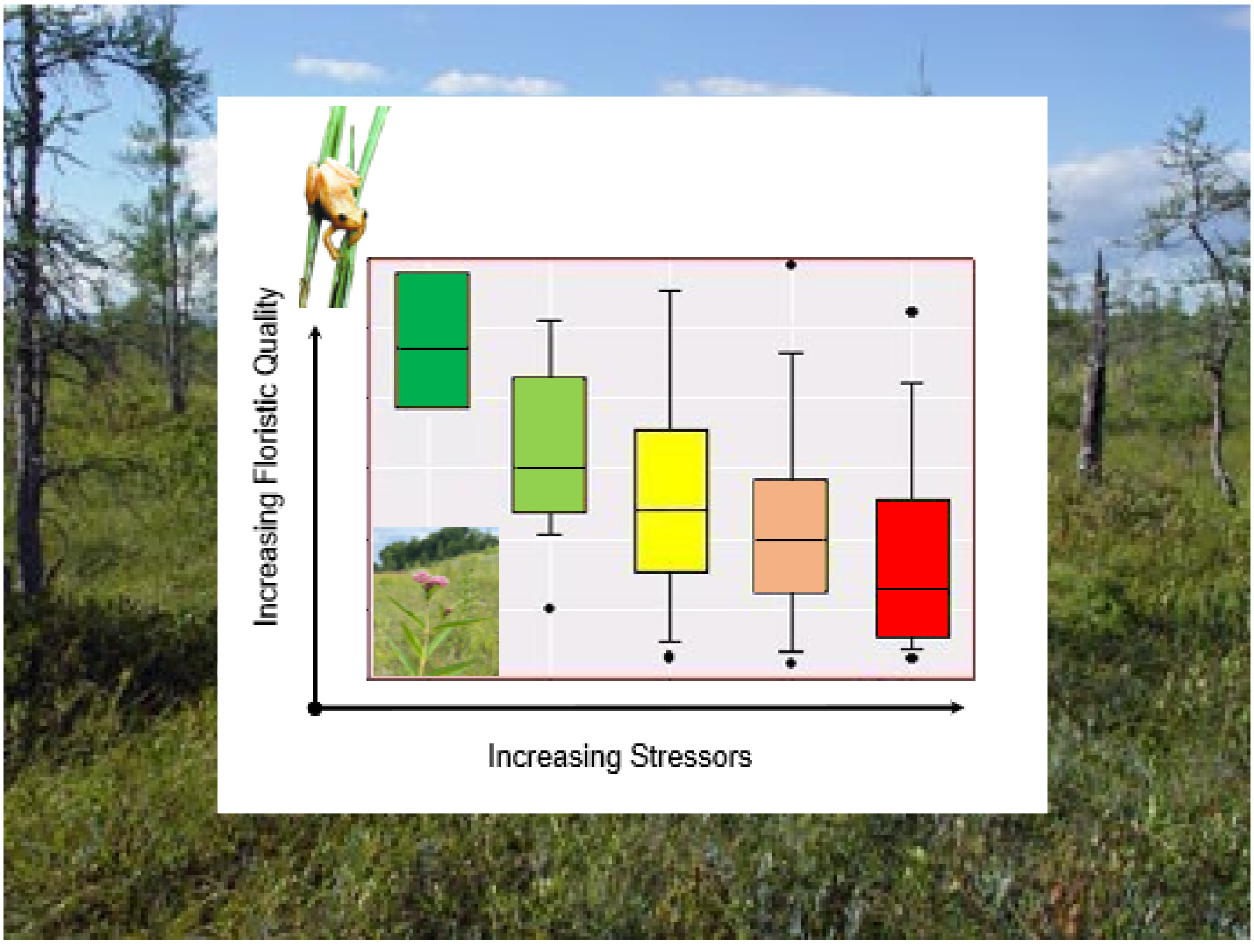
Enhancing Northeast Wetland Monitoring & Assessment with Ecoregional FQA Metrics



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NatureServe

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Photos on cover: Photos on cover: Swamp milkweed (*Asclepias incarnata*); photo by Don Faber-Langendoen. Spring peeper (*Pseudacris crucifer*); photo from the Tribune Chronicle, March 21, 2022.

