golet 2001). An objective of this study is to determine the condition of fill removal sites over time post restoration. The ten study sites were selected from the DEM Office of Compliance and Inspection database of restored wetlands. An approach to evaluating restoration outcomes is *reference-based* assessment. Reference-based assessment uses quantitative indicators of environmental quality, and compares the indicator values of a study unit (or sample) with indicator values from a representative reference sample (Stoddard et al. 2006). A reference sample can be established across a known gradient of environmental conditions to allow a user to measure restoration outcomes directly against a meaningful range of conditions (U.S. EPA 2006; Faber-Langendoen et al. 2010). The reference-based approach is objective and quantitative, and may provide reliable and meaningful information that could lead to more fully-functional restorations and mitigations in future efforts.

1.4 Study Objectives

An effective and broadly-applicable level-3 bioindicator could provide DEM with an objective, precise, and meaningful measure for assessing general wetland condition in natural and restored wetlands. A bioindicator based on adult damselfly and dragonfly (Odonata) composition, the Odonata index of wetland integrity (OIWI), was developed and validated against the RIRAM and % surrounding impervious surface area (ISA) in 2011 (Kutcher 2011c). Validation outcomes suggest that the OIWI can effectively indicate general freshwater condition across a broad range of wetland types. But although it may be broadly effective, OIWI applicability is limited by (1) the number of experts qualified in identifying adult odonate species on the wing, (2) the level of effort required to collect a representative sample across the Odonata flight season, and (3) the range of wetland types that can be effectively surveyed. An efficient method employing a vegetation-based bioindicator, such as FQA, should be less limited in these three respects.

The New England Interstate Water Pollution Control Commission and the New England Biological Assessment of Wetlands Work Group recently developed state-specific plant CCs for

regional FQA-based assessment of wetland condition (Bried et al. 2012). The resulting Rhode Island-specific CCs were applied, in this current study, to various FQA indices, which were analyzed against RIRAM, OIWI, and ISA data to identify the most effective (i.e. best-fit) FQA variants. FQA sampling effort was also analyzed to determine the minimum level necessary for proper index function. The best-fit FQA variants were then applied alongside RIRAM and OIWI to investigate the capability of each index to evaluate wetland restoration condition. The objectives of this study can be summarized as follows:

1. Test the efficacy of RI-specific plant coefficients (CCs) in freshwater wetlands
2. Compare the effectiveness and functionality of various FQA formulas
3. Develop and test practical methods of FQA implementation
4. Use FQA to further validate existing wetland assessment methods
5. Demonstrate index applicability to assessment of restoration condition

1.5 Existing Measures

1.5.1 Rhode Island Rapid Assessment Method

RIRAM v.2.10 is an evidence-based rapid assessment method that was developed to document wetland characteristics and produce a relative index of freshwater wetland condition (Kutcher 2011b). RIRAM favors estimation over interpretation to maximize objectivity. The RIRAM index is produced by rating and summing stressor intensity and wetland integrity, which closely follows EPA wetland monitoring and assessment guidelines (U.S. EPA 2006). Specifically, three sub-indices evaluating landscape stresses, in-wetland stresses, and the integrity of wetland functional characteristics can be summed to generate a single index of general wetland condition. The RIRAM index is based on 100 possible points, comprising ten metrics, each carrying ten points. A score of 100 indicates undisturbed condition, and scores approaching zero would indicate extremely disturbed conditions. RIRAM scoring is based on the assumption that that the impacts of diverse human disturbances additively contribute to the degradation of general wetland condition (U.S. EPA 2006; Fennessy et al. 2004). RIRAM meets EPA criteria for establishing wetland reference conditions (per U.S. EPA 2006; Faber-Langendoen et al. 2010), and has been validated against landscape and intensive assessment data (Kutcher 2011c).

The first RIRAM section, Section A, comprises five attributes that document assessment unit size, hydrologic characteristics, and habitat characteristics; classify the unit by hydrogeomorphic, vegetation, and community-based classification schemes; and identify simplified wetland values (refer to the RIRAM v.2.10 field datasheet, App. 1). Section A is not scored because these attributes may be largely intrinsic and thus may not indicate wetland condition per se. Section B, the first scored section, comprises two metrics evaluating buffer and surrounding landscape stress by estimating the proportion of land use categories within 100 and 500 feet (30 and 150 m, respectively). Section C comprises seven metrics evaluating in-wetland stress by its intensity and the proportion of the assessment unit it affects. In-wetland stress metrics are categorized by stress type, and also document associated evidence, stressors, and sources of stress. Lastly, Section D summarizes and evaluates the observed integrity of five wetland characteristics that, in theory, control wetland functions and values.

1.5.2 Odonata Index of Wetland Integrity

The OIWI is a biological indicator of freshwater wetland condition based on the aggregate conservatism of adult Odonata species (Kutcher 2011c). Using data from using the Rhode Island Odonata Atlas (V. Brown, unpublished data), Odonata CCs were generated empirically based on each species' affinity to objectively-assigned disturbance classes. The mean CC of adult Odonata species observed per site is used as the OIWI. Prior work has indicated that OIWI is a sensitive indicator of general wetland condition that can effectively discriminate among reference designations (Kutcher 2011c).

1.5.3 Impervious Surface Area

Impervious surface area (ISA) is a landscape-scale ecological indicator that reflects the cover of impervious surfaces such as paved roads, parking lots, rooftops, and sidewalks. Impervious surfaces displace natural and pervious-cultural land covers, causing flashy (accelerated) runoff and reduced infiltration, which can entrain nutrients, solids, hydrocarbons, pathogens, and other pollutants, and transport them directly to surface waters rather than through vegetation and soils, where they would be filtered before entering larger water systems. ISA is a straightforward, objective, and repeatable land use/land cover product, requiring minimal user interpretation in processing. Percent ISA within 1000 feet (300 m) of the wetland edge was found to effectively indicate general wetland condition in relation to RIRAM and OIWI, among 51 diverse freshwater wetlands in Rhode Island (Kutcher 2011c).

2. Methods

2.1 Study Design

There were two parts to this study, (1) the development of an FQA-based bioassessment method for evaluating freshwater wetland condition, and (2) the testing of FQA, OIWI, and RIRAM for evaluating wetland restoration condition. FQA methods development (1) used a *reference sample* (n = 20), which was drawn from a larger sample of freshwater wetland assessment units (n = 51) from prior DEM/RINHS work that had produced OIWI, RIRAM, and ISA values for each unit. New vegetation data were collected at the reference units to generate FQA index values (based on various tested and theoretical models) for each unit. The new FQA index values were compared against OIWI, RIRAM, and ISA values to determine the best-fit (i.e., most effective) FQA models based on index agreement using correlation and box-plot analyses. These analyses were also applied to best-fit FQA index values generated from reduced-effort vegetation data to determine the loss of efficacy with reduced sampling effort.

Testing indices in the evaluation of restoration condition (2) required the reference sample and an additional *restoration sample* (n = 10) of previously restored wetlands, which was selected largely from DEM Office of Compliance and Inspection records. New vegetation, Odonata, and RIRAM data were collected at the restoration units to generate FQA, OIWI, and RIRAM values for each unit. These values were compared against the reference-sample index values, directly and in the context of surrounding land use, to indicate the condition of the restoration units relative to the un-restored reference units.

2.2 Site Selection

2.2.1 Reference Sample

The 20 reference units were selected from 51 existing study sites that spanned a wide range of wetland conditions, and had been assessed by OIWI, RIRAM, and ISA methods in 2010 (Kutcher 2011c). The reference units were selected to reflect wetland characteristics predominant among the restorations units, which were mainly small, open-canopy wetlands with an emergent component, according to prior findings of Cavallaro and Golet (2002). Reference units were therefore selected partly based on canopy cover (<50%), the presence of emergent vegetation (>25% cover), and size (<50 acres). The final reference units spanned a range of wetland conditions (according to the existing indices) and types, and were distributed statewide (Fig. 1).

Reference unit boundaries were determined according to rules adapted from prior DEM protocols (unpublished) and described in the RIRAM Users' Guide (Kutcher 2011b). The units were delineated as discrete areas of wetland habitat bounded by any combination of upland, riverine open water, or lacustrine open water. Large roads and railways lacking culverts further divided assessment units, as did narrowing of the wetland habitat to less than 50' or 10% of its wide point. The units were also bounded at the junction of linear (river dominated) and non-linear (e.g. basin/flat) wetlands. Wetlands surrounding rivers were considered a single unit until contiguity was broken on both sides of the channel; the river channel was included only if it was vegetated or ephemeral. Reference units were not divided by vegetation type, thus a single unit could contain multiple vegetation communities.

2.2.2 Restoration Sample

Ten (10) restoration units were identified through consultation with DEM Office of Compliance and Inspection (Fig. 1). Restoration units were selected based upon size (>10,000 ft^2), age (>5 years old), accessibility, and the interests of DEM. In contrast to the reference units, the restoration units were delimited by the boundaries of the restoration actions prescribed by DEM. Therefore, some restoration units comprised entire wetland units as defined for the reference sample (Sec. 2.2.1), whereas others were part of a larger wetland. Like the reference units, the restoration units were not divided by vegetation type, thus a single unit could contain multiple vegetation communities.

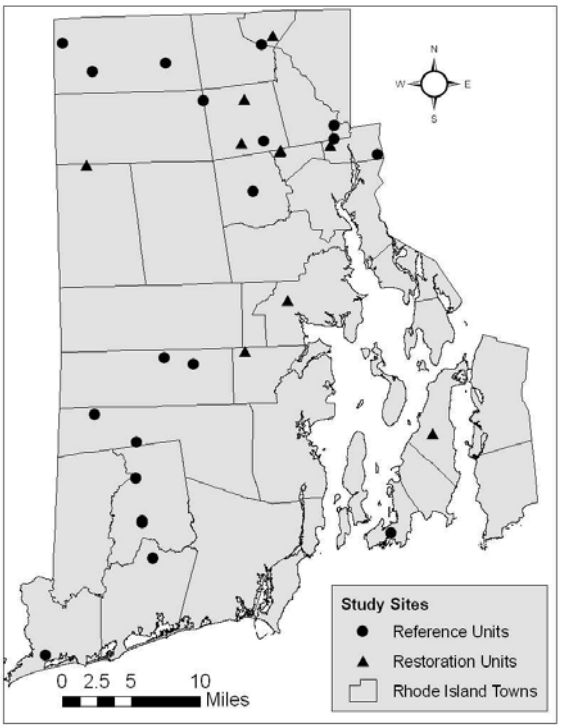


Figure 1: Locations of 30 wetland assessment units

2.3 Sampling Methods

2.3.1 Vegetation Sampling

Vegetation data were collected at all 30 study sites (including the reference and restoration units) from August 1 through September 14, 2011. Study sites were accessed with written or oral permission from fee or easement owners of containing properties, or their representatives (e.g. park managers, town planners, land trust directors). The objective of the vegetation sampling was to produce a nearly-complete list of vascular plant species per unit, and estimate the relative cover of each species, using an efficient method that standardized sampling effort, adjusted for unit size. Vegetation data were collected along three 4-m wide belt transects, the first running centrally along the longest dimension of the unit, and the remaining two running perpendicular to the first at one-third and two-thirds the distance from the starting point of the first transect. For sinuous linear units (i.e., riverine wetlands), the first transect was composed of a minimal series of straight lines needed to approximately follow the contours of the unit. Transects were hand-drawn on field maps depicting aerial photographic imagery prior to site visits. Two investigators followed an approximate straight line between landmarks (such as evergreen trees, rocks, roads), rectified from maps to the ground, as transect guides. Transects were walked and, when necessary, canoed. Every vascular plant observed was identified to species and recorded onto field datasheets (App. 1). Plants that could not be identified in the field were placed in plastic bags for laboratory identification.

Following each transect, a rank representing a broad cover class was assigned to each species for that transect; these included rank 1 (<10% cover), rank 2 (10-60% cover), and rank 3 (>60% cover), reflecting scarce, common, and dominant species, respectively. Individual transect ranks were averaged in the field following the final transect to reflect total cover of each

species in the unit. Incidental observations of new species were documented in species totals and assigned a total cover class rank of 1. Species that could not be identified in the field or laboratory were not included in the floristic indices.

2.3.2 OIWI Sampling

OIWI values for the reference units were taken from Kutcher (2011c). "Refined" OIWI values (i.e. those based on refined Odonata CCs; see Kutcher 2011c) were used in this study. To generate OIWI values for the restoration units, adult Odonata were sampled at each unit using equal effort. A single investigator (V. Brown) recorded every adult odonate observed within a one-hour period during ideal flight conditions (full daylight and warm, calm, dry weather). Three surveys were conducted at each unit; one in late June, one in late July, and one in late August, 2011. Observed odonates were identified to species. Unknowns and those identified only to Genus were recorded but were not used in generating OIWI values. Distinct observations of species were tallied as an estimate of species abundance, to document sampling rigor at sites with low species richness, but abundance was not incorporated in the OIWI. The OIWI was derived from refined Odonata CCs according to Kutcher (2011c) by taking the mean CC of species identified per restoration site.

2.3.3 RIRAM Sampling

RIRAM data were collected according to the RIRAM User's Guide (Kutcher 2011b) between August 30 and October 26, 2010 at the reference units, and concurrent with FQA sampling at the restoration units. Sites were accessed on foot or by canoe, when necessary. The principal investigator conducted the assessments. The perimeter and multiple transects of each unit were assessed when possible, otherwise assessments were made by accessing and observing as many areas within and around the unit as possible.

Field maps of each assessment unit, produced using GIS, were used for field orientation and determining wetland community and buffer characteristics. Each map contained a backdrop of 2008 leaf-off, color aerial photography at a scale sufficient to illustrate wetland habitats and surrounding land uses, and included a delineation of the unit, delineations of 100' and 500' buffer-zones, a scale bar, and other identifying information (Fig 2). Data obtained during field investigations were recorded on RIRAM field datasheets (App. 1) and complemented using GIS analysis before data entry, as outlined in Kutcher (2011b).

Figure 2: Sample field map for RIRAM assessment, scaled down from 8.5 × 11 in.

2.3.4 Impervious Surface Area

Impervious surface area (ISA) values for reference units were taken from Kutcher (2011c). ISA values for a 1000-ft zone surrounding each unit were generated from recent high-resolution impervious surface data. Using ESRI ArcMap® 9.3 GIS software, 1000 ft surrounding-area polygons were generated for each unit using the Buffer command and selecting "outside only". Surrounding-area polygons were used to clip the RIGIS (2010) *Impervious Cover 2003-04* raster dataset. The resulting impervious surrounding-area raster data were coded and analyzed to determine the percent impervious cover surrounding each unit.

2.4 Generating FQA Indices

All FQA index variants were derived using recent Rhode Island-specific plant CCs (App. 2). The CCs were assigned by R. Enser (unpublished data), to all vascular plant species known to exist in Rhode Island, according to methods outlined in Bried et al. (2012). The CCs were based mainly on each species' relative sensitivity to human disturbances and, to a lesser degree, on niche width (R. Enser, personal communication). All species believed to be non-native (exotic) to Rhode Island were assigned a CC of zero (0). In total, 1558 species were assigned CCs; values ranged from 0 to10 with a mean of 3.7 ± 2.9 and a median of 3; exotic species comprised 28% of these species. The CCs were applied to six FQA variants and to one additional floristic measure, *% Native* (Table 1). Vegetation data collected according to Sec. 2.3.1 were used to generate indices for each variant per site for both study samples. Midpoints of cover class ranges were used in generating FQA indices weighted by species abundance ranks, where rank 1 = 5%, rank 2 = 35%, and rank 3 = 80%.

Table 1. Variants of the *FQAI* formula and their recent applications in freshwater wetland assessment

Metric Variant	Formula[a]	Applications	Equivalent Formula
FQAI	$\frac{\sum CC}{N} \times \sqrt{N}$	Swink and Wilhelm 1979; Lopez and Fennessy 2002	
Mean CC_n	$\frac{\sum CC}{N}$	Rooney and Rogers 2002; Cohen et al. 2004; Miller and Wardrop 2006	
Mean CC_t	$\frac{\sum CC}{S}$	Cohen et al. 2004; Matthews et al. 2009	*Mean* $CC_n \times \frac{N}{S}$
Weighted mean CC_n [b]	$\frac{\sum (CC \times P_n)}{N \times \sum P_n}$	Cohen et al. 2004	
Weighted mean CC_t	$\frac{\sum (CC \times P_s)}{S \times \sum P_s}$	Developed in this study	
FQAI'	$\left(\frac{\sum CC}{N \times 10} \times \frac{\sqrt{N}}{\sqrt{S}}\right) \times 100$	Miller and Wardrop 2006; Vaselka et al. 2010	*Mean* $CC_n \times \sqrt{\frac{N}{S}} \times 10$
$FQAI_t$	$\frac{\sum CC}{S} \times \sqrt{S}$	Matthews et al. 2009	
% Native	$\frac{N}{S}$	Ervin et al. 2006	

[a] *CC* = plant species coefficient of conservatism; *N* = number of native plant species recorded; *S* = total number of plant species recorded (including exotics); P_n = proportional cover of native plant species recorded and P_s = proportional cover of all plant species recorded
[b] not tested in this study; discussed in Sec. 4.1.2

The FQA formulas tested in this study were either taken directly from prior studies in which an FQA index variant was demonstrated to meaningfully indicate freshwater wetland condition, or were developed, based on a logical extension of published, empirically-tested formulas (Table 1). The original formula describing the Floristic Quality Assessment Index (*FQAI*) is comprised of three components, conservatism, richness, and nativity (Swink and Wilhelm 1979). *FQAI* weights the *Mean CC* of native species (*Mean* CC_n) by the square root of the number of native species observed per site (a proxy for native species richness); exotic species are disregarded (Table 1). Rooney and Rogers (2002) contend that *Mean* CC_n alone may be a better measure of ecological condition, since it does not incorporate species richness and thus is not sensitive to sample size; preserves the information inherent in the CCs; and generates a more logical and understandable result. A *Mean CC* variant including exotic species (*Mean* CC_t, where *t* indicates total species), and a variant weighting *Mean* CC_n by species abundance (*Weighted mean* CC_n) have shown promise for wetland assessment (Cohen et al. 2004); a variant of *Weighted mean* CC_n incorporating exotic species (*Weighted mean* CC_t) is tested in this current study. Additionally, Miller and Wardrop (2006) demonstrated the effectiveness of FQA expressed as the proportion of "maximum-attainable *FQAI*" (*FQAI'*), which discounts species richness and incorporates exotic species, whereas Mathews et al. (2009) demonstrated a version

of the original *FQAI* incorporating both exotic species and richness ($FQAI_t$). And, Ervin et al. (2006) found that simply *% Native*, discounting both richness and conservatism, outperformed *FQAI*.

2.5 Reduced Effort Methods

The effects of reduced sampling effort on index performance were analyzed by generating reduced-effort index values for each unit and re-running statistical analyses for comparison against full-effort results. Best-fit indices, as determined by methods in Sec. 2.4, were analyzed with (1) reductions in the number of transects sampled, (2) reductions in the number of plants used per transect, and (3) reductions in both. Specifically, (1) index values generated with vegetation data from a single (first) transect were compared with values from the full method (using three transects). Next, (2) index values generated from data representing only species from cover class ranks 2 and 3 (species with ≥10% cover in the unit) from all three transects were compared with values from the full method (using species from all cover classes). Finally, (3) index values generated from data representing only species from cover class ranks 2 and 3 recorded only along the first transect were compared with values from the full method.

2.6 Analysis

Statistical analyses were conducted using WinSTAT® statistical software (2006, R. Fitch Software) appended to Microsoft Excel® spreadsheet software. Descriptive statistics were generated to characterize the study sites in some tables and figures. Rank-based and non-parametric methods were used in most statistical analyses to compensate for the ordinal nature of the RIRAM data and for the skews and gaps inherent in the samples.

Spearman rank correlation analysis was used to determine the best-fit FQA index variants in relation to OIWI, RIRAM, and ISA values among the reference units. Additionally, box-and-whisker analysis was applied to demonstrate FQA sensitivity to reference designations and to analyze relationships between data types, following Barbour et al. (1996). Specifically, three reference classes were designated to the reference units, based on 25th and 75th percentile RIRAM and ISA index values, to identify most-disturbed (degraded) and least-disturbed (reference-standard) thresholds, respectively. All other reference units (those with index values falling between the 25th and 75th percentiles) were considered intermediately-disturbed. The degree of OIWI distribution overlap among these classes was used to evaluate FQA index performance. Specifically, non-overlapping FQA index interquartile ranges (boxes) within most-disturbed and least-disturbed reference designations indicate high sensitivity to disturbance and excellent metric performance, whereas various degrees of interquartile-median overlap indicate lower sensitivity and performance (Barbour et al. 1996; Veselka et al. 2010).

Mann-Whitney *U-test* (non-parametric analogue of *t-test*) analysis was conducted to analyze restoration unit condition in relation to the reference sample. Surrounding landscape integrity was accounted for by comparing the restoration units to reference units with similar RIRAM *Surrounding Land Use* metric scores, i.e. those reference units within the range occupied by the restoration units. One reference unit with a value slightly above that range and one with a value slightly below that range were used to increase statistical power (resulting in $n = 6$ reference units and $n = 10$ restoration units).

3. Results

3.1 Reference Sample

3.1.1 Description

Information in this section was derived from RIRAM data; refer to charts in App. 3 for more detailed information and to App. 4 for site maps. Reference units (n = 20) ranged in size from 0.3 to 30 acres with a mean of 6.3 acres. Basin hydrogeomorphic classes (per Kutcher 2011b, modified from Brinson 1993) represented were isolated depression (n = 10), connected depression (n = 5), and floodplain riverine (n = 5). The most commonly represented vegetation classes (per Cowardin et al. 1979) in the reference sample were emergent (100% of units), scrub-shrub (75% of units), and forested (60% of units) wetlands. The most commonly observed primary in-wetland stresses were multiple, dams, and roads, whereas the most common surrounding landscape stresses were raised roads, footpaths, and residential development. Sixty percent (60%) of the units were impounded by dams or roads, and 60% were partly filled to upland grade, primarily from public roads and development filling. Sixteen (16) documented invasive plant species (according to IPANE 2011) were identified among 11 (55%) of the reference units. Common reed (*Phragmites australis*) was the most common invader (25% of sites). Invasive species cover ranged from *none noted* (45% of units) to *high* (51-75% cover at 10% of the units).

3.1.2 Index Data

Vegetation surveys identified 281 vascular plant species among the reference units, of which 27 (10%) were classified as exotic and10 (3.6%) were classified as *State Heritage* species. The number of species identified per site ranged from 19 to 96 with a mean of 50 ± 21 and the percentage of exotic species ranged from 0 to 28%. Floristic and wetland condition index values for the reference units are presented in Table 2. The OIWI values ranged from 4.68 to 7.29 with a mean of 5.92 ± 0.80; RIRAM values ranged from 44.2 to 100 with a mean of 79.9 ± 18.2; and ISA values ranged from 0.00 to 62.4% with a mean of 11.5 ± 17.1%.

Table 2. Values of floristic, Odonata, rapid, and landscape assessment indices of freshwater wetland condition from 20 wetland reference units; refer to Table 1 and Sec. 1.5 for index descriptions

Site Code	*FQAI*	*MCC_n*	*MCC_t*	*$WMCC_t$*	*FQAI'*	*$FQAI_t$*	*N*	*S*	*%N*	*OIWI*	*RIRAM*	*%ISA*
AUD-NEW-PND	30.9	3.86	3.74	3.95	3.80	30.4	64	66	97.0	5.83	87.2	3.3
PRV-BLRD-PRK	15.4	3.53	2.79	2.74	3.14	13.7	19	24	79.2	4.80	63.9	13
PRV-BOTH-PND	30.4	4.69	4.69	4.59	4.69	30.4	42	42	100	6.82	93.7	0.3
PRV-BRCH-STA	31.7	3.76	3.56	3.32	3.66	30.8	71	75	94.7	5.89	86.3	3.2
PRV-GLAC-PND	24.8	4.45	4.06	4.20	4.31	23.3	31	33	93.9	6.24	82.0	6.3
PRV-JACK-SCPD	32.3	4.43	4.43	4.06	4.43	32.3	53	53	100	5.95	84.9	1.6
PRV-LONS-MRSH	28.5	3.81	3.25	2.86	3.54	26.2	56	65	86.2	4.92	57.6	19
PRV-MOSH-PND	22.5	3.61	2.56	1.78	3.06	18.8	39	54	72.2	4.68	44.2	62
PRV-PYSZ-FEN	28.3	4.85	4.71	5.13	4.78	27.9	34	35	97.1	6.34	88.8	3.1
PRV-SLTR-PRK0	31.3	3.85	3.30	2.77	3.56	28.9	66	77	85.7	5.30	50.4	31
PRV-WOON-STA3	29.0	3.87	3.24	3.25	3.57	26.3	56	66	84.8	4.96	54.9	38
PRV-WOON-STA4	25.6	3.95	3.06	3.19	3.48	22.5	41	53	77.4	4.73	55.5	35
SMA-ARC-BFFEN	27.2	4.31	4.31	4.73	4.31	27.2	39	39	100	7.29	99.7	0.0
SMA-ARC-MOON	38.6	4.71	4.56	4.32	4.64	37.9	62	64	96.9	5.94	86.3	8.3
SMA-ARC-RBPD	43.7	4.46	4.41	4.43	4.43	43.4	95	96	99.0	6.77	87.7	0.8
SMA-BIG-CAP	35.7	5.15	5.04	5.19	5.09	35.3	48	49	98.0	6.54	87.2	0.7
SMA-BUCK-PD	24.5	4.63	4.63	4.82	4.63	24.5	27	27	100	5.85	99.7	0.7
SMA-CAR-FISH	21.2	4.74	4.74	5.16	4.74	21.2	19	19	100	6.47	100	0.0
SMA-CAR-WLPD	25.8	4.96	4.93	4.73	4.96	25.6	27	27	100	7.04	100	0.0
TNC-CRTR-WET1	22.7	4.29	4.29	4.03	4.29	22.7	28	28	100	6.15	87.8	3.6

3.2 Evaluation of FQA Variants

3.2.1 FQA Index Performance

Four FQA index variants and the proportion of native species (% *Native*) were strongly correlated with OIWI, RIRAM, and ISA among the reference units; none of these measures incorporated the proxies of species richness (i.e. numbers of *native species identified* and *total species identified*; Table 3). Proxies of species richness, and all floristic measures incorporating those proxies, varied with hydrogeomorphic class; these same measures also tended to vary with assessment unit size (Table 4).

Table 3. Spearman rank correlation coefficients comparing various floristic measures against existing measures of freshwater wetland condition among 20 reference wetland units; $P < 0.01$ except where noted

Index	*OIWI*	*RIRAM*	*ISA*
FQAI	0.24 *	-0.08 *	-0.09 *
Mean CC_n	0.75	0.70	-0.70
Mean CC_t	0.82	0.81	-0.84
Weighted Mean CC_t	0.82	0.85	-0.86
FQAI'	0.82	0.78	-0.80
$FQAI_t$	0.39 *	0.11 *	-0.27 *
% Native	0.81	0.89	-0.89
Native Species Identified	-0.13 *	-0.40 *	0.27 *
Total Species Identified	-0.29 *	-0.54 **	0.44 *

* not a significant correlation ($P > 0.05$) ** $P = 0.01$

Table 4. Kruskal-Wallace *H*-values (non-parametric analog to ANOVA) and Spearman rank correlation coefficients (r_s) comparing measures of freshwater wetland condition against hydrogeomorphic class (n = 3) and unit size (n = 20), respectively, among 20 reference wetland units

	Hydrogeomrophic Class		Unit Size	
Index	*H*	*P*	r_s	*P*
Floristic Index based on Richness				
Native Species Identified	10.25	0.01	0.44	0.06*
Total Species Identified	7.84	0.02	0.48	0.03
FQAI	11.11	<0.01	0.43	0.06*
FQAI$_t$	10.06	0.01	0.31	0.18*
Floristic Index discounting Richness				
Mean CC$_n$	1.05	0.59*	0.18	0.45*
Mean CC$_t$	1.70	0.43*	0.03	0.88*
Weighted Mean CC$_t$	0.84	0.65*	-0.07	0.77*
FQAI'	1.65	0.44*	0.06	0.79*
% Native	3.74	0.15*	-0.28	0.23*
Other Measure				
OIWI	2.28	0.32*	-0.07	0.39*
RIRAM	2.91	0.23*	-0.30	0.20*
ISA	1.93	0.38*	0.25	0.29*

* not a significant relationship

Mean CC$_t$, *Weighted Mean CC*$_t$, and *% Native* index values were most strongly correlated across the existing indices (r_s > 0.80 across all, Table 3), and were thus applied as best-fit variants in further analyses. The variant *FQAI'* was not included as a best-fit index because it is functionally similar to the more-straightforward *Mean CC*$_t$ (discussed in Sec. 4.1.2). Distributions of the best-fit variants were completely non-overlapping among least-disturbed and most-disturbed reference categories identified by RIRAM and ISA (Fig. 3). Additionally, these best-fit variants were significantly correlated with multiple RIRAM metrics and submetrics, suggesting the range of anthropogenic factors contributing to floristic variability (Table 5).

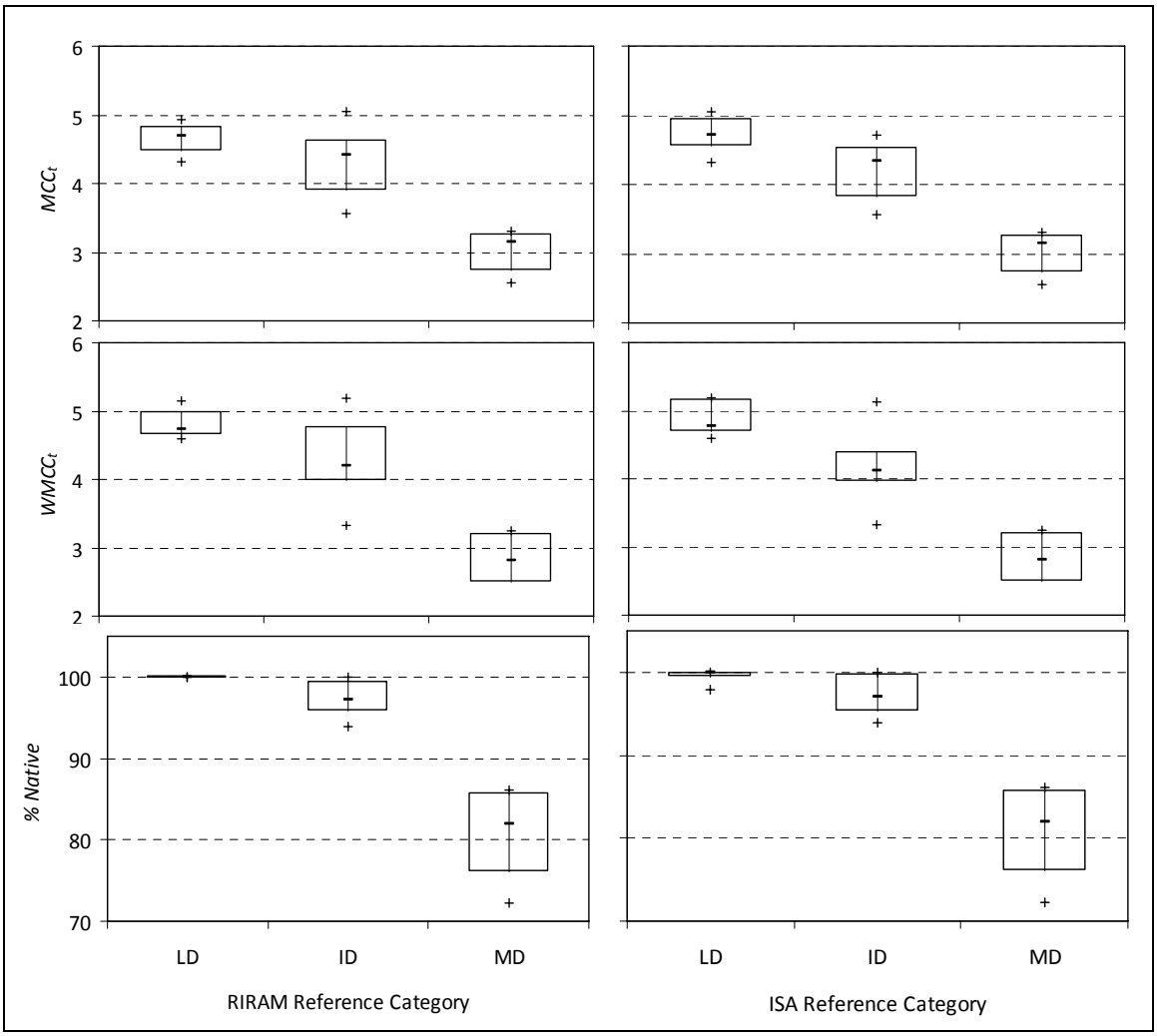


Figure 3. Box plots depicting the distributions of best-fit floristic index values among RIRAM- and ISA-based reference designations of freshwater wetland condition for 20 wetlands; boxes represent interquartile ranges, crosses represent minimum and maximum values, and dashes represent median values; LD = least disturbed, ID = intermediately disturbed, and MD = most disturbed

Table 5. Significant Spearman rank correlation coefficients comparing best-fit floristic measures with RIRAM metrics and submetrics among 20 reference wetland units

	Mean CC $_t$	*Weighted Mean CC $_t$*	*%Native*
RIRAM Stress Metric			
Degradation of Buffers	0.77	0.76	0.85
Surrounding Land Use	0.85	0.84	0.89
Fluvial Inputs	-0.74	-0.77	-0.84
Filling and Dumping	-0.76	-0.83	-0.62
Substrate Disturbance	-0.69	-0.73	*
Invasive Species Cover	-0.74	-0.73	-0.91
RIRAM Observed State Submetric			
Water and Soil Quality	0.80	0.82	0.84
Vegetation / Microhabitat Structure	0.89	0.87	0.89
Vegetation Composition	0.72	0.71	0.90
Habitat Connectivity	0.69	0.72	0.83

* not significant considering a Bonferroni-adjusted critical *P* value of 0.0036

3.1.2 Reduced Sampling Effort

In reduced effort analyses, single-transect vegetation sampling of all cover classes (ranks 1-3) produced 15 to 71 vascular plant species per unit with a mean of 39 ± 17; three-transect sampling of only rank 2 and 3 cover classes (≥10% total cover) produced 3 to 10 species per unit with a mean of 6.1 ± 2.1; and single-transect sampling of only rank 2 and 3 cover classes produced 3 to 12 species per unit with a mean of 6.9 ± 2.4. The strength of correlations between the floristic indices and the existing indices declined incrementally as sampling effort was reduced; this decline was most pronounced for *% Native* with a reduction in cover classes sampled (Table 6). This trend is also evident when comparing the full-effort floristic indices directly against reduced-effort floristic indices (Table 7).

Table 6. Spearman rank correlation coefficients comparing reduced-effort floristic measures against existing measures of freshwater wetland condition among 20 reference wetland units; $P < 0.01$ for all

	OIWI	***RIRAM***	***ISA***
Mean CC$_t$			
Full Sampling	0.82	0.81	-0.84
Single Transect	0.82	0.79	-0.82
≥10% Cover	0.74	0.81	-0.79
Single Transect ≥10% Cover	0.77	0.74	-0.78
Weighted Mean CC$_t$			
Full Sampling	0.82	0.85	-0.86
Single Transect	0.82	0.83	-0.84
≥10% Cover	0.79	0.85	-0.82
Single Transect ≥10% Cover	0.80	0.77	-0.80
% Native			
Full Sampling	0.81	0.89	-0.89
Single Transect	0.82	0.86	-0.86
≥10% Cover	0.73	0.70	-0.71
Single Transect ≥10% Cover	0.73	0.67	-0.70

Table 7. Spearman rank correlation coefficients comparing reduced-effort floristic index values against their full-effort values among 20 reference wetland units; $P < 0.01$ for all

	Sampling Effort		
	Single Transect	≥10% Cover	Single Trans ≥10%
Mean CC$_t$	0.98	0.83	0.84
Weighted Mean CC$_t$	0.95	0.96	0.90
% Native	0.98	0.74	0.74

3.3 Restoration Sample

3.3.1 Description

Information in this section was derived from RIRAM data; refer to charts in App. 3 for more detailed information and to App. 4 for site maps. Restoration units ranged in size from 0.2 to 1.8 acres, with a mean of 1.1 acres. The most commonly represented vegetation classes in the restoration sample were emergent (90% of units), scrub-shrub (50% of units), and forested (20% of units) wetlands. The main hydrogeomorphic classes represented were connected depression (60%) and floodplain riverine (20%). The most commonly observed primary in-wetland stresses were multiple, development fill, and roads, whereas the most common surrounding landscape

stresses were raised roads, residential development, and commercial or industrial development. Sixty percent (60%) of the restoration units remained partly filled (50% to upland grade or higher), primarily from development fill. Sixteen (16) invasive plant species were identified among all (100%) restoration units, including a cryptic invader, rusty willow (*Salix atrocinerea*). Common reed, wild rose (*Rosa multiflora*), bittersweet nightshade (*Solanum dulcamara*), and the overgrowing upland vine bittersweet (*Celastrus orbuculatus*) were the most common invaders (present at 70% of sites each). Four of the units (40%) were dominated by invasive species (>50% total cover); another 3 units (30%) had moderate (26-50%) cover (Table 8).

Table 8. Estimated cover classes of invasive plant species observed during RIRAM assessments of 10 wetland restoration units; primary and secondary species are listed in order of prevalence

	Invasive Species					
Site Code	Total cover	# spp. observed	Primary species	Cover	Secondary species	Cover
453a	> 75 %	3	*Phragmites australis*	> 75 %	*Solonum dulcamara*	< 5 %
453b	> 75 %	5	*Phragmites australis*	> 75 %	*Solonum dulcamara*	< 5 %
2349	> 75 %	9	*Phragmites australis*	51 - 75 %	*Lythrum salicaria*	51 - 75 %
91-088	51 - 75 %	8	*Phragmites australis*	51 - 75 %	*Rosa multiflora*	< 5 %
01-0015	26 - 50 %	7	*Phragmites australis*	26 - 50 %	*Lythrum salicaria*	26 - 50 %
0-DOT-RT7	26 - 50 %	8	*Lythrum salicaria*	26 - 50 %	*Salix atrocinerea*	5 - 25 %
03-0100	26 - 50 %	8	*Salix atrocinerea*	5 - 25 %	*Rosa multiflora*	5 - 25 %
99-0372	5 - 25 %	4	*Salix atrocinerea*	5 - 25 %	*Polygonum cuspidatum*	< 5 %
1791	5 - 25 %	6	*Phragmites australis*	< 5 %	*Polygonum cuspidatum*	< 5 %
02-0238	< 5 %	4	*Phragmites australis*	< 5 %	*Celastrus orbiculatus*	< 5 %

3.3.2 Index Data

Vegetation surveys identified 226 vascular plant species among the restoration units, of which 45 (20%) were classified as exotic. One (0.4%) *State Heritage* (RINHS, unpublished data) species was identified, blunt spike-rush (*Eleocharis ovata*). The number of species identified per site ranged from 15 to 88 with a mean of 59 ± 24 and the percentage of exotic species ranged from 11 to 38%. Odonata surveys at the restoration units identified 36 species (Table 9). Floristic and wetland condition index values for restoration units are presented in Table 10; the OIWI values ranged from 4.39 to 6.44 with a mean of 5.19 ± 0.53, and RIRAM values ranged from 58.3 to 76.2 with a mean of 66.5 ± 5.28.

Table 9. Odonata species identified at 10 Rhode Island wetland restoration sites and their refined coefficients of conservatism (CC) according to Kutcher (2011c)

Species	CC	Species	CC	Species	CC
Aeshna verticalis	8.5	*Ischnura posita*	4.1	*Nehalennia gracilis*	7.5
Anax junius	4.9	*Ischnura verticalis*	3.5	*Nehalennia irene*	6.5
Argia apicalis	1.7	*Lestes congener*	6.5	*Pachyidiplax longipennis*	4.2
Argia fumipennis-violacea	4.4	*Lestes rectangularis*	5.9	*Pantala flavescens*	2.9
Calopteryx maculata	5.6	*Leucorrhinia intacta*	6.7	*Pantala hymenaea*	2.5
Celithemis eponina	4.3	*Libellula cyanea*	6.4	*Perithemis tenera*	3.5
Celithemis martha	7.1	*Libellula incesta*	5.3	*Somatochlora tenebrosa*	8.6
Chromagrion conditum	6.8	*Libellula luctuosa*	3.9	*Sympetrum internum*	5.1
Enallagma geminatum	4.5	*Libellula lydia*	5.7	*Sympetrum semicinctum*	6.8
Epitheca cynosura	6.2	*Libellula pulchella*	4.3	*Sympetrum vicinum*	5.3
Epitheca princeps	5.0	*Libellula semifasciata*	7.6	*Tramea carolina*	5.8
Erythemis simplicicollis	5.3	*Libellula vibrans*	5.0	*Tramea lacerata*	4.3

Table 10. Values of floristic, Odonata, and rapid assessment indices of freshwater wetland condition from wetland 10 restoration units. Refer to Table 1 for index descriptions.