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For our vegetation plot data, we thank the ecologists in the State Natural Heritage Programs (Maine – Justin Schlawin; New Hampshire – Bill Nichols; New Jersey – Kathleen Walz; New York – Greg Edinger, Laura Shappell; Pennsylvania – Ephraim Zimmerman; Vermont – Eric Sorenson and Bob Zaino) for their willingness to share all available plot data. We thank Ken Metzler for sharing his legacy dataset from Connecticut. We thank Charlie Hohn, with the Vermont Wetlands Bioassessment Program, for sharing wetland data. Scott Jackson and Ethan Plunkett, at the University of Massachusetts, filled in an important gap in Massachusetts by contributing their extensive wetland data sets for this project. Peter Marks (Cornell University) provided us a copy of his plot data in the Finger Lakes region. Michael Lee was instrumental in managing the import of all the data into the NatureServe database (EcoObs).

Finally, we thank the Technical Advisory Committee (members are listed in Appendix 1) for their feedback through the entire process, both for this project and for prior FQA projects that were needed to get to this stage. Many members are part of the New England Biological Assessment of Wetlands Workgroup (NEBAWWG), and we hope that they and others reap the benefits of our work to improve the monitoring and assessment of wetlands throughout the region.

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EXECUTIVE SUMMARY

INTRODUCTION

Many wetland programs in the northeastern region of the U.S. have as their goal to develop and improve wetland monitoring and assessment methods. A consistent set of tools applicable across the region would greatly facilitate a common understanding of the current condition of wetlands. One of the more common methods is that of Floristic Quality Assessment (FQA). Here we focus on improving the use of two FQA metrics - Mean C and Cover-weighted Mean C metrics for assessing condition of northeast wetlands. Our goal was to provide for a set of metric thresholds (benchmark) ratings of excellent, good, fair, and poor conditions for each major wetland type We piloted our study in New Jersey, then expanded to a nine-state region from New Jersey, Pennsylvania, New York, and the six New England states.

METHODS

We compiled all available wetland plot data across a nine-state region, including all plots that were sampled within specific wetland types and for which species percent cover values were recorded. Plots came from state Natural Heritage Programs, other state agencies, and university researchers. A total of 4,726 plots were used in the final analyses, including 616 from New Jersey. We assigned plots to the U.S. National Vegetation Classification (USNVC) at the group level, a mid-scale regional wetland type. The study area contains coastal (estuarine) tidal salt marshes and freshwater wetlands. 26 wetland groups had at least 15 plots overall, which we judged to be a minimum requirement to be included in our analyses.

To calculate Mean C and Cover-weighted Mean C (CwMean C) for each plot, we accessed a database of ecoregional C (eC) values, posted on the Universal FQA Calculator website. Using the plot coordinates, we were able to determine which ecoregion the plot was in, and thereby to assign the ecoregional C (eC) value to each species in the plot.

We calibrated our two FQA metrics in three steps:

- developed a stressor gradient for all plots, using two measures of stressors; a landscape context stressor measure based on NatureServe's Land Use Index, and an on-site stressor based on the percent cover of invasives. Each plot was assigned a Good, Fair, Poor rating for level of stressors.
- piloted the testing of the FQA metrics response to the stressor gradient in a well-curated set of wetland plots in New Jersey.
- extended the metric tests across the Northeast (Pennsylvania and New Jersey to New York and the six New England states).

For each NVC wetland group, we compared how well the two metrics were able to distinguish stressor levels using box-and-whisker plots, and one-way analysis of variance (ANOVA). We first tested whether there was an overall significant difference among the means (F test), and second, to see which of the three Stressor levels could be distinguished. Wee then tested thresholds for Good, Fair, Poor, but flagged all thresholds where there were < 10 plots in a category, as these are of lower confidence Because our plot data were aggregated across multiple projects and our estimates of stressors were not strongly field based, we used the 25th percentile as our threshold for Good, then inferred that Excellent would be the 75th percentile of Good. Because our data are stronger for Fair than Poor sites, our percentiles for Poor are likely an underestimate of high stress; thus, we used the 10th percentile of the Poor Category, when available.

RESULTS

RESULTS: New Jersey: Of the 13 wetland groups found in NJ, only 4 had sufficient plots in each stressor category (i.e., ≥ 10 plots) to compare Good/Reference Condition versus Fair & Poor / Non-Reference condition; but all had sufficient plots to calculate Good/Reference condition scores.