Site Code	*FQAI*	*MCC_n*	*MCC_t*	*$WMCC_t$*	*FQAI'*	*$FQAI_t$*	*N*	*S*	*%N*	*OIWI*	*RIRAM*
1791	20.65	3.23	2.02	1.52	2.55	16.25	40	64	63	4.92	69.5
2349	25.19	3.67	2.79	2.01	3.20	21.97	47	62	76	4.91	60.4
01-0015	29.23	3.63	3.06	2.77	3.33	26.89	65	77	84	4.39	68.6
02-0238	29.01	3.75	3.35	3.38	3.54	27.41	59	66	89	5.53	76.2
03-0100	26.85	3.41	2.60	2.31	2.98	23.40	61	80	76	4.96	68.2
0DOT-RT7	33.47	3.79	3.28	2.96	3.54	30.87	77	88	88	5.10	66.4
453A	13.27	4.00	2.93	1.47	3.43	11.36	11	15	73	5.21	64.5
453B	21.18	3.87	3.14	2.31	3.48	19.07	30	37	81	5.30	62.6
91-088	28.36	3.66	3.10	2.63	3.37	26.11	60	71	85	6.44	58.3
99-0372	20.59	4.04	3.28	3.96	3.64	18.56	26	32	81	5.19	70.7

3.4 Evaluation of Restoration Condition

All three best-fit floristic index values from the 10 restoration units were significantly lower than those from the reference units (n = 20), overall (Mann-Whitney U-test; Z = -3.12 to -3.30, P = 0.001 to 0.002); this trend held for OIWI values as well (Z = -2.17, P = 0.03), but not significantly for RIRAM values (Z = -1.89, P = 0.06). The best-fit floristic and OIWI values from the restoration units were approximately equal to values from the most-degraded wetlands, and significantly different from intermittently-degraded and least-degraded values (Fig. 4). Normalizing for surrounding landscape integrity, floristic index values from the restoration units were still significantly lower than values from the reference units (n = 6) in similar landscape settings (Z = -2.06 to -2.16, P = 0.03 to 0.04), whereas OIWI and RIRAM values were not (P > 0.35 for both). The general trend is visually represented in Figure 5, showing most restoration units falling below the reference trend line for the best-fit floristic indices, OIWI, and *Mean* CC_n.

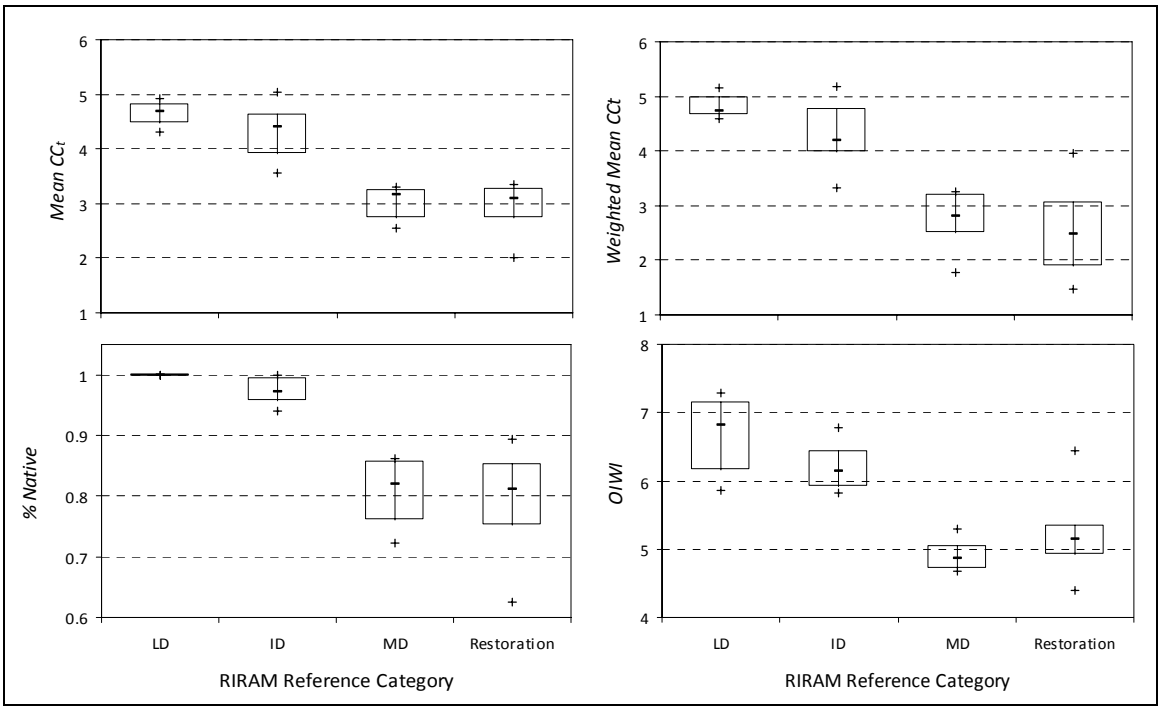
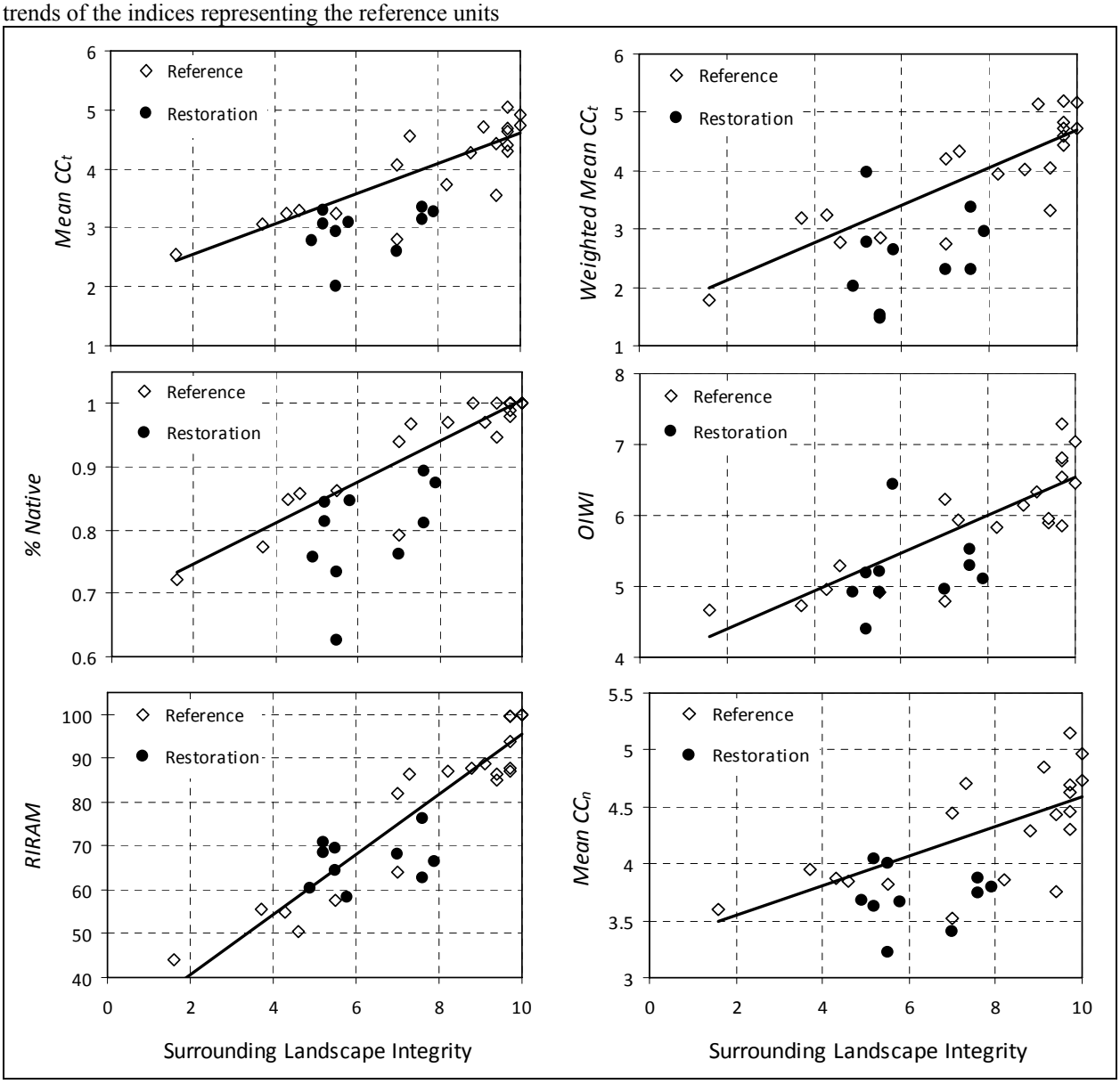


Figure 4. Box plots depicting the distributions of floristic and OIWI index values among RIRAM-based reference designations of freshwater wetland condition for 20 reference wetlands, compared with 10 restoration wetlands; boxes represent interquartile ranges, crosses represent minimum and maximum values, and dashes represent median values; LD = least disturbed, ID = intermediately disturbed, and MD = most disturbed; ANOVA, F (3, 26) = 23.6-36.3, $P \ll 0.01$; post hoc, for all metrics, LD ≥ ID > MD = Restoration, at $P < 0.05$ significance level

Figure 5. Scatterplots depicting the relationships between surrounding landscape integrity and various indicators of freshwater wetland condition among reference and restoration assessment units; lines represent linear regression trends of the indices representing the reference units



4. Discussion

4.1 Effectiveness and Functionality of FQA

4.1.1 Performance of Best-fit FQA Variants

Evaluation of FQA variants (Sec. 3.2) suggests that floristic measures can precisely and meaningfully indicate general freshwater wetland condition. The most effective (best-fit) measures were (1) FQA variants incorporating exotic species and disregarding species richness (*Mean* CC_t and *Weighted Mean* CC_t), and (2) the proportion of native species (*% Native*). Non-overlapping interquartile ranges between least-disturbed and most-disturbed categories in box plot analyses indicate excellent sensitivity of these three floristic metrics to categories of wetland disturbance (Barbour et al. 1996; Vaselka et al. 2010). And, consistently strong, monotonic correlations with previously-validated landscape (ISA), rapid (RIRAM), and intensive-biological (OIWI) indicators demonstrate FQA effectiveness in responding to indirect (ISA) and direct stresses and impacts (RIRAM), and support its efficacy as a meaningful biological indicator. This weight-of-evidence approach (using multiple reference measures) provides stronger evidence than correlation with any single model because (1) the probability of a *Type 1* error (indicating a relationship when one does not truly exist) is reduced and (2) no single measure can comprehensively represent wetland condition in the context of the all the various functions and values ascribed to wetlands; i.e., such a *gold standard* of wetland condition is unlikely to exist (Stein et al 2010). Stronger agreement (r_s approaching 1) cannot be expected due to mechanistic differences among these approaches and unavoidable ecological noise.

Strong, significant correlations with multiple RIRAM metrics and submetrics suggest that floristic assessment can reflect a wide range of human disturbances. Aggregating and reflecting multiple, cumulative impacts is considered a key trait for an effective ecological indicator (Karr and Chu 1979). Interestingly, none of the floristic measures was strongly correlated with any RIRAM metrics rating hydrologic modification, including impoundment, draining or diversion of water, and apparent hydrologic integrity (although evidence of fluvial inputs was strongly correlated with FQA). This suggests that hydrologic modification does not strongly affect the relative conservatism (sensitivity) or proportional nativity of plant species, even though it is known to largely control species composition (Mitch and Gosselink 2000). This may reflect the fact that wetland vegetation can adapt to hydrologic change (F. Golet, unpublished manuscript). In this light, FQA may not be a reliable indicator of hydrologic modification.

4.1.2 FQA Variant Functionality

The original *FQAI* did not effectively indicate wetland condition across the reference sample, whereas (1) FQA variants excluding species richness (*Mean* CC_n, *Mean* CC_t, *Weighted Mean* CC_t, and *FQAI'*) were strongly correlated with the three known measures (OIWI, RIRAM, and ISA); (2) those richness-free variants incorporating exotic species (*Mean* CC_t, *Weighted Mean* CC_t, and *FQAI'*) performed better (stronger correlation); (3) additionally incorporating species cover increased performance yet more (*Weighted Mean* CC_t); and (4) the percentage of native species (*% Native*) was most-strongly correlated with RIRAM and ISA in full-effort sampling. These findings suggest the following, respectively:

(1) Richness confounded the FQA models
(2) Exotic species were important components of FQA functionality

(3) Species abundance enhanced FQA performance, and

(4) Perhaps proportional nativity drove all outcomes and conservatism was ineffective.

Before supporting the first three suggestions (below), the suggestion that conservatism was ineffective (4) can be discredited. Aggregate conservatism of native species (*Mean* CC_n)—a strictly independent measure from the proportion of native species—was strongly correlated with all three of the known measures (Table 3), clearly indicating that conservatism alone (according to RI State CCs) was an effective component of FQA functionality. But because RI CCs were assigned by a single botanist, whereas they are typically assigned by consensus or averaging of values assigned by a *panel* of botanists, improvement of CC functionality (in representing actual relative conservatism) is certainly possible.

1. Species Richness and FQA

Better performance of richness-free FQA (over *FQAI*) has been previously demonstrated. In their seminal FQA study, Lopez and Fennessy (2002) applied the original *FQAI* to 20 depressional wetlands and found that *FQAI* was significantly correlated with a disturbance index that evaluated buffer condition within 100m. But subsequent studies—including this current study—clearly demonstrate that variants *excluding* species richness are superior indicators of wetland condition (Cohen et al. 2004; Miller and Wardrop 2006; Matthews et al. 2009; Vaselka et al. 2010). This is not surprising since species richness can *increase* with moderate disturbance (Rooney and Rogers 2002; Mathews et al. 2009) and thus does not consistently follow the monotonic trend best suited for reliable indicator function. Indeed, this current study found that native species richness (*N*) was not correlated with any known measure of condition, and that total species richness (*S*) *increased* with greater disturbance according to RIRAM, a trend that counteracts the *decrease* in conservatism (with increased disturbance) that drives FQA evaluation. Additionally, nearly all floristic measures incorporating species richness varied with wetland type (hydrogeomorphic class) and unit size. Assuming, then, that species richness is innately variable across wetland types (independent of condition), richness-weighted metrics would necessitate additional classification restrictions compared to metrics based on conservatism alone; this may be partly responsible for the poor performance of *FQAI* and other richness-weighted measures in this current study because multiple wetland types (according to HGM and vegetation classifications) were used. Although *FQAI* could conceivably be appropriate in situations where native species richness is known to monotonically decrease with increased disturbance, the empirical evidence suggests that richness more-often confounds the indicator value of FQA (Cohen et al. 2004; Miller and Wardrop 2006; Matthews et al. 2009; Vaselka et al. 2010; this study).

2. Exotic Species and FQA

Of the FQA variants designed to eliminate the effects of species richness, those incorporating exotic species (*Mean* CC_t, *Weighted Mean* CC_t, and *FQAI'*) performed best against the known measures (OIWI, RIRAM, and ISA). Indeed, the prevalence of exotic species alone (*% Native*), performed as well as the best-fit FQA indices in all but reduced cover-class analyses. Cohen et al. (2004) observed slightly-improved performance by including exotic species in *Mean CC* (*Mean* CC_t over *Mean* CC_n). Miller and Wardrop (2006) found no difference between *FQAI'* and *Mean* CC_n, but they present a hypothetical scenario demonstrating how an increase in exotic species would desirably lower their *FQAI'* score while *Mean* CC_n would remain constant. Exotic species are widely considered reliable indicators of wetland condition and their relative

dominance has been shown to indicate restoration condition (Matthews et al. 2009). Ervin et al. (2006) found that exotic species richness alone outperformed *FQAI* in indicating wetland disturbance, and contend that, since exotic species are integral in wetland species composition, exotic species should be included in FQA unless otherwise indicated; findings of this current study strongly support that statement.

The formulas of two richness-free FQA variants that incorporate exotic species, *Mean* CC_t and *FQAI'*, may appear dissimilar, but in function they are nearly equivalent. Miller and Wardrop (2006) present *FQAI'* as "*FQAI* relative to maximum-attainable *FQAI*" (Table 1 second column), but this is algebraically equivalent to the product of *Mean* CC_n and the square root of the proportion of native species (× 10, which in relative terms is irrelevant); similarly, *Mean* CC_t is equivalent to the product of *Mean* CC_n and the proportion of native species (Table 1, fourth column). So functionally, *FQAI'* only differs from *Mean* CC_t in that the effects of exotic species are reduced by applying the square root in the former. Equal performance of *FQAI'* and *Mean* CC_n (Miller and Wardrop 2006), coupled with improved performance of *Mean* CC_t over *Mean* CC_n (Cohen et al. 2004; this study), suggest that buffering the proportion of native species is unnecessary or perhaps counterproductive. Thus the more straightforward *Mean* CC_t (simply the mean CC of all species) prevails as the most effective and parsimonious measure among non-weighted FQA variants.

3. Incorporating Abundance in FQA

Although *Mean* CC_t may indeed be an efficient indicator of wetland condition, it is functionally incomplete. Species composition is generally described in terms of identity and abundance (often relative abundance); both attributes are relevant in describing site conditions, but the latter is absent in *Mean* CC_t. Cohen et al. (2004) found that *Weighted Mean* CC_n slightly outperformed *Mean* CC_n, suggesting that incorporating species abundance could improve metric performance. Further improvement should be gained by incorporating exotic species (*Weighted Mean* CC_t, Table 1) for reasons offered above, and indeed *Weighted Mean* CC_t performed better than *Mean* CC_t in this current study. But the ecological and practical implications of abundance in FQA are relevant even in the absence of such empirical improvement; this can be clarified if taken to a reasonable extreme. Consider two wetlands with identical plant species but differing in that one is dominated by the exotic reed *Phragmites australis* with a remnant section of native vegetation, whereas the other is dominated by native vegetation with a single stem of *P. australis*. Measured by *Mean* CC_t, the two wetlands would be scored equally, whereas *Weighted Mean* CC_t would incorporate the functional consequence of *P. australis* domination, lowering the index value. Among wetlands with more even species distributions, *Weighted Mean* CC_t would function nearly equivalently to *Mean* CC_t. The weighted FQA variant therefore provides a more relevant and defensible indication of wetland condition at the local scale, which is particularly important for evaluating restoration outcomes.

4.1.3 Sampling Effort and Performance

DEM must consider three matters associated with sampling effort in floristic assessment. The first and primary consideration is the preservation of index performance (reliability); the second is the logistical feasibility of the method in terms of available botanical expertise; and the third is the feasibility of the method in terms of the amount of time the method takes. Full-effort sampling time was practical, usually less than three hours. A reduction in the number of transects sampled per unit (from three to one) had the smallest (of the reduced-effort methods evaluated)

negative effect on best-fit metric performance and could reduce in-wetland sampling time by as much as 67%. But because most species are identified in the first transect, single-transect sampling would not alleviate limitations of botanical expertise or reduce laboratory identification time. Even single-transect assessment using *% Native* would not alleviate botanical expertise limitations because the investigator would still need to identify all species observed to determine their nativity.

In contrast, reduced cover-class sampling greatly reduces species identification requirements (from a mean of 50 for full-effort sampling to a mean of 6 or 7 and as few as 3), greatly alleviating expertise and time limitations, but it also reduces precision. This study's findings indicate that this loss may be relative to the simplicity of the FQA model. The precision of *% Native*, based only on the proportion of nativity, declined considerably using reduced-cover-class sampling; *Mean* CC_t, which incorporates proportional nativity and conservatism (see Table 1, last column), was less-strongly affected; and the precision of *Weighted Mean* CC_t, which incorporates proportional nativity, conservatism, and relative abundance, was not strongly affected. Lastly, reduced sampling of transects *and* cover-classes incrementally decreased floristic metric performance, relative to RIRAM and ISA.

Overall, the abundance-weighted *Weighted Mean* CC_t outperformed *Mean* CC_t against RIRAM and ISA and was the most stable floristic measure in maintaining indicator precision when cover-class sampling effort was reduced. Cohen et al. (2004) suggest that the apparent increase in effectiveness gained by incorporating abundance classes is not worth the extra sampling effort. But the standardized sampling method developed for this study, which focused on species identification and the estimation of a broad cover class per species, added little extra effort over identity sampling alone (~2 min. per transect × 3 transects = ~6 min. per unit for full-effort sampling). Furthermore, applying the cover classes to *Mean* CC_t was a simple spreadsheet operation. The increased precision of *Weighted Mean* CC_t may be worth the small added increase in effort, particularly in evaluating an individual wetland, such as for evaluating restoration condition. Furthermore, this extra effort may be a worthwhile tradeoff for the apparent increased stability of *Weighted Mean* CC_t (over the other floristic measures) with a reduction in cover-class sampling effort, where reduced-effort sampling is appropriate. And although *Weighted Mean* CC_t is operationally somewhat more complex than *Mean* CC_t, the concept is still straightforward and intuitive: mean CC of all species, weighted by relative cover.

Three cover classes for abundance-weighted sampling were used in this study to increase producer precision (repeatability) at the cost of accuracy (deviation from actual values). Using five or six cover classes is a more common approach for estimating vegetation cover, but this is typically applied to smaller plots from which cover classes are easier to estimate (Mueller-Dombois and Ellenberg 1974), compared with the long, wide transects used in this study. Estimating five cover classes could potentially increase the precision of the *Weighted Mean* CC_t, but could also require additional time estimating cover per transect or partial transect in the field. The small increase in the performance of *Weighted Mean* CC_t relative to *Mean* CC_t suggests that further gains associated with more precise cover classes may be negligible.

The tradeoff between practicality and reliability of the FQA method will need to be considered for further implementation, perhaps on a per-project basis. Critical applications of floristic assessment would certainly be *best*-served by running the full sampling method and applying the data to *Weighted Mean* CC_t or *% Native*. Running reduced-cover-class sampling across three transects and applying the data to *Weighted Mean* CC_t may be the most efficient method for DEM for less critical evaluations. Testing the best-fit FQA metrics and sampling

methods on a larger study sample would clarify these tradeoffs, which would be helpful in developing more specific protocols for FQA implementation in RI.

4.2 Evaluating Wetland Restoration Outcomes

4.2.1 Characterizing Restoration Success

Wetland restoration success is an elusive concept that has sparked a great deal of discussion among wetland ecologists and managers (Mitsch and Wilson 1996, Kentula 2000, Hilderbrand et al. 2005, Palmer and Filoso 2009). Success can be assessed in terms of achieving specific (e.g. regulatory) goals, or in terms of restoring original ecological functionality, and these measures are not always entirely congruous (Kentula 2000). Additionally, methods of measuring success vary. For example, success can be measured in terms of the expected functions and values that have been restored, or in terms of general ecological functionality, which can be measured against reference wetlands using functional indicators (Mitsch and Wilson 2006). Even once absolute or relative functionality is established, there may be an ultimate need to quantify the cumulative ecosystem services gained from restoration activities across multiple restorations, which may represent another measure of success (Kentula 2000, Palmer and Filoso 2009). Rectifying the disparate methods and measures of restoration success is beyond the scope of this study. It may, therefore, be more relevant here to discuss how the tools developed in this study may be applied in informing and improving restoration practice, in general.

This study represents the second broad assessment of compliance-associated restoration wetlands conducted for the DEM. Cavallaro and Golet (2002) assessed the functional outcomes of 23 restored wetlands by determining whether each wetland performed each of six wetland functions identified by the Army Corps of Engineers (U.S. ACOE 2003). From that study, the authors were able to apply general observed trends about wetland functions, within the context of surrounding land use, and apply this information to develop restoration recommendations. Cavallaro and Golet suggest that compliance restorations should focus on the more realistic goals of providing particular functions and ecosystem services rather than on restoring original conditions. The authors identify invasive species as a problematic restoration outcome.

In contrast, this current study used floristic and Odonata-based indicators to set restoration units against a reference gradient. With this method, functions and values are not explicitly identified; functionality is instead implied by aggregate biological response to ambient wetland conditions. Whereas the functions-and-values assessment provides direct, qualitative information on specific wetland functions, reference-based assessment provides objective, quantitative information that can indicate the extent to which the functional potential of a restoration has been achieved (i.e. evaluate restoration condition), regardless of the specific functions and values it may inherently, or by-design, possess. Although it has been suggested that a single ecological indicator cannot adequately reflect multiple ecosystem processes in restoration evaluation (Palmer and Filoso 2009), the strong correlations of the floristic measures with multiple stress and impact metrics (Table 5) indicate that these measures indeed respond to (i.e. reflect) multiple aspects of wetland condition directly associated with ecosystem processes. Such broad indication could be applied to improving restoration methods to maximize the inherent potential of restoration projects. Additionally, this study suggests that the best-fit floristic and Odonata bioassessment tools tested here are capable of assessing restoration

condition across wetland types and sizes, which may be useful for evaluating management practices across multiple restorations.

4.2.2 Index Applicability

Concurrence of all best-fit floristic metrics, *Mean* CC_n, and OIWI in relating the restoration units to the reference sample indicates their proper function in assessing restoration condition. Although floristic quality assessment relies on subjective assignment of CCs, its application is objective for relative comparisons, if sampling and analysis methods are objective (Lopez and Fennessy 2002); strong correlations with independent level 1, 2, and 3 assessment data support this assumption and indicate the meaningfulness of the best-fit floristic measures. In contrast, because floristic measures relying on species richness may respond positively to competitive release caused by the disturbances associated with restoration, rather than simply reflecting a compositional similarity to reference wetlands, they are not appropriate indicators of restoration outcome (Matthews et al. 2010); findings of this current study support that assertion. Also supported here, Matthews et al. found *Mean* CC_t and *% Native* to be most effective at distinguishing between successful and unsuccessful restoration efforts, suggesting that these are valuable indicators of restoration-wetland condition. This current study additionally suggests that *Weighted Mean* CC_t may be the most precise and reliable FQA metric to evaluate any single wetland (see Sec. 4.1.2(3) and 4.1.3).

This study's findings demonstrate the utility of bioassessment methods for evaluating restoration outcomes and informing restoration planning. All of the best-fit floristic measures, *Mean* CC_n, and the OIWI agreed in indicating that restored wetlands were performing similarly to the most-degraded reference wetlands in general. Additionally, floristic indicators implied that restoration wetlands were slightly underperforming when evaluated in the context of adjacent land use (within 500'). In contrast, RIRAM detected no difference between restored and reference wetlands; this discrepancy may be the result of methodological viability. Rapid assessment could misrepresent restoration condition because differentiating between the effects of destructive and constructive manipulations may be difficult. For example, the *net result* of removing fill from a filled wetland (i.e., a restoration action) is structurally equivalent to removing all vegetation and disturbing the soils of a non-filled wetland (i.e., severe disturbance), yet devaluating RAM metrics for such well-intended manipulations may be counterintuitive. Bioassessment measures species response to resulting (*net*) site conditions regardless of the intent; it should therefore be a more objective and effective measure of restoration-wetland condition.

4.2.3 Implications of Findings

Findings imply that the restoration units may not be performing to their complete functional potential. This is not unusual; restoration and mitigation wetlands that meet regulatory requirements often fail to provide the full range of ecosystem services provided by natural wetlands (Mitsch and Wilson 1993, Kentula 2000, Palmer and Filoso 2009). Several factors could contribute to the apparent underperformance of these restorations. Foremost is the restoration context. Most of these restorations were conducted by private property owners in response to a DEM notice of violation. Many had been filled to upland grade, and the required restorative actions were to excavate the fill to a level at or below the original wetland grade, and to plant an evergreen buffer in the adjacent upland. In-wetland planting is generally not required by DEM, because the high costs of planting native wetland vegetation would eliminate the

plausibility of many privately-funded restorations. Additionally, preserving the existing seed bank is not always possible or practical due to the inaccuracies of heavy equipment or its operators, inherent wetland micro-topographic relief, a lack of qualified oversight, and other factors (S. Tyrell personal communication). As a consequence of these limitations, the immediate outcome of restoration is potentially an open basin containing bare, saturated or flooded mineral substrate with minimal viable propagules; this leaves opportunity for the establishment of opportunistic colonizers including invasive species.

Similar to prior assessment findings (Cavallaro and Golet 2002), invasive plant species affected the condition of the restoration units assessed in this study. Four units were dominated (>50% cover) by invasive *P. australis*, an additional three sites had >25% total cover of invasive species, and all units contained some invasive species. The strong correlation of invasive species total cover with all best-fit floristic measures among the reference units, coupled with previous findings that invasive species were strongly associated with Odonata conservatism (OIWI), surrounding impervious cover (ISA), and apparent cumulative impacts to functional indicators (i.e. RIRAM *Observed State*; Kutcher 2011c), indicates a strong negative relationship between invasive species cover and general wetland condition. Cavallaro and Golet (2002) offered guidelines for future restorations that included quickly establishing dense, native groundcover to reduce the likelihood of invasive species establishment; this would require one or a combination of the following: salvaging the original propagule bank (if it does not contain invasive species), planting or seeding with native vegetation, or transplanting a native seed bank from another wetland. Not all of these options may be practical in the context of compliance restoration, but they may be important to consider for fully restoring ecosystem functionality.

4.3 Conclusions

Floristic indicators can provide reliable, relevant, and valuable information on freshwater wetland condition. Indicators that ignore species richness and incorporate exotic species provide the most precise indication of general wetland condition according to their best fit among three levels of independent wetland assessment data. The straightforward *Mean* CC_t (simply the average sensitivity of all species to human disturbance) prevails as the most effective and parsimonious measure among non-weighted FQA variants. However, because it incorporates relative species abundance and is thus more ecological relevant, *Weighted Mean* CC_t should be the primary metric considered in wetland assessment applications where weighting CCs by relative abundance is practical. The simple proportion of native species (*% Native*) may also be a reliable and straightforward indicator of general wetland condition, although due to its simplicity, it may be particularly vulnerable to loss of effectiveness with a reduction in sampling effort, compared with the CC-based variants. This study suggests that the *Weighted Mean* CC_t FQA variant may be the floristic measure least vulnerable to a reduction in the number of species identified, which can significantly reduce total effort. Indeed, reducing plant identification effort to only species comprising ≥10% cover resulted in <10% loss of *Weighted Mean* CC_t index effectiveness compared with full sampling effort.

Using a weight of evidence approach, strong covariance among the best-fit floristic measures, Odonata conservatism (OIWI), rapid assessment (RIRAM), and surrounding impervious cover (ISA) strongly indicates the proper function of all of these measures in quantifying general freshwater wetland condition. This information could be applied to equip the monitoring and assessment toolbox of DEM and other interested parties. Specifically, ISA could be applied to quickly automate an indication of wetland condition across large areas; RIRAM

could be used to collect important classification, characteristic, and condition information within specific areas of concern and answer a range of questions regarding wetland condition (i.e. address DEM objectives), with low effort and good reliability; floristic assessment could be applied to further assess important wetlands, evaluate restoration outcomes, and run objective analyses, such as change analyses over time; and OIWI could be applied to existing Odonata datasets, or to new Odonata sampling data in special cases where floristic assessment is impractical or where a preponderance of high-resolution evidence is required. Of these assessment tools, those measuring species response may be the most appropriate for assessing restoration condition. Specifically, floristic and odonate (OIWI) bioindicators could be confidently applied to gauge restoration condition, i.e. the extent to which a restoration is fully performing its potential ecological functions. Information on restoration condition can compliment direct functions and values information to help managers evaluate restoration success. This information could be fed back into management planning and practice to improve subsequent restoration outcomes.

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Appendix 1

Rhode Island Rapid Assessment Method version 2.10 Field Datasheet

RIRAM V.2.10 Investigators_____ Site Code_____ Date_____

A. Wetland Characteristics; apply to the *current* state of the wetland. Not Scored.

1) Assessment Unit Area; select one:

- ☐ <0.25 acres
- ☐ 0.25 to <1.0 acres
- ☐ 1.0 to <3.0 acres
- ☐ 3.0 to <10 acres
- ☐ 10 to <25 acres
- ☐ 25 to 50 acres
- ☐ >50 acres

2) Hydrologic Characteristics

Source of water; select main source:

- ☐ Precipitation
- ☐ Groundwater
- ☐ Surface water

Maximum water depth, today; select one:

- ☐ Dry
- ☐ Saturated
- ☐ <1 foot
- ☐ 1 to 3 feet
- ☐ >3 feet

Water Regime; select one or two dominant regimes:

- ☐ Permanently flooded
- ☐ Semi-permanently flooded
- ☐ Seasonally flooded
- ☐ Temporarily flooded
- ☐ Permanently saturated
- ☐ Seasonally saturated
- ☐ Regularly flooded (tidal)
- ☐ Irregularly flooded (tidal)

3) Habitat Characteristics

Habitat stratum diversity; estimate total cover of all habitat strata within unit using classes at right:

___ Trees
___ Shrubs
___ Emergent
___ Aquatic bed
___ Sphagnum
___ Surface water, today
___ Unvegetated substrate, today

Cover Classes:
0…..< 1%
1…..1-5%
2…..6-25%
3…..26-50%
4…..51-75%
5…..>75%

Microhabitat diversity; rate each present using the scale at right:

___ Vegetated hummocks or tussocks
___ Coarse woody debris
___ Standing dead trees
___ Amphibian breeding habitat

Ecological Significance Scale:
0…..None Noted
1…..Minor Feature
2…..Significant Feature
3…..Dominant Feature

4) Wetland Classification

Hydrogeomorphic Class; select main one:

- ☐ Isolated Depression
- ☐ Connected Depression
- ☐ Floodplain (riverine)
- ☐ Fringe
- ☐ Slope
- ☐ Flat

NWI Classes; select all comprising unit and indicate *Dominance Type*:

- ☐ Forested _____
- ☐ Scrub-shrub _____
- ☐ Emergent _____
- ☐ Aquatic Bed _____
- ☐ Unconsolidated Bottom or Shore
- ☐ Rock Bottom or Shore

RINHP natural community types; select all present within unit:

- ☐ Freshwater tidal marsh*
- ☐ Interdunal swale*
- ☐ Intermittent stream
- ☐ Eutrophic Pond
- ☐ Coastal plain pondshore*
- ☐ Coastal plain quagmire*
- ☐ Deep emergent marsh
- ☐ Shallow emergent marsh
- ☐ Emergent fen*
- ☐ Dwarf shrub bog / fen*
- ☐ Dwarf tree bog*
- ☐ Scrub-shrub wetland
- ☐ Floodplain Forest*
- ☐ Red Maple Swamp
- ☐ Vernal pool*
- ☐ Hemlock-hardwood swamp
- ☐ Atlantic white cedar swamp*
- ☐ Black Spruce Bog*
- ☐ Other Type: _____

5) Wetland values; select all known or observed:

- ☐ Within 100 year flood plain
- ☐ Between stream or lake and human use
- ☐ Part of a habitat complex or corridor
- ☐ Falls in aquifer recharge zone
- ☐ Contains known T/E species
- ☐ Significant avian habitat
- ☐ Contains *GCN** habitat type
- ☐ Educational or historic significance

*Identified by DEM as habitat of *Greatest Conservation Need*

RIRAM V.2.10 Investigators_____ Site Code_____ Date_____

B. Landscape Stresses. Sum metrics 1 and 2

1) Degradation of Buffers

Estimate % cultural cover within 100-foot buffer. Select one.

- ☐ <5% (10)
- ☐ 6 to 25% (7)
- ☐ 26-50% (4)
- ☐ 51-75% (1)
- ☐ >75% (0)

Associated Stressors: Check all that apply

- ☐ Commercial or industrial development
- ☐ Unsewered Residential development
- ☐ Sewered Residential development
- ☐ New construction
- ☐ Landfill or waste disposal
- ☐ Channelized streams or ditches
- ☐ Raised road beds
- ☐ Foot paths / trails
- ☐ Row crops, turf, or nursery plants
- ☐ Poultry or livestock operations
- ☐ Orchards, hay fields, or pasture
- ☐ Piers, docks, or boat ramps
- ☐ Golf courses / recreational development
- ☐ Sand and gravel operations
- ☐ Other _____

2) Intensity of Surrounding Land Use

Land Use Intensity weighted average within 500-foot buffer.
Estimate proportion of each class to the nearest tenth and multiply.

	Proportion	Score	Weighted Value
Very Low	_____	× 10 =	_____
Low	_____	× 7 =	_____
Moderately High	_____	× 4 =	_____
High	_____	× 1 =	_____

Sum weighted values for score = _____

Very Low…….Natural areas, open water
Low……Recovering natural lands, passive recreation, low trails/dirt roads
Mod High……Residential, pasture/hay, mowed areas, raised roads to 2-lane
High……Urban, impervious land cover, new construction, row crops, turf crops, mining operations, paved roads > 2-lane

Sum of Metrics 1 and 2 = ☐ **B. Landscape Stress Score**

C. Wetland Stresses. Sum metrics 3 to 9 and subtract from 70.

3) Impoundment.

Sum a and b (Max = 10)

a. Increase in depth or hydroperiod. Select one and multiply by the proportion of the unit affected to the nearest tenth. = _____

- ☐ None (0)
- ☐ Wetland was *created* by impoundment (1)
- ☐ Change in velocity only (2)
- ☐ Change of less than one water regime (4)
- ☐ Change of one water regime (6)
- ☐ Change of two or more water regimes (8)
- ☐ Change to deepwater (10)

Proportion of unit affected (circle one)
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

Evidence: check all that apply

- ☐ Physical barrier across flow downstream of wetland
- ☐ Abrupt and unnatural edge downstream of wetland
- ☐ Dam or restricting culvert downstream of wetland
- ☐ Deepening of wetland upstream of barrier
- ☐ Widening of wetland upstream of barrier
- ☐ Change in vegetation across barrier
- ☐ Dead or dying vegetation

Primary Associated Stressor; check one:

- ☐ Road
- ☐ Railway
- ☐ Weir / Dam
- ☐ Raised Trail
- ☐ Development Fill
- ☐ Other

b. Artificial barrier to movement of resources through water. Select all that apply and sum. = _____

- ☐ None (0)
- ☐ Barrier to upstream movement at low water (1)
- ☐ Barrier to downstream movement at low water (1)
- ☐ Barrier to upstream or downstream movement above low water (1)

Primary Source of Stress; indicate as current (C) or historic (H):

- __ Private / Residential
- __ Commercial
- __ Agricultural
- __ Public transportation
- __ Public utilities
- __ Public recreation
- __ Undetermined

Water Regimes

(Upland)……Temporarily Flooded……Irregularly Flooded
Seasonally Saturated ……Seasonally Flooded……Regularly Flooded
Permanently Saturated ……Semi-permanently Flooded
Permanently Flooded

4) Draining or diversion of water from wetland.

Decrease in depth or hydroperiod. Select one and multiply by the proportion of the unit affected to the nearest tenth.

- ☐ None (0)
- ☐ Change in velocity only (3)
- ☐ Change of less than one water regime (5)
- ☐ Change of one water regime (7)
- ☐ Change of two or more water regimes or to upland (10)

Water Regimes

(Upland)……Temporarily Flooded…… Irregularly Flooded
Seasonally Saturated ……Seasonally Flooded……..Regularly Flooded
Permanently Saturated ……Semi-Permanently Flooded
Permanently Flooded

Proportion of unit affected (circle one)
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

Evidence: check all that apply
- ☐ Drainage ditches or tiles evident
- ☐ Evident impoundment upstream of wetland
- ☐ Severe root exposure
- ☐ Moderate root exposure
- ☐ Soil fissures
- ☐ Uncharacteristically dry groundcover
- ☐ Dead or dying vegetation
- ☐ Change in vegetation across barrier

Primary Associated Stressor; Check one:
- ☐ Road
- ☐ Railway
- ☐ Dike
- ☐ Fill
- ☐ Drainage ditch / tile
- ☐ Major well withdrawals
- ☐ Surface water pumps
- ☐ Other

Primary Source of Stress; indicate as current (C) or historic (H):
- __ Private / Residential
- __ Commercial
- __ Agricultural
- __ Public transportation
- __ Public utilities
- __ Public recreation
- __ Undetermined

5) Anthropogenic fluvial inputs.

Rank the evidence of impact for each and sum (Max = 10).

____ a. Nutrients

____ b. Sediments / Solids

____ c. Toxins / Salts

____ d. Increased flashiness

Evidence-of-Impact Ranks
0…..No evidence
1…..Sources evident, only
3…..Slight impact evident
5…..Moderate to strong impact evident

Evidence: check all that apply
- ☐ Runoff sources evident
- ☐ Point sources evident
- ☐ Excessive algae or floating vegetation
- ☐ Excessive rooted submerged or emergent vegetation
- ☐ Uncharacteristic sediments
- ☐ Obvious plumes or suspended solids
- ☐ Chemical smell
- ☐ Strangely tinted water
- ☐ Dead, dying, or patchy vegetation
- ☐ Dead fauna or stark lack of life
- ☐ Root exposure or bank erosion due to scouring

Primary Associated Stressor; Check one:
- ☐ Point runoff
- ☐ Sheet runoff
- ☐ Effluent discharge
- ☐ Organic / yard waste
- ☐ Other point _____
- ☐ Riverine (up-stream)
- ☐ Multiple / non-point
- ☐ Channelization

Primary Source of Stress; indicate as current (C) or historic (H):
- __ Private / Residential
- __ Commercial
- __ Agricultural
- __ Public transportation
- __ Public utilities
- __ Public recreation
- __ Multiple / non-point
- __ Undetermined

6) Filling and dumping within wetland. Select one and multiply by the proportion of the unit affected to the nearest tenth (Max = 10).

Intensity of filling
- ☐ None (0)
- ☐ Affects aesthetics only (2)
- ☐ Affects water regime, vegetation, or soil quality (6)
- ☐ Changes area to upland (10)
- ☐ Fill is above surrounding upland grade (12)

Proportion of unit (or perimeter) affected (circle one)
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

Evidence: check all that apply
- ☐ Unnaturally abrupt change in ground level
- ☐ Abrupt change in soil texture or content
- ☐ Unnaturally straight or abrupt wetland edge
- ☐ Unnatural items on or within the sediments

Primary Associated Stressor; Check one:
- ☐ Road
- ☐ Raised Trail
- ☐ Railway
- ☐ Trash
- ☐ Fill
- ☐ Organic / yard waste
- ☐ Dam
- ☐ Dike
- ☐ Other

Primary Source of Stress; indicate as current (C) or historic (H):
- __ Private / Residential
- __ Commercial
- __ Agricultural
- __ Public transportation
- __ Public utilities
- __ Public recreation
- __ Undetermined

7) Excavation and other substrate disturbances within wetland. Select one and multiply by the proportion of the unit affected to the nearest tenth.