- For forested wetlands, swamps had Mean C scores for Reference stands between 5.19 and 5.44, whereas floodplain forests had Mean C scores of 4.42 (Table 4). CwMean C values were very similar.
- In the Marsh, Wet Meadow & Shrubland formation, freshwater marshes and coastal plain pond shore had Mean C values for Reference Condition between 6.02 and 6.62, as compared to wet meadow-shrub swamps and interdunal wetlands, whose reference Conditions were 4.28 and 4.94 (Table 4). CwMean C values for Reference Condition were largely comparable, except that CwMean C values were higher for the interdunal wetlands (4.85 vs 5.41) and tidal freshwater marshes (4.94 vs 5.50).
- For Bog & Fen Formation, the North Atlantic Coastal Bog Mean C score for Reference Conditions (Good) was considerably lower (6.16) than the Central Appalachian-Northeast Alkaline Fen (8.61) (Table 4). CwMean C values were very similar.
- The Brackish Salt Marsh scored lower for Reference Condition (5.45) than either the High Salt Marsh (6.72) or Low Salt Marsh (7.11). Table 4). CwMean C values were very similar.
- For all groups, the difference between Reference Conditions (Good) versus Non-Reference (Fair or Fair & Poor) were accentuated using CwMean C. But our results for CwMean C are influenced by potential autocorrelation between the criterion of using percent cover of nonnatives to define our stressor categories and the CwMean C metric [see Methods above].

RESULTS: Northeast: For the 26 Northeast wetland groups, 16 had sufficient plots to compare all 3 categories of Good, Fair and Poor. For the other 10, we were able to assess Reference Condition versus Fair & Poor combined. All 13 NJ wetland groups now have robust data sets from across the region to strengthen the threshold ratings initially established within the state, due to additional regional data.

- For forested wetlands, floodplain forests had mean C scores for Reference stands between 4.4 and 4.5 (Table 5, Fig. 7a). Circumneutral to alkaline swamps scores ranged from 4.7 to 5.0; acid swamps consistently had scores of 5.4, and Great Lakes flatwoods and swamps scored 5.9. CwMean C values were very similar.
- In the Marsh, Wet Meadow & Shrubland formation, riverbed and riverscour wetlands had low scores for reference conditions (3.7 to 4.1), whereas freshwater marshes, wet meadows, and shrublands had scores between 4.3 and 4.7 Table 5, Fig. 7b). Interdunal wetlands, tidal freshwater marshes, and coastal plain pond shore had the highest scores at 4.9, 5.1, and 6.5, respectively. CwMean C values were very similar.
- For Bog & Fen Formation, the North Atlantic Coastal Bog Mean C score was higher (6.1) than the Central Appalachian-Northeast Alkaline Fen (5.6) (cf. New Jersey scores in Table 4, where this

fen type scored 8.6), but boreal-subboreal bogs had the highest score at 6.4 (Fig. 7c). CwMean C values were very similar to Mean C values.

- The Brackish Salt Marsh scored lower (5.2) than either the High Salt Marsh (6.6) or Low Salt Marsh (7.3) (Fig. 7d). CwMean C values were very similar.
- For all groups, the difference between Reference Conditions (Good) versus Non-Reference (Fair or Fair & Poor) were accentuated using CwMean C; that is to say, differences in CwMean C values were larger between Good versus Fair or Fair & Poor than for Mean C. But our results for CwMean C are influenced by partial autocorrelation between the criterion of using percent cover of nonnatives to define our stressor categories and the CwMean C metric.

<u>RESULTS: Comparison of New Jersey and Northeast Metric Ratings:</u> Of the metric ratings for the 13 New Jersey groups, only 4 showed significant differences between Northeast and NJ Mean C values and 2 showed differences for CwMean C. Of the 4 NJ groups, 3 had < 10 plots to provide Good scores, suggesting that the main reason for the differences was lack of sufficient plot data.

<u>RESULTS: Threshold Ratings for Northeast Wetland Groups</u>**:** A summary of the thresholds (benchmarks) for all 26 northeast wetland groups is provided for Mean C in the table below. A comparable table is also provided for CwMean C. These thresholds are based on the specified quartiles from box and whisker plots (see Methods). We combined thresholds [we merged cells] where threshold scores were based on categories with < 10 plots, typically for Fair versus Poor thresholds. But for comparisons with future studies, we provided the Poor threshold in square brackets.