Proportion of unit (or perimeter) affected (circle one)
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

Intensity of disturbance
- ☐ None (0)
- ☐ Wetland unit was *created* by excavation (1)
- ☐ Soil quality or vegetation disturbed (4)
- ☐ Changes water regime (7)
- ☐ Excavated to deep water (10)

Evidence: check all that apply
- ☐ Unnaturally abrupt lowering in ground level
- ☐ Loss of vegetation
- ☐ Unnaturally straight and abrupt wetland edge
- ☐ Direct evidence of disturbance

Primary Associated Stressor; Check one:
- ☐ Vehicle disturbance
- ☐ Plowing / cultivation
- ☐ Excavation / Grading
- ☐ Channelization / Dredging
- ☐ Ditching
- ☐ Footpaths
- ☐ Trampling
- ☐ Other

Primary Source of Stress; indicate as current (C) or historic (H):
- __ Private / Residential
- __ Commercial
- __ Agricultural
- __ Public transportation
- __ Public utilities
- __ Public recreation
- __ Undetermined

8) Vegetation and detritus removal within wetland. Rank extent and multiply by the estimated proportion affected for each layer; then sum (Max = 10).

Proportion of unit affected
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

Layers affected	Extent		Proportion		
☐ Aquatic Bed	_____	×	_____	=	_____
☐ Detritus	_____	×	_____	=	_____
☐ Emergent	_____	×	_____	=	_____
☐ Shrub	_____	×	_____	=	_____
☐ Canopy	_____	×	_____	=	_____

Sum =_____

Evidence: check all that apply
- ☐ Cut stems or stumps
- ☐ Immature vegetation strata
- ☐ Missing vegetation strata
- ☐ Mowed areas
- ☐ Browsing or grazing

Extent of removal
0.....None
2.....Partial or recovering
3.....Complete

Primary Associated Stressor; Check one:
- ☐ Power lines
- ☐ Grazing
- ☐ Cultivation
- ☐ Timber Harvest
- ☐ Development clearing
- ☐ Trails / non-raised roads
- ☐ Excavation / ditching
- ☐ Other

Primary Source of Stress; indicate as current (C) or historic (H):
- __ Private / Residential
- __ Commercial
- __ Agricultural
- __ Public transportation
- __ Public utilities
- __ Public recreation
- __ Undetermined

9) Invasive species within wetland.

9a. Select one class for total coverage.
- ☐ None noted (0)
- ☐ Nearly absent <5% cover (2).....Cover Class 1
- ☐ Low 6-25% cover (4).....Cover Class 2
- ☐ Moderate 26-50% cover (6).....Cover Class 3
- ☐ High 51-75% cover (8).....Cover Class 4
- ☐ Extensive >75% cover (10).....Cover Class 5

9b. List and select a cover class for each invasive plant species noted.

Cover Class	Species
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

Primary Abutting Stressor; Check one:
- ☐ Road
- ☐ Railway
- ☐ Raised Trail
- ☐ Footpath
- ☐ Dam / Dike
- ☐ Organic / yard waste
- ☐ Other Fill
- ☐ Drainage ditch / tile
- ☐ Stormwater input
- ☐ Clearing
- ☐ Multiple
- ☐ Other

Primary Source of Stress; indicate as current (C) or historic (H):
- __ Private / Residential
- __ Commercial
- __ Agricultural
- __ Undetermined
- __ Public transportation
- __ Public utilities
- __ Public recreation

Sum of C3 to C9 Scores = ☐ **70 Minus Sum =** ☐ **C. Wetland Stress Score**

D. Observed State of Wetland Characteristics. Circle one score for each characteristic and sum. Refer to Sections A through C to inform scores. Consider current wetland types.

Characteristics	Characteristic*		Degraded		Destroyed
Hydrologic Integrity……	2	1.5	1	0.5	0
Water and Soil Quality……	2	1.5	1	0.5	0
Vegetation/microhabitat Structure……	2	1.5	1	0.5	0
Vegetation Composition……	2	1.5	1	0.5	0
Habitat Connectivity……	2	1.5	1	0.5	0

SUM = ☐ **D. Observed State Score**

B. Landscape Stress Score (max 20) _____ **+**

C. Wetland Stress Score (max 70) _____ **=**

B+C. Total Stress Score (max 90) ☐

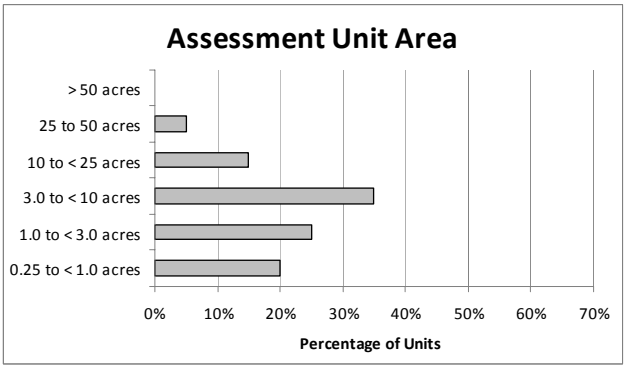
D. Observed State Score (max 10) _____ **=**

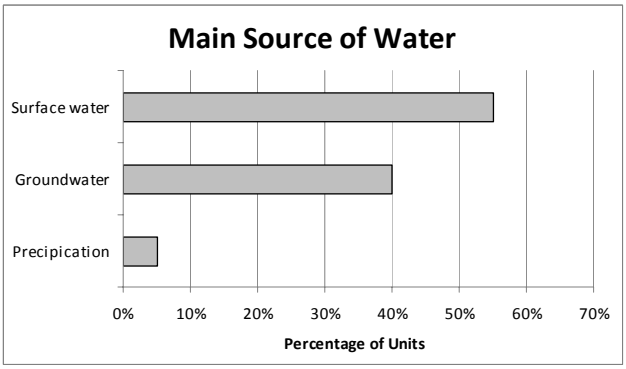
RIRAM V. 2.10 Condition Index ☐

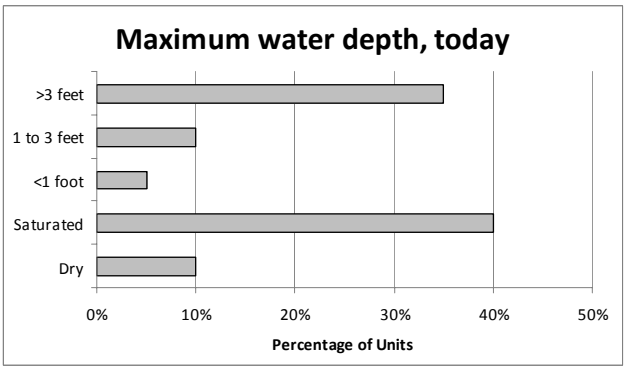
* Characteristic of wetland type in an unstressed setting

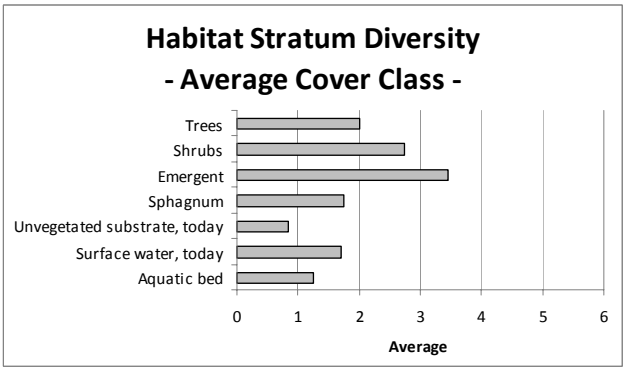
A. Wetland Characteristics and Classification

Reference Sample

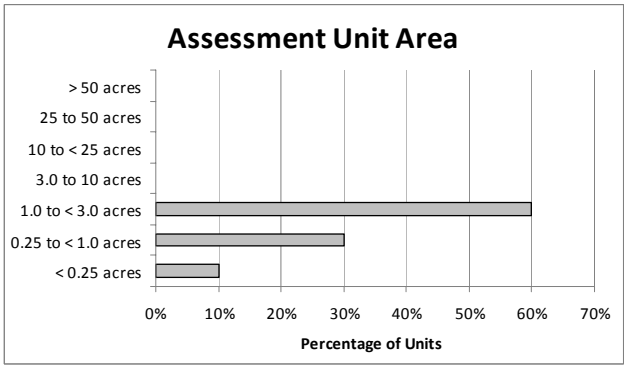


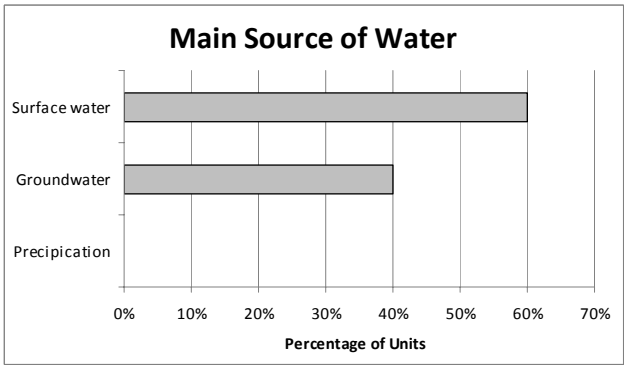


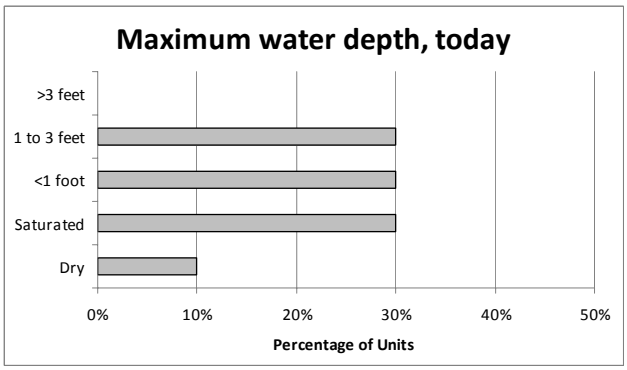


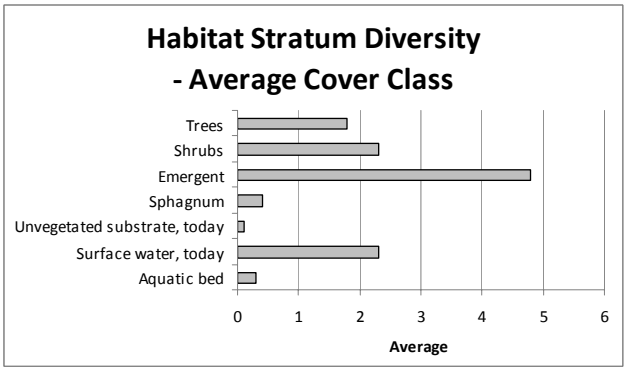


Restoration Sample









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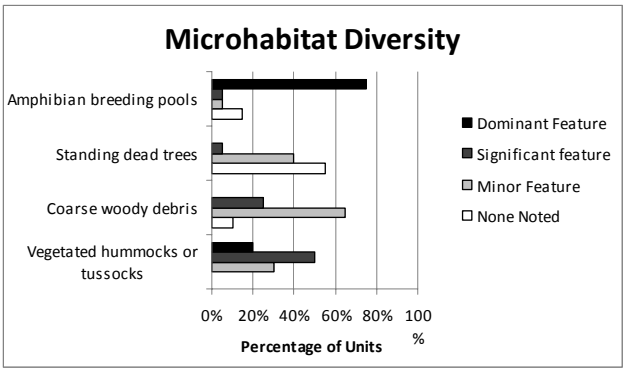

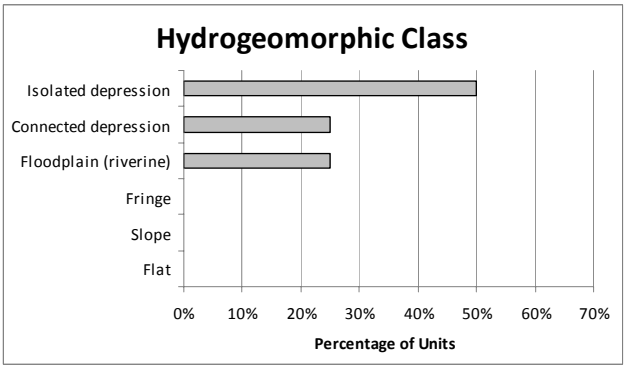

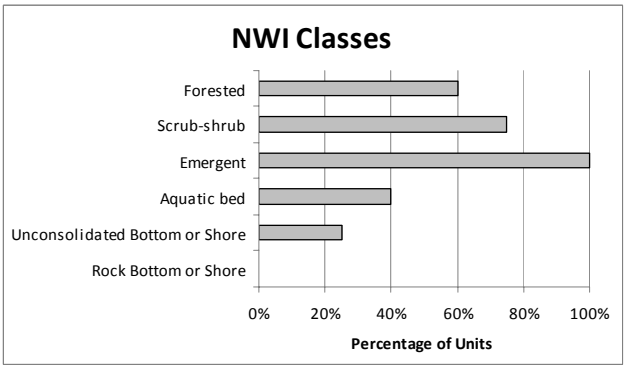

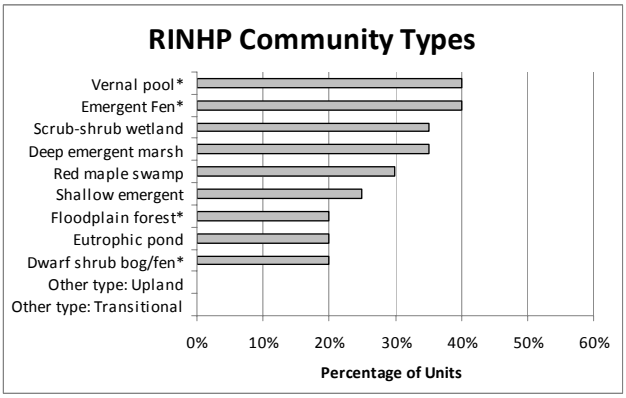

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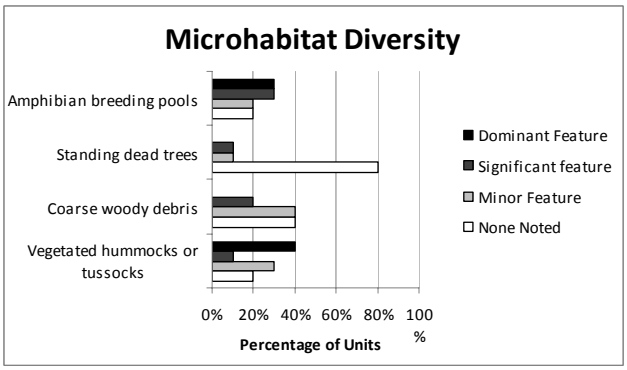

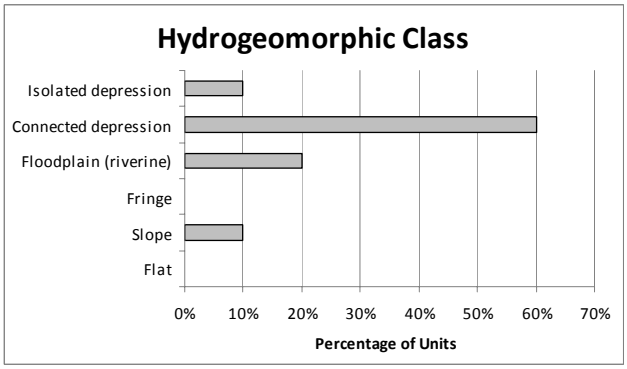

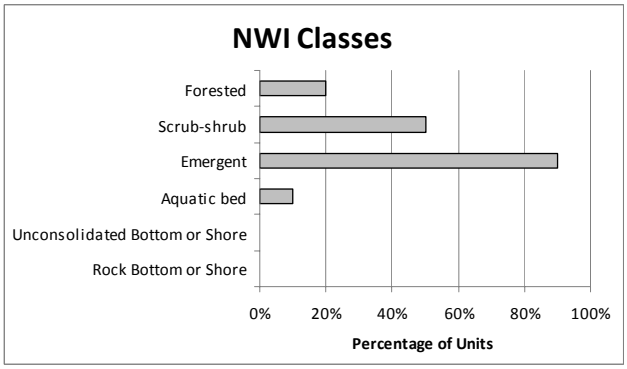

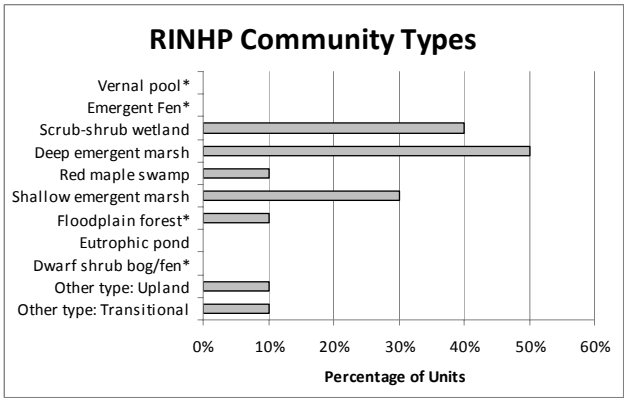

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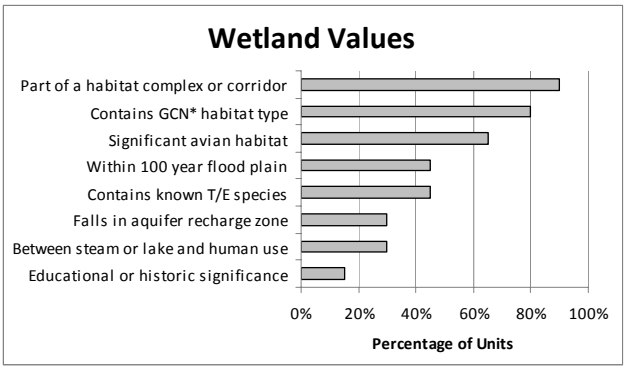

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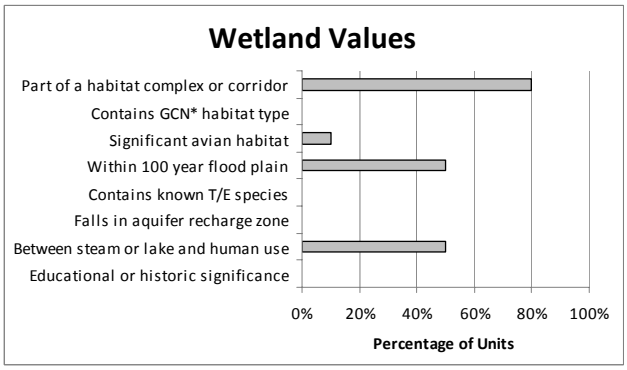
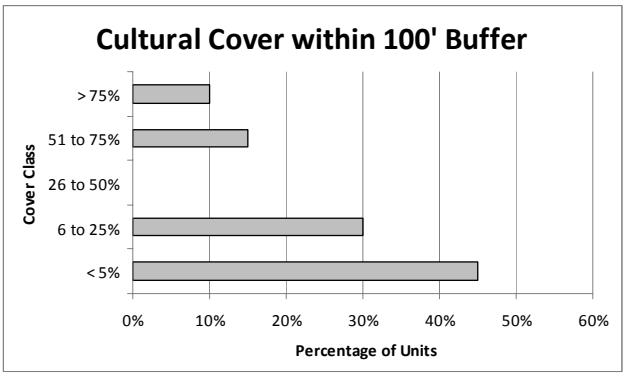
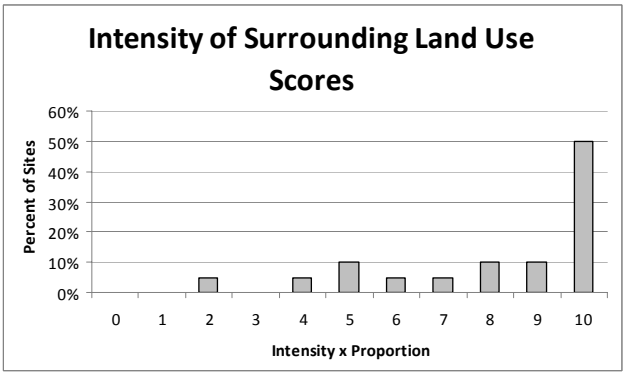
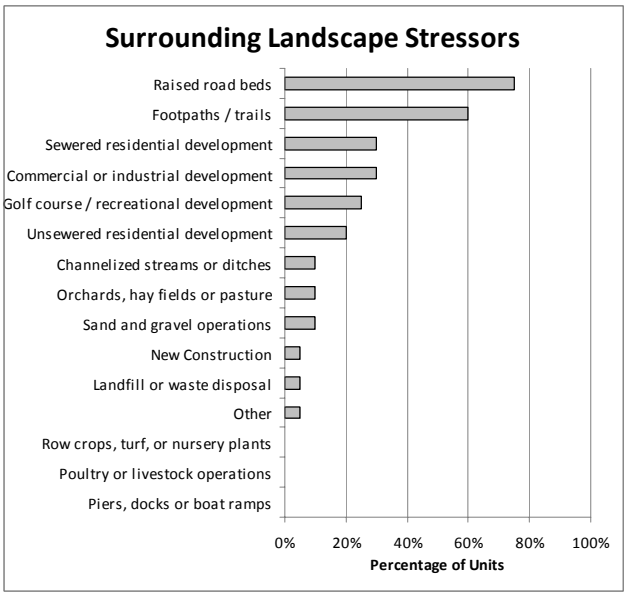


B. Landscape Stresses

Reference Sample







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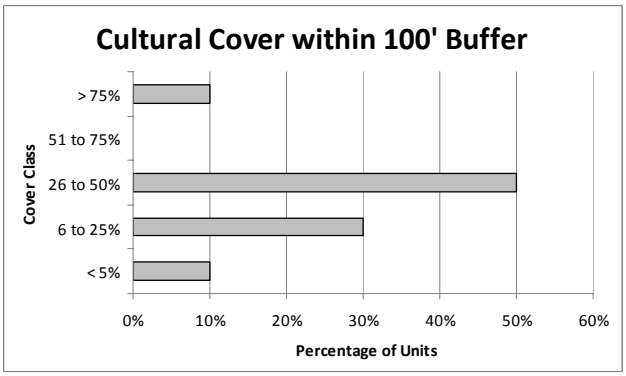
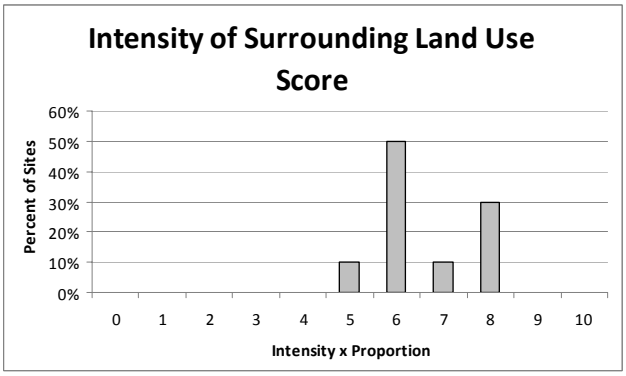
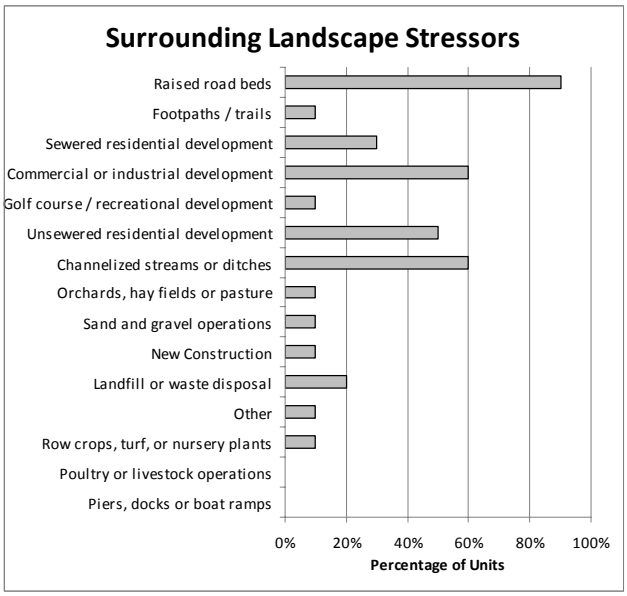


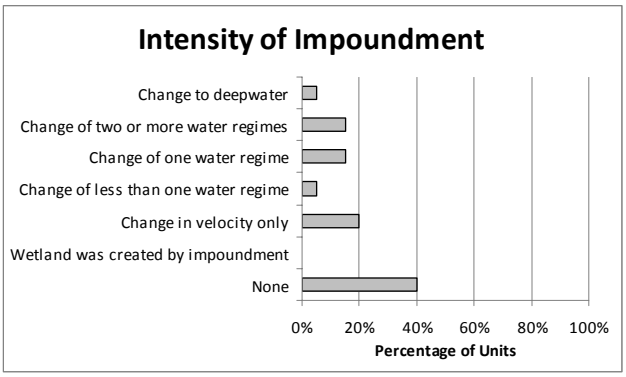


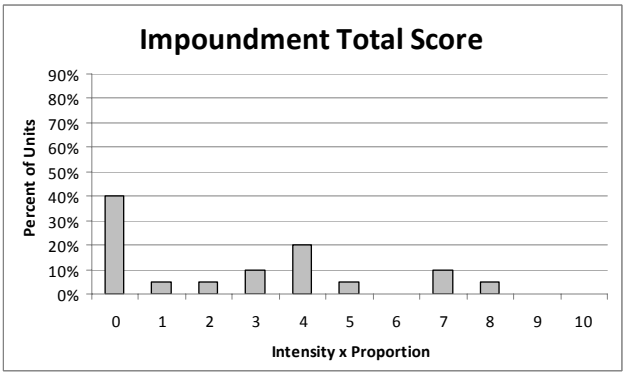


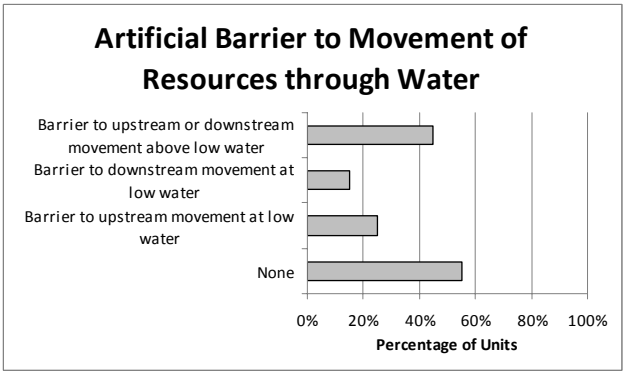
C. Wetland Stresses

1. Impoundment

Reference Sample







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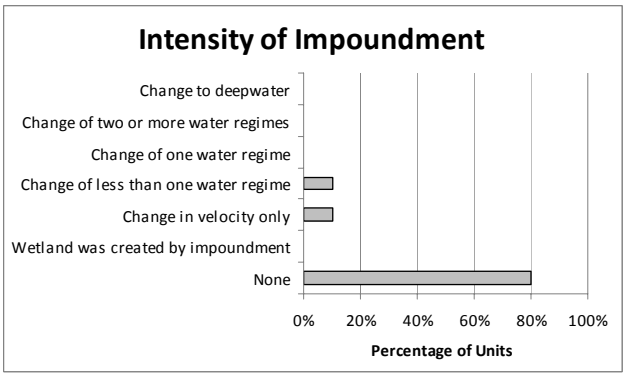

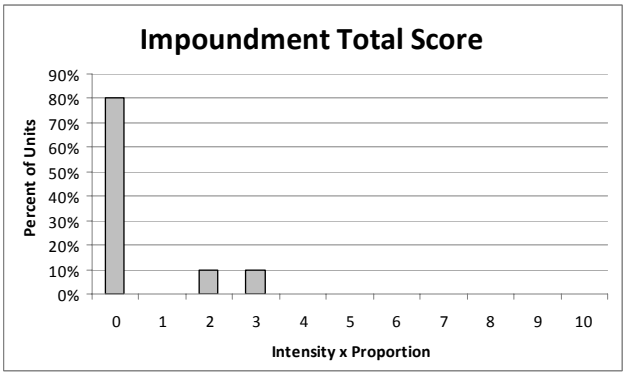

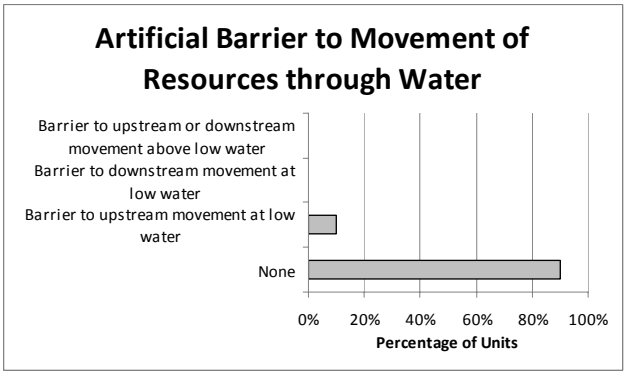

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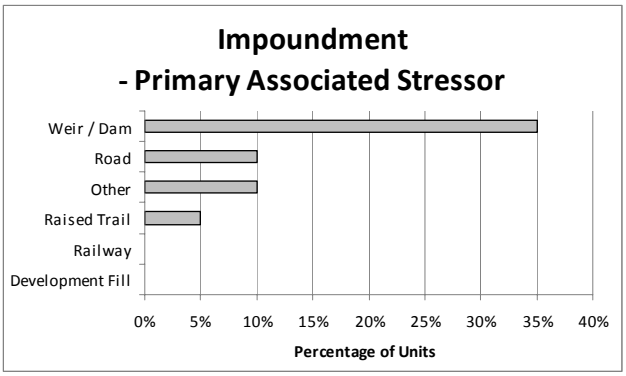
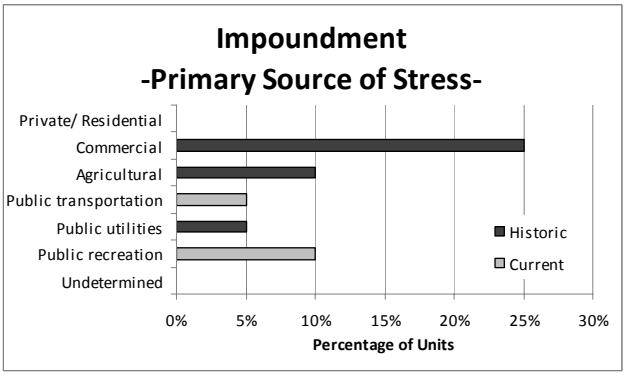
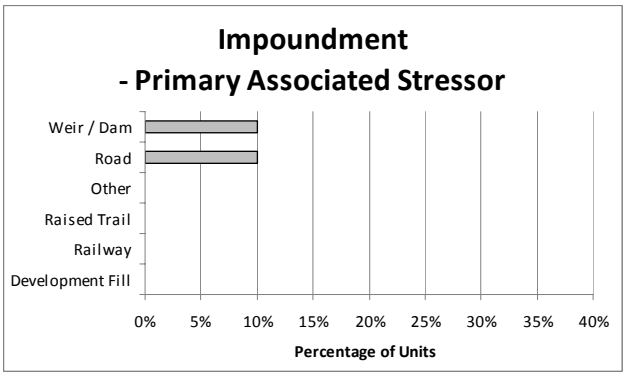
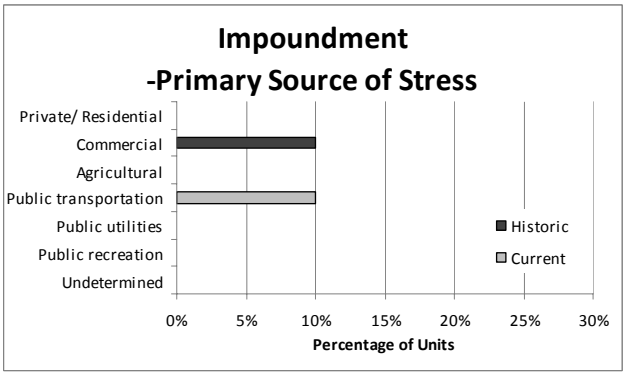