			MEAN C			
Formation	**Group Code**	**GROUP_NAME**	**E**	**G**	**F**	**P**
Flooded & Swamp Forest	G902	Central Appalachian-Northeast Acidic Swamp	> 5.9	5.9-4.9	4.9-3.8	< 3.8
	G918	Central Appalachian-Northeast Alkaline Swamp	> 5.0	5.0-4.3	4.3-3.3	< 3.3
	G917	Central Interior-G. Lake Flatwood & Swamp Forest	> 6.3	6.3-4.7		< 4.7
	G045	Laurentian-Acadian Acidic Swamp	> 6.2	6.2-4.9	< 4.9	[3.4]
	G046	Laurentian-Acadian Alkaline Swamp	> 5.3	5.3-4.7	4.7-3.6	< 3.6
	G653	Laurentian-Acadian Floodplain Forest	> 4.6	4.6-4.1	4.1-2.9	< 2.9
	G667	Northeastern Forest Vernal Pool	> 5.0	5-4.3	< 4.3	[3.6]
	G039	Northern Coastal Plain Swamp	> 5.7	5.7-5.0	5.0-4.0	< 4.0
	G673	Southcentral-Appalachian-Northeast Floodplain Forest	> 4.9	4.9-4.2	4.2-2.8	< 2.8
Freshwater Marsh, Wet Meadow & Shrubland	G903	Appalachian-Northeast Wet Meadow & Shrub Swamp	> 5.1	5.1-4.2	4.2-2.6	< 2.6
	G753	Central Interior-Appalachian Riverscour Barrens & Prairie	> 4.4	4.4-3.9	< 3.9	[2.7]
	G125	Eastern North American Freshwater Marsh	> 4.8	4.8-3.8	3.8-1.1	< 1.1
	G755	Eastern North American Scrub & Herb Riverbed Wetland	> 4.1	4.1-3.1	3.1-2.0	< 2.0
	G904	Laurentian-Acadian Wet Meadow & Shrub Swamp	> 5.1	5.1-4.2	<4.2	[2.2]
	G925	Laurentian-Acadian-Northeast Riverscour Vegetation	> 4.4	4.4-3.6	<3.6	[3.2]
	G752	North Atlantic Coastal Interdunal Wetland	> 5.3	<5.3	[4.5,	4.4]
	G916	North Atlantic Coastal Plain Pondshore	> 7.3	7.3-5.9	5.9-3.3	< 3.3

	G914	North Atlantic Coastal Tidal Freshwater Marsh	> 5.5	5.5-4.4	<4.4	[4.0]
	G189	Northcentral & Northeastern Seep	> 5.6	5.6-4.7	4.7-3.5	< 3.5
Bog & Fen	G805	Central Appalachian-Northeast Alkaline Fen	> 5.9	5.9-5.0	5.0-3.8	< 3.8
	G804	Eastern North American Boreal-Subboreal Alkaline Fen	> 6.5	6.5-5.2	< 5.2	[4.2]
	G1172	Eastern North American Boreal-Subboreal Bog & Acidic Fen	> 6.9	6.9-5.7	5.7-4.4	< 4.4
	G1171	North Atlantic Coastal Bog & Fen	> 7.0	7.0-5.3	5.3-4.4	< 4.4
Salt Marsh	G120	Atlantic & Gulf Coastal Brackish Salt Marsh	> 6.2	6.2-4.4	4.4-3.6	< 3.6
	G121	Atlantic & Gulf Coastal High Salt Marsh	> 7.5	7.5-5.7	5.7-4.2	<4.2
	G122	Atlantic & Gulf Coastal Low Salt Marsh	> 7.6	7.6-7.3	<7.3	[4.8]

DISCUSSION

Our methodology followed standard methods for calibrating metrics – the Biological Condition Gradient – whereby an independent stressor rating is used to assess the biological response (FQA metric) of the wetland type to the stressor rating. Although our information about stressor levels was limited to a land use index and to abundance of nonnative species, it had the advantage of being consistent across multiple data sets and regions. However, we recognize that studies that more rigorously stratify plots across the region and develop site-based assessments of stressors will provide a more robust assessment of how wetlands response to increasingly degrading factors, ultimately leading to their collapse.