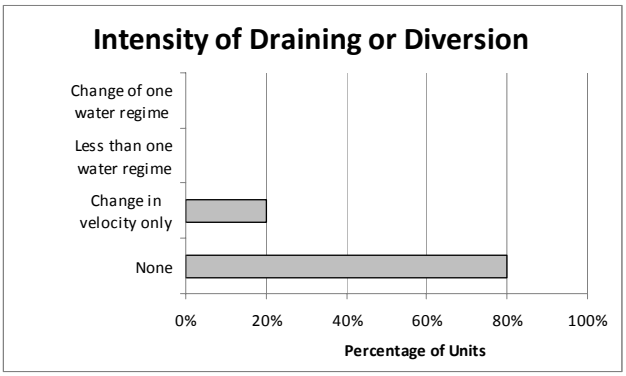
Restoration Sample

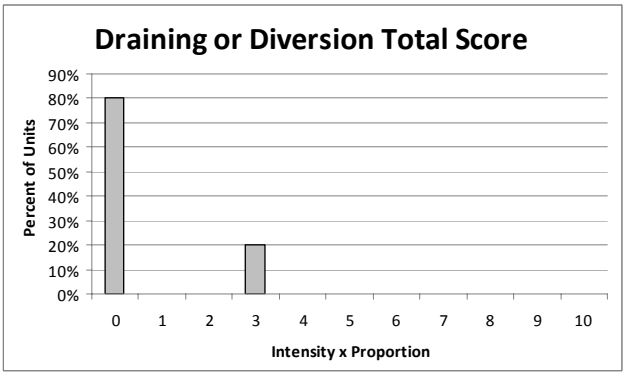


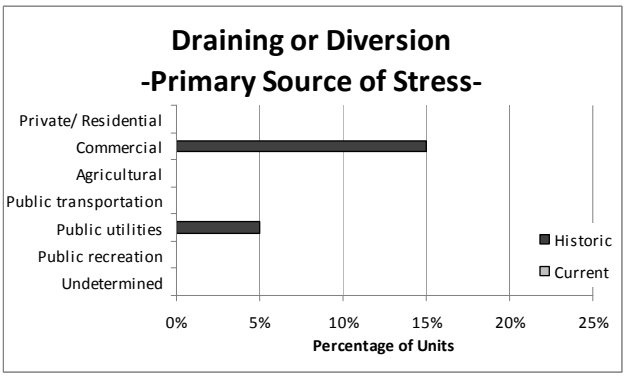


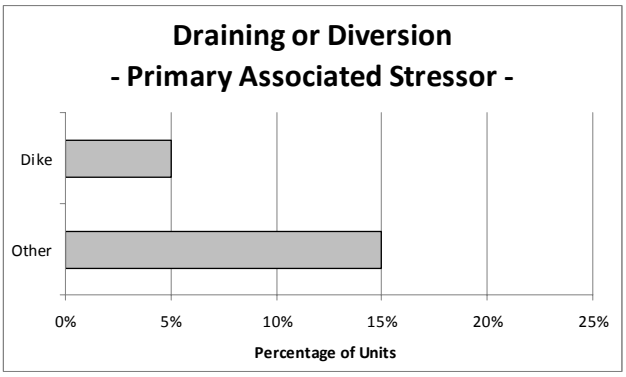
4. Draining or Diversion of Water

Reference Sample

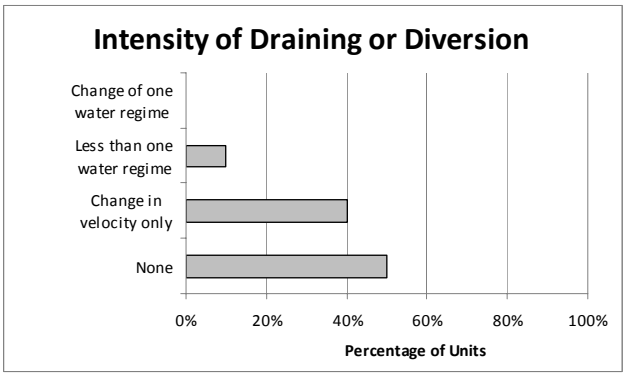


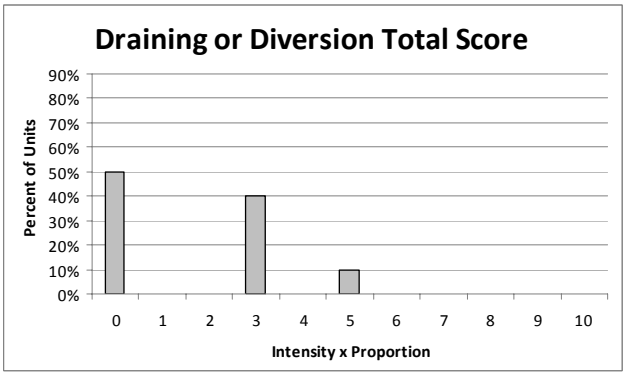


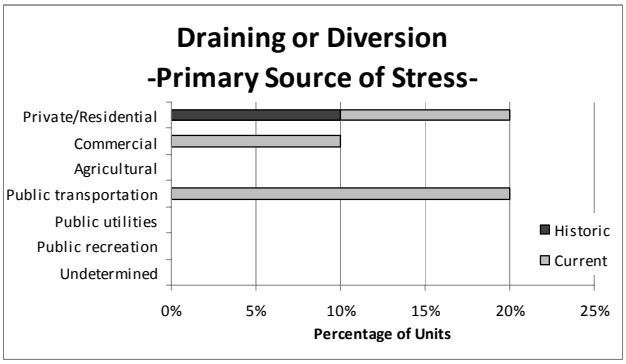


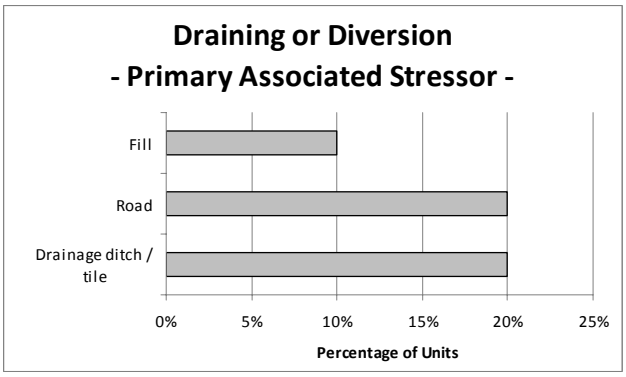


Restoration Sample



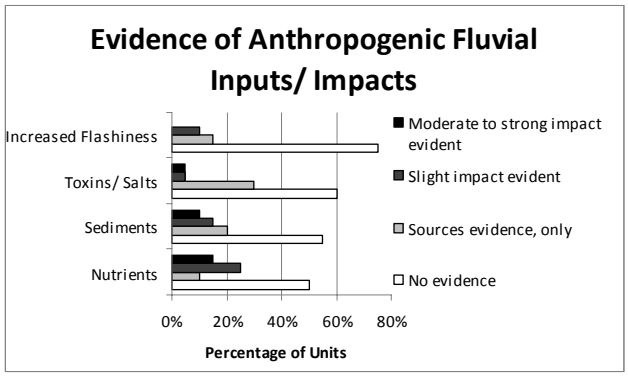


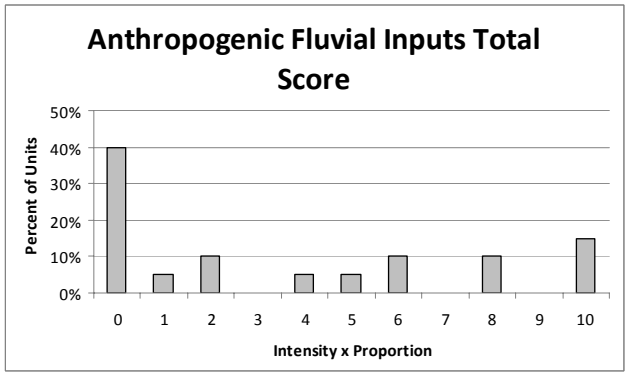


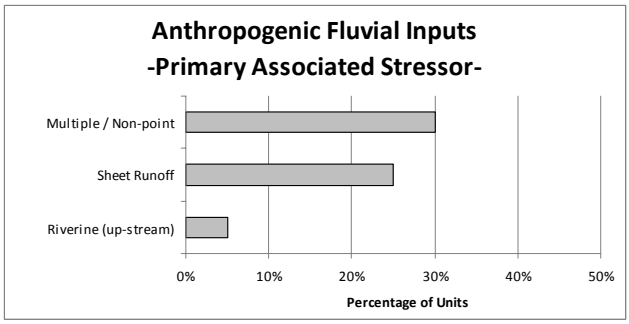


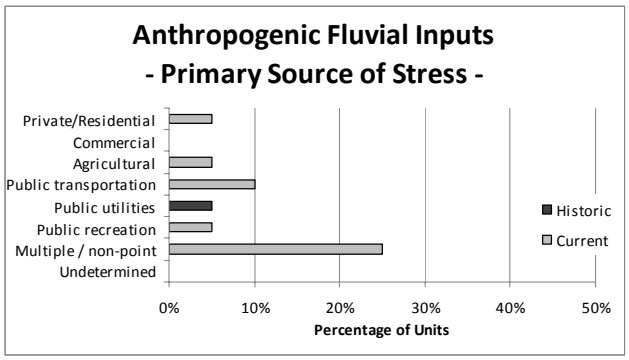
5. Anthropogenic Fluvial Inputs

Reference Sample

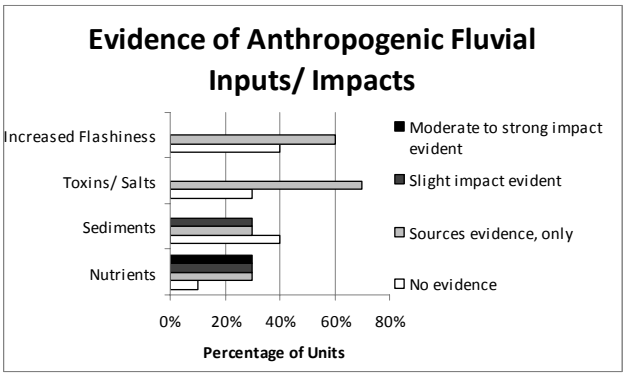


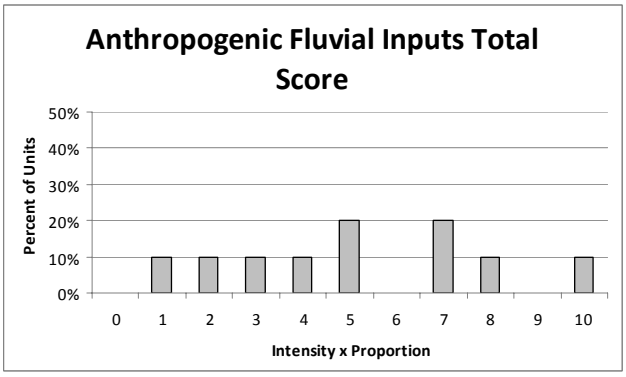


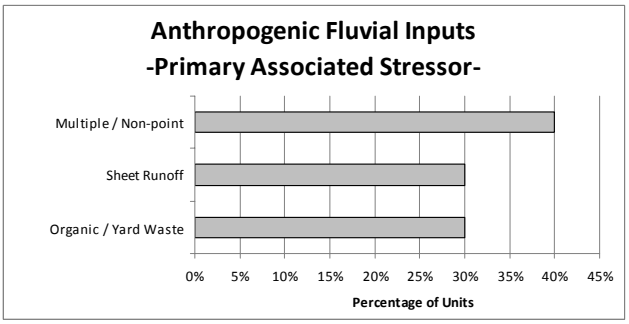


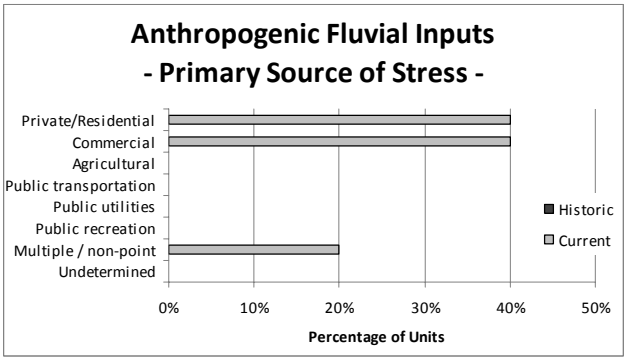


Restoration Sample



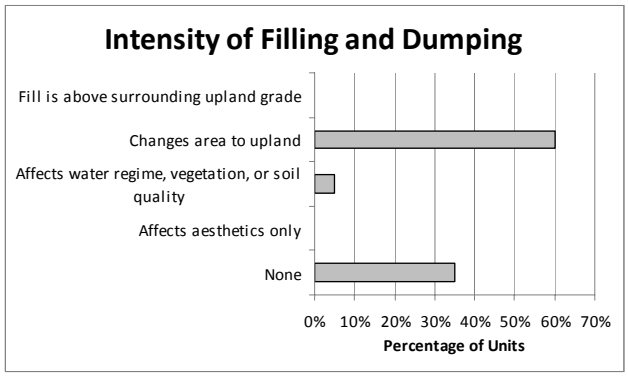


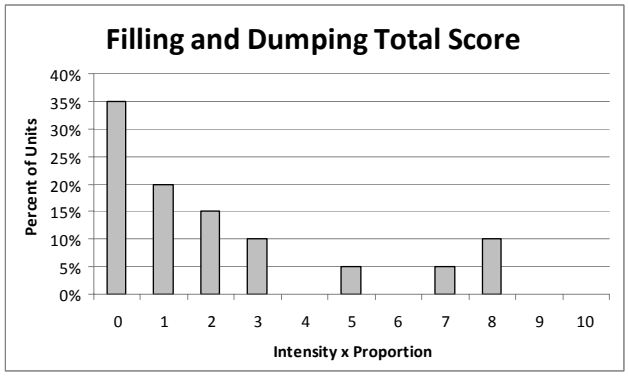


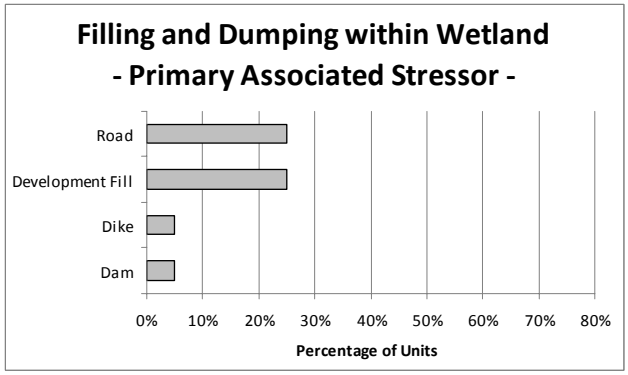


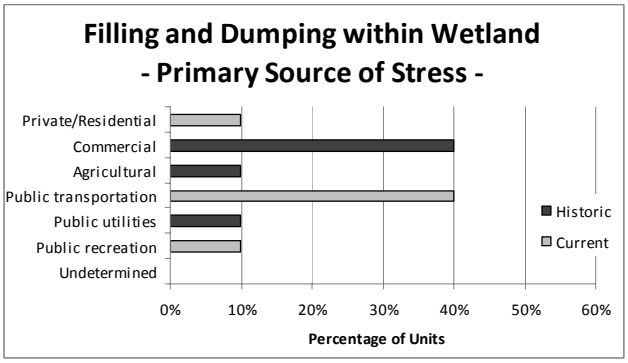
6. Filling and Dumping

Reference Sample

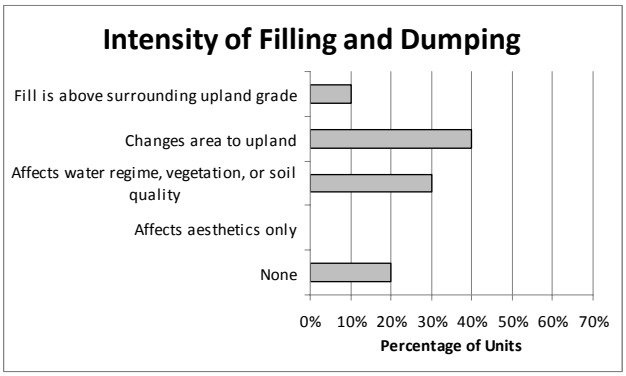


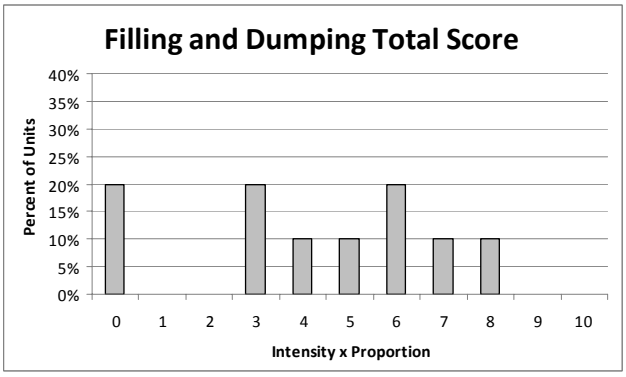


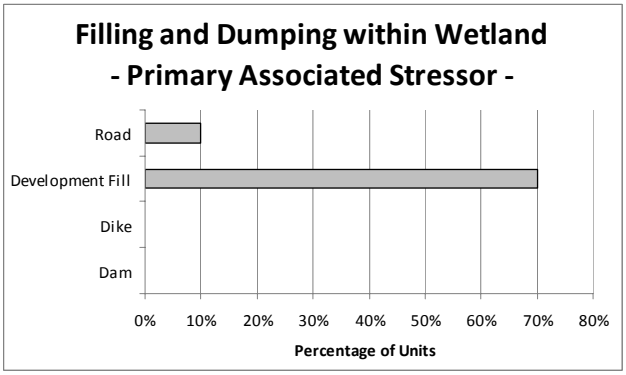


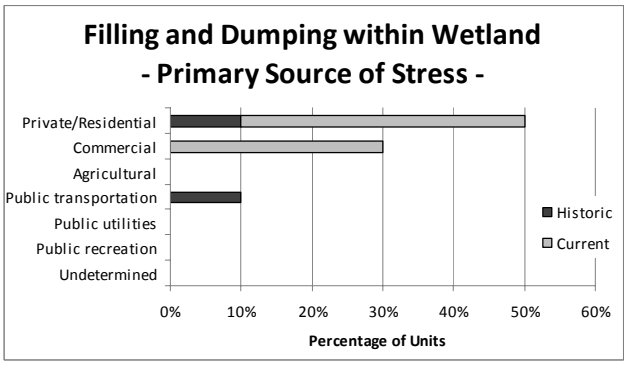


Restoration Sample



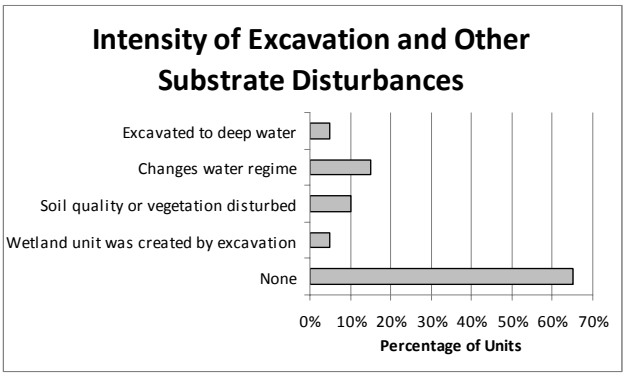


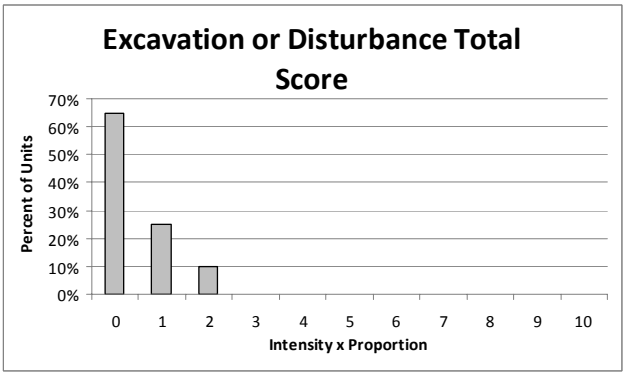


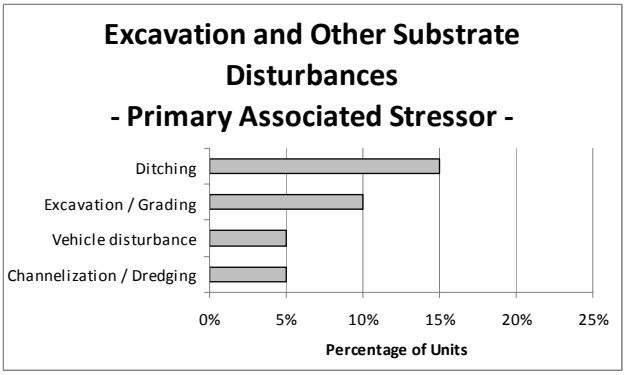


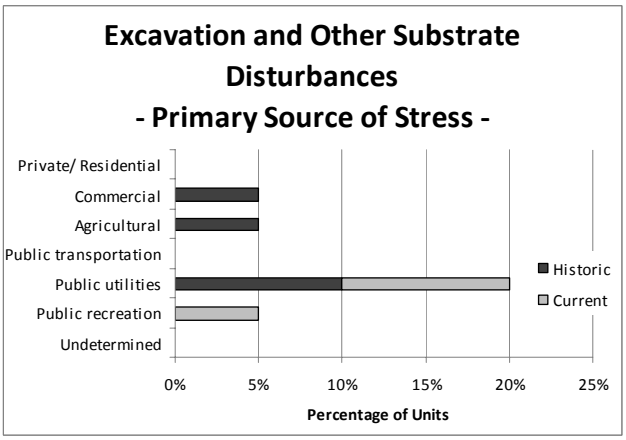
7. Excavation and Other Substrate Disturbances