Our study is based on a very large data set across the Northeast region (over 4,700 plots), which gave us the ability to address a wide range of wetland types. We used the U.S. National Vegetation Classification (USNVC) because it is being rigorously peer reviewed across the entire U.S., is a federal standard, and types are carefully crosswalked to or directly used as part of state Natural Heritage Program classifications, which regularly survey and track information on exemplary and rare occurrences of wetland types. These types have distinct hydrologic and floristic composition, important for guiding mitigation and restoration efforts.

A major finding of our research was the ability to produce wetland specific threshold ratings, as shown in the table above. Although our data were uneven, both by wetland type and by stressor category, our data were remarkably consistent with other research findings. Nonetheless, our thresholds are provisional for northeast wetland types, given our heterogeneous datasets and the general assessment of stressor categories. We look forward to more rigorous tests of our findings for those groups we were unable to develop thresholds for across all stressor levels.

Our results add to a growing body of knowledge that indicate the value of FQA metrics in describing wetland condition. Vegetation integrates and reflects the cumulative impacts of multiple stressors, and the FQA metrics tested here provides a well-developed methodology for documenting the vegetation response. The FQA metric approach is relatively straightforward to understand, making it a practical tool that managers and researchers can use to communicate their findings. That said, FQA alone does not describe all aspects needed to describe wetland condition. Degradation of hydrologic functions may not be fully captured, nor may various structural features, such as woody regeneration, coarse woody debris, or old growth conditions. If managers are looking for guidance to assess resilience of wetlands to a variety of stressors, a fuller assessment may be needed, such as those conducted to assess ecological integrity and other wetland values.

Our development of thresholds of FQA metric response to the stressor gradient can provide guidance to ongoing monitoring and assessment programs, where knowledge of reference conditions can guide interpretation of the status of wetlands in a watershed, state, or region. Similarly, these thresholds can guide restoration and mitigation efforts by helping set standards for restoration success or, in the case of mitigation, compliance. FQA metrics are an important component of mitigation and restoration assessments, particularly if used in combination with a fuller set of metrics that inform vegetation, soils, hydrology, and landscape context that together provide a reliable guides to the success or compliance of wetland mitigation and restoration. We encourage embedding these metrics within current state wetland monitoring and assessment programs to facilitate standard evaluations of wetlands across the northeast.

Contents

INTRODUCTION

Throughout the Northeast region, there has been a concerted effort to develop better tools for monitoring and assessing the ecological integrity of wetlands (their wetland condition). These efforts are guided by the need to track not just wetland loss, but also wetland degradation and restoration. For that reason, NEIWPCC collaborates with the New England Biological Assessment of Wetlands Workgroup (NEBAWWG), State Natural Heritage Programs, and NatureServe to encourage improved methods for wetland monitoring and assessment. NEBAWWG's goal is to "*to develop, improve and/or refine scientifically valid wetlands monitoring and assessment methods; and further develop and institutionalize the wetlands biomonitoring programs of northeast states."* A consistent set of tools applicable across the region would greatly facilitate a common understanding of the current condition of wetlands.

Methods for monitoring and assessing wetlands vary from remote sensing based (Level 1), rapid field assessments (Level 2) and intensive (Level 3), with various gradations between these three levels. Vegetation indicators are an important aspect of any assessment method because we know a great deal about the ecological behavior of individual species, species assemblages, and vegetation structure, as well as their spatial and historical variability (USEPA 2016). For that reason, we focused on two commonly used vegetation metrics for assessing wetland condition, namely Mean C and Cover-weighted Mean C, which are part of the Floristic Quality Assessment method (DeBerry et al. 2015). However, to provide a consistent rating of wetland condition across wetland types, states and watersheds, these metrics need to be calibrated. Calibration typically involves assessing the response of the metrics to a disturbance gradient, with consideration given to calibrating by wetland type, as wetlands vary in how they respond to disturbances (Bourdaghs 2012, Bried et al. 2013, Kutcher and Forrester 2018).