Reference Sample

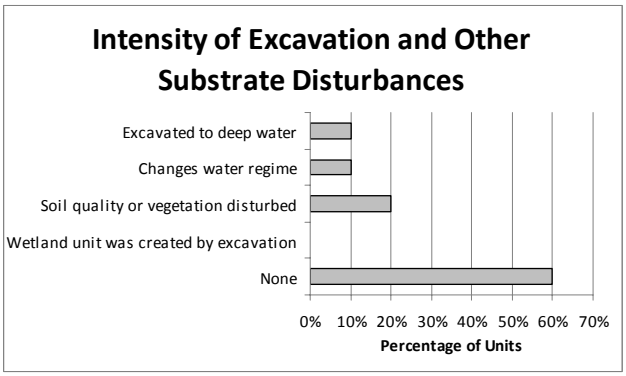


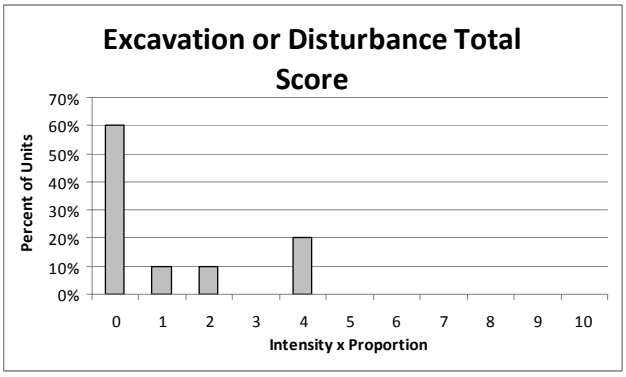


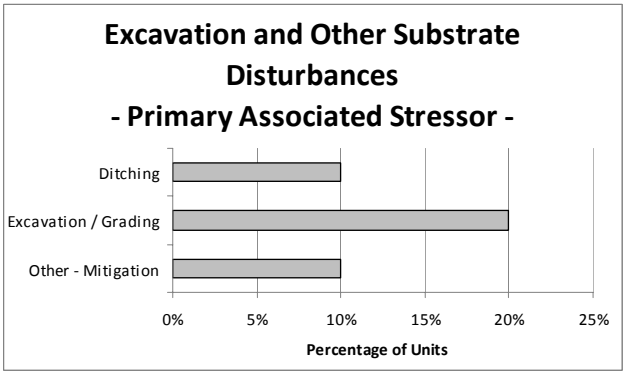


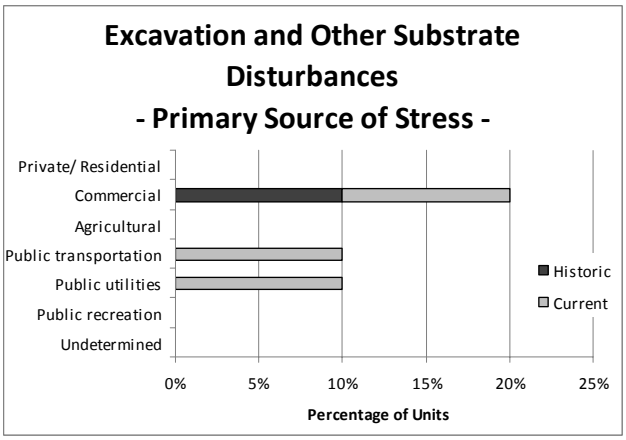


Restoration Sample



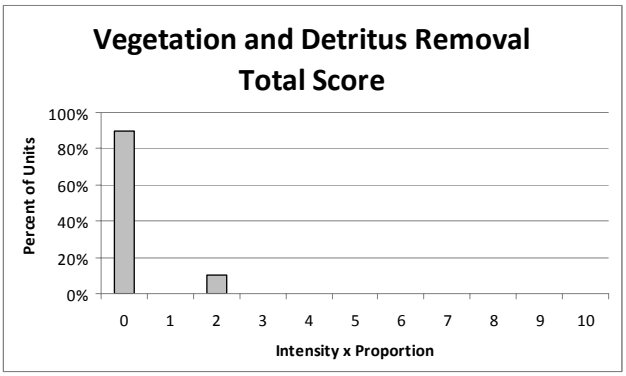


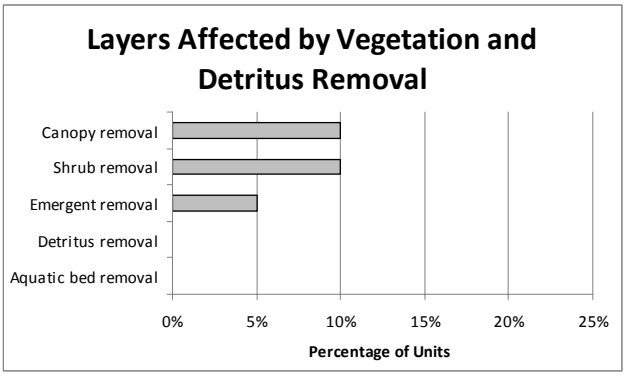


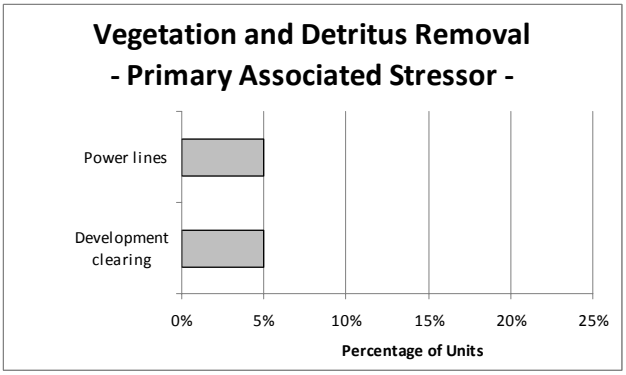


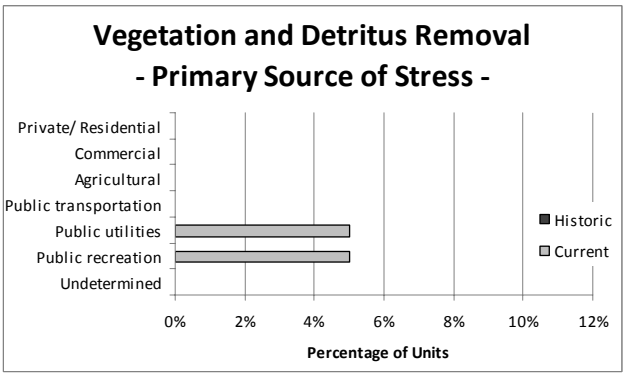
8. Vegetation and Detritus Removal

Reference Sample

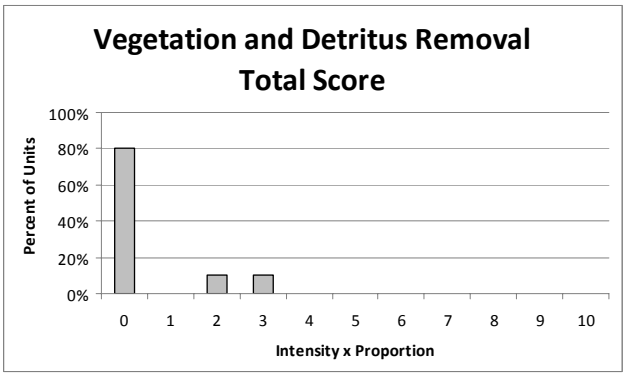


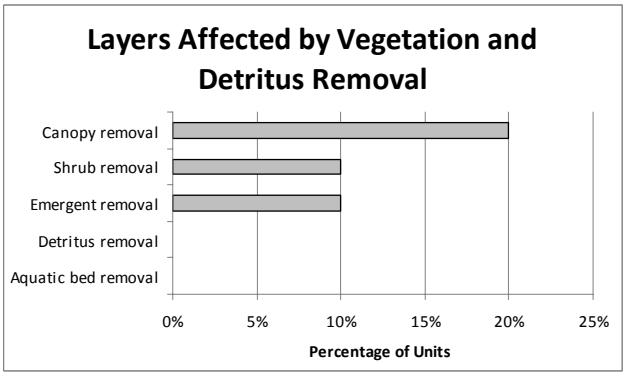


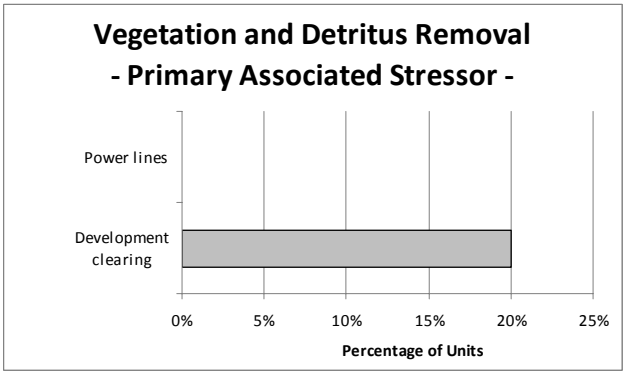


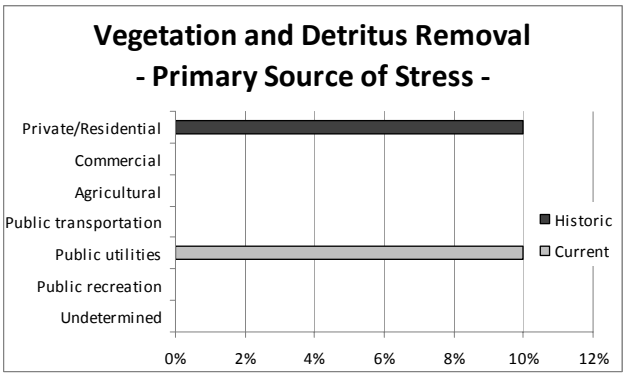


Restoration Sample



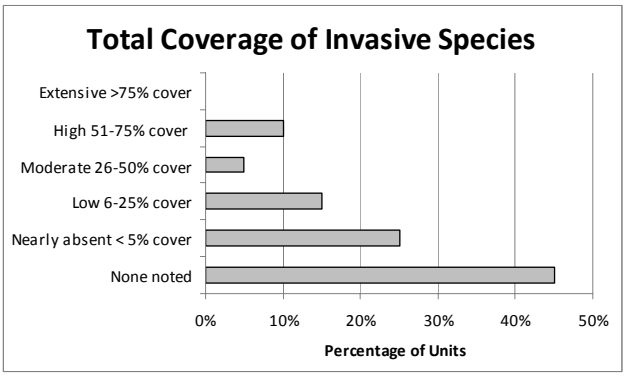


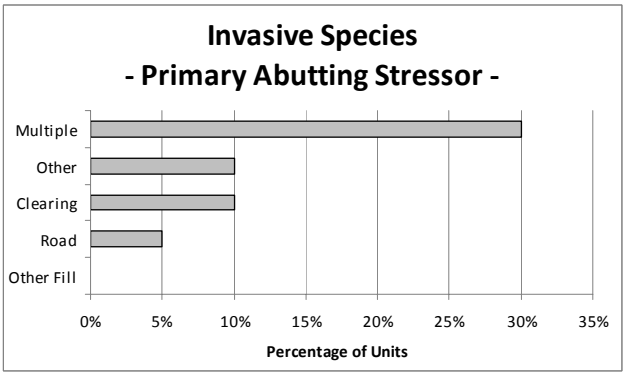


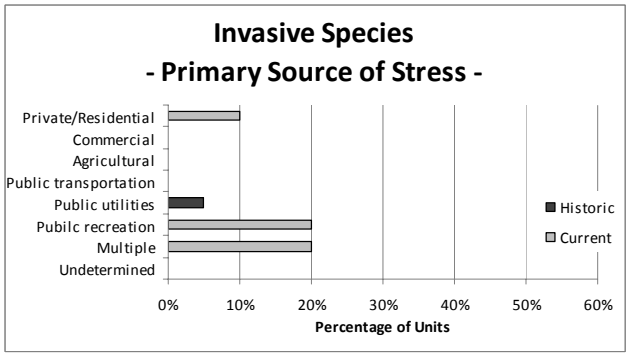


9. Invasive Species

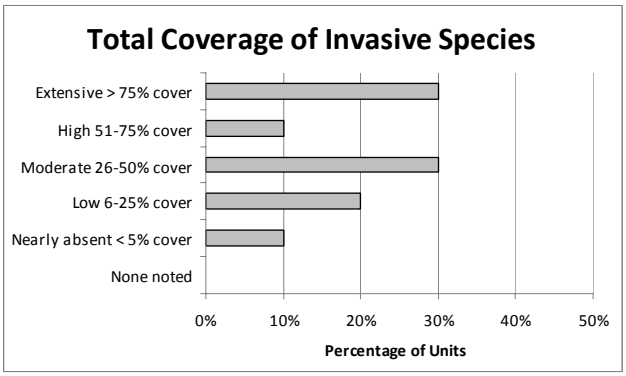
Reference Sample

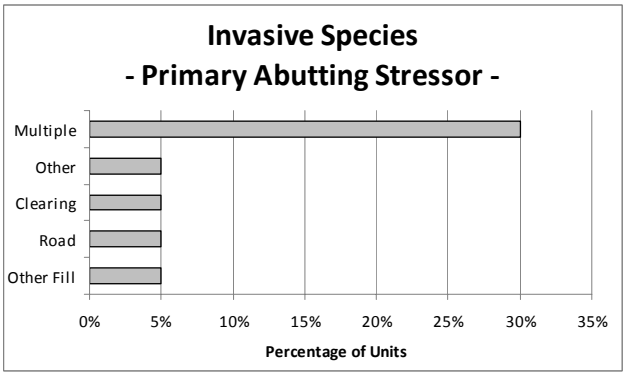


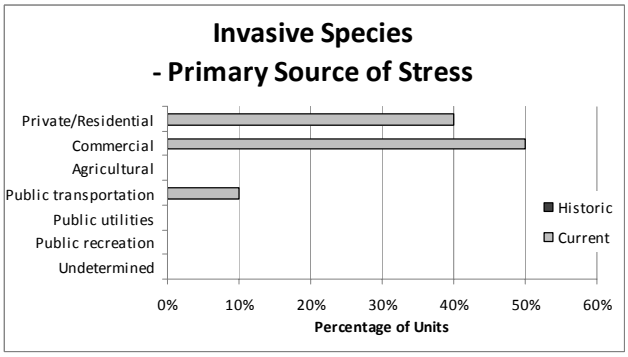




Restoration Sample







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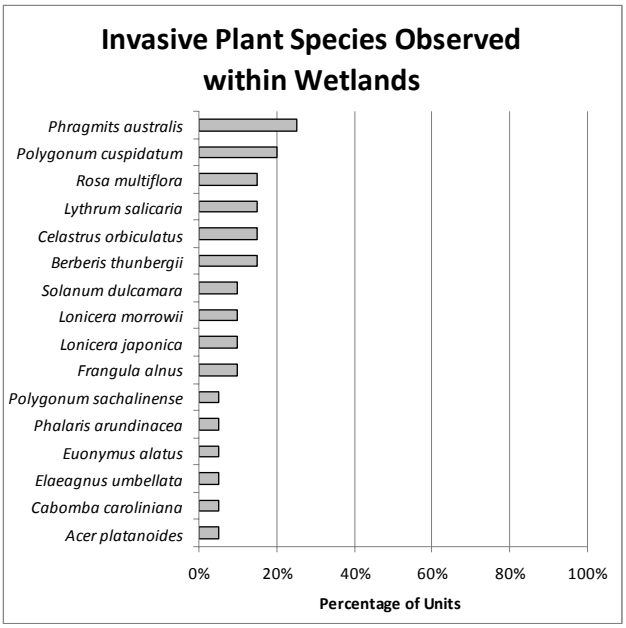
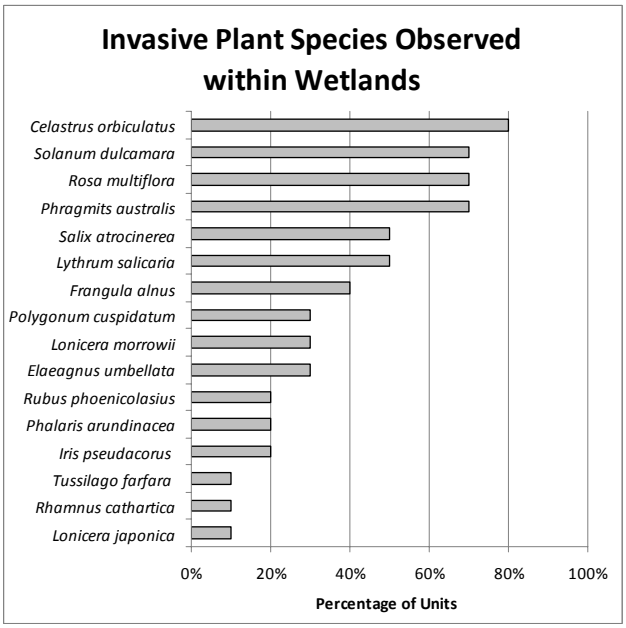
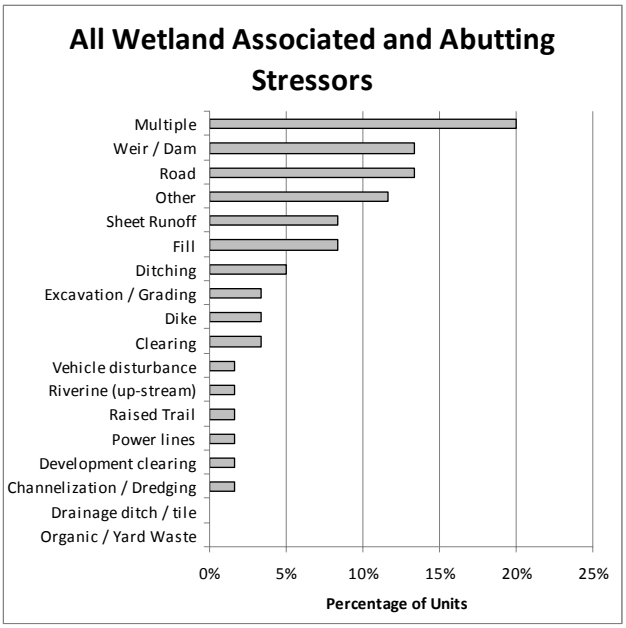


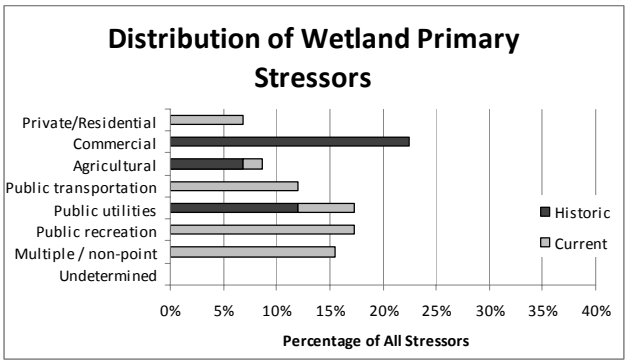
Restoration Sample



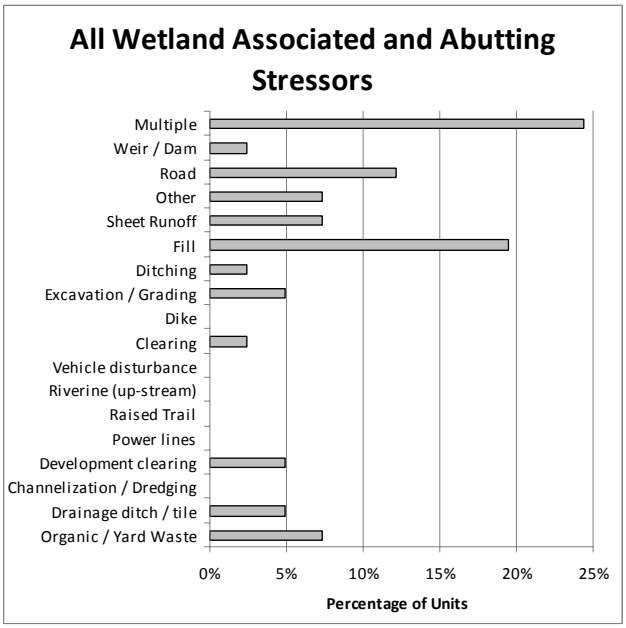
Summary of Wetland Stressors

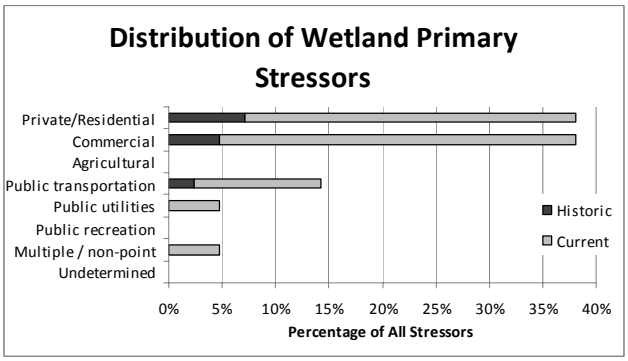
Reference Sample





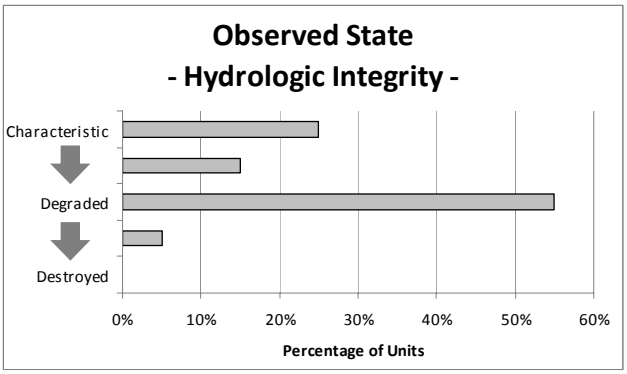
Restoration Sample

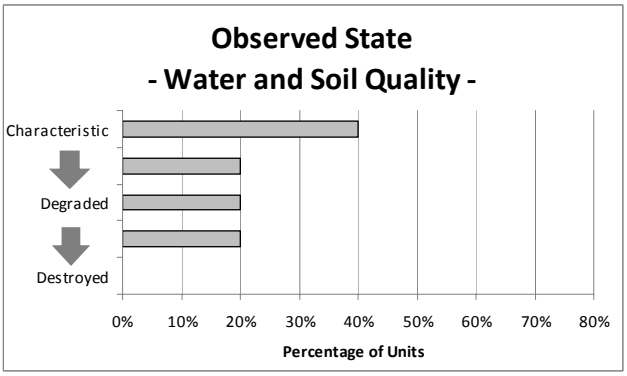


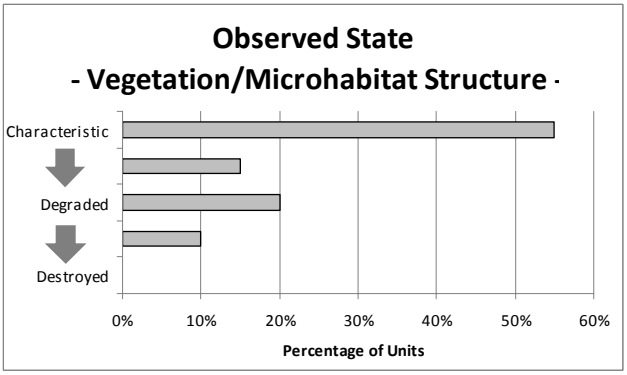


D. Observed State

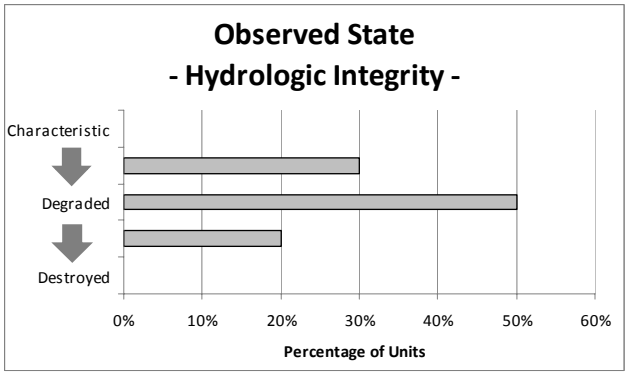
Reference Sample

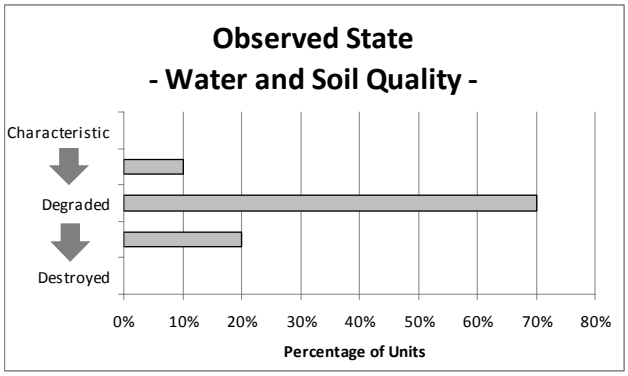


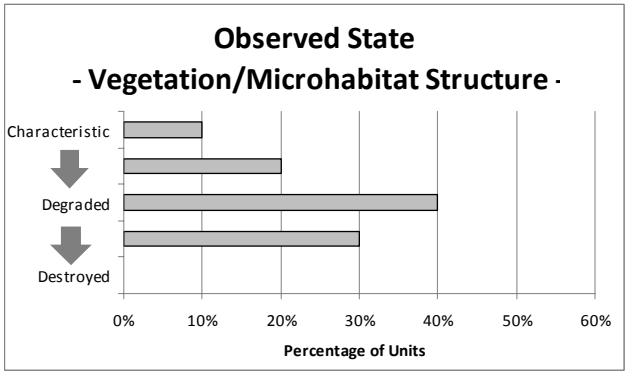




Restoration Sample







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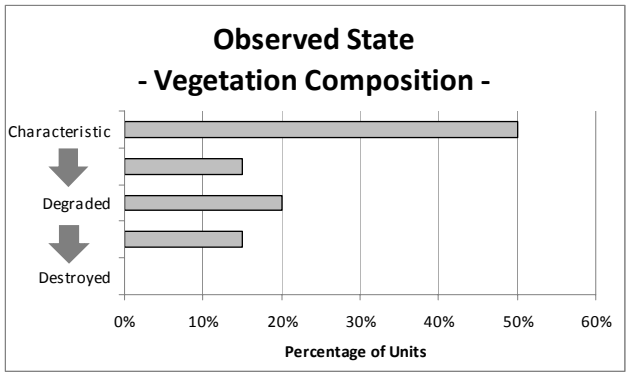

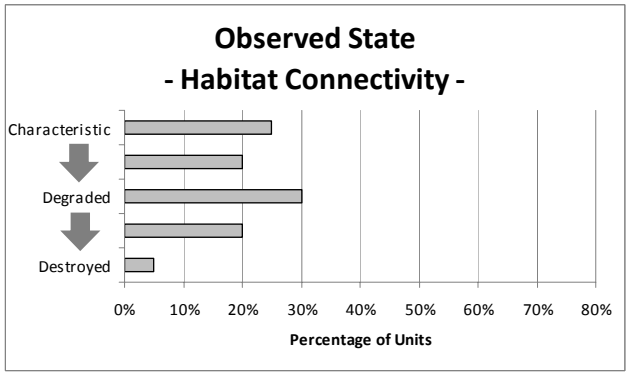
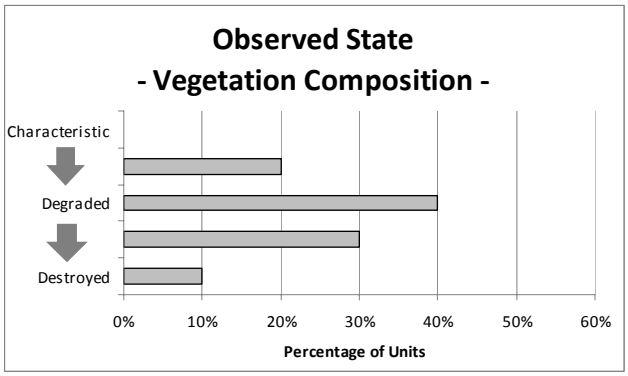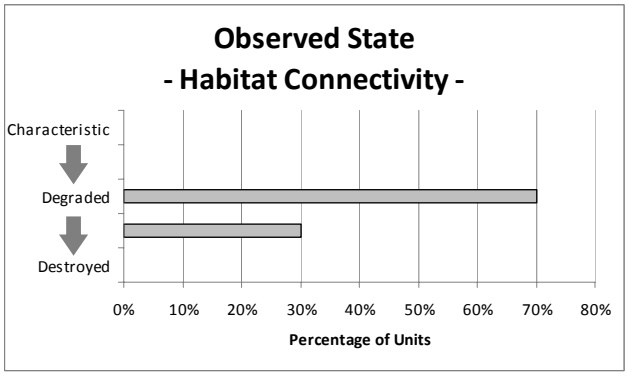
Restoration Sample