Here we focus on improving the use of the Mean C and Cover-weighted Mean C metrics for Northeast wetlands by using an ecoregional FQA approach (Faber-Langendoen et al. 2019a). We compiled all available wetland plot data across 10 ecoregions in a nine-state region, including all plots that were sampled within specified wetland types and for which species cover values were recorded. Our goal was to provide for a set of metric thresholds (benchmark) ratings of excellent, good, fair, and poor conditions for each major wetland type in the northeast.

METHODS

Study Area

Our study areas include nine states in the northeastern United States, from Pennsylvania and New Jersey on the south end to New York and the six states of New England (Fig. 1). The study area spans 10 ecoregions. The study area contains coastal (estuarine) tidal salt marshes and freshwater wetlands. Freshwater wetlands occur on the coastal plain and inland. On the coastal plain, they include pondshores, bogs and fens, interdunal wetlands, depressional swamps, and floodplain wetlands. The inland freshwater wetlands include forested swamps, floodplain forests, bogs and fens, wet meadows, marshes, and shrub swamps, which vary floristically and ecologically from the central Appalachian to the northern Appalachian-Acadian regions.

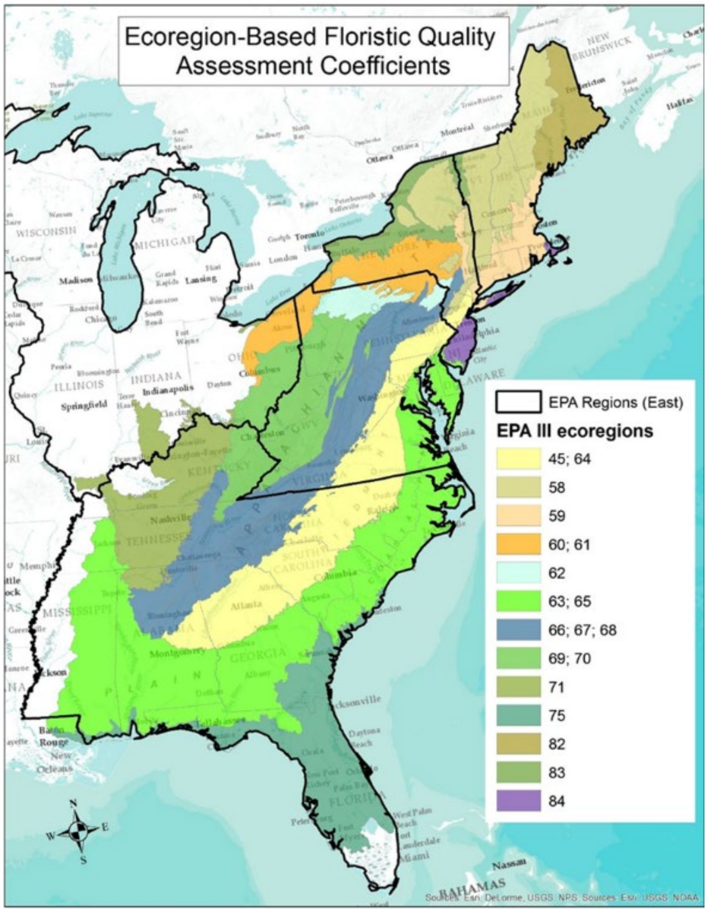


Figure 1. Omernik (USEPA 2013) regions in the Eastern U.S. This study encompasses the northern parts of the EPA Region 3 (PA), EPA R2 (NJ, NY), and EPA R1 (New England states). Ecoregion-based Floristic Quality Assessment coefficients are available across this region. The 10 ecoregions included in our 9-state study include: Acadian Plains & Hills 82; Northeastern Highlands 58; Northeastern Coastal Zone 59; Eastern Great Lakes Lowlands 83; Allegheny Plateau, Glaciated 60,61; Allegheny Plateau, Unglaciated 62,69,70; Ridge & Valley 66,67,68; Piedmont 45,64; Atlantic Coastal Pine Barrens 84; Coastal Plain 63,65.

Regional Data Set and Wetland Types

Plot Data

Our vegetation plot data came from multiple sources across the 9 states. The bulk of the data came from standard relevé vegetation plots; that is, plots that are scaled to represent the wetland community type at a site. Plot sizes were either adjusted for wetland type, typically a minimum of 10x10 m in shrub-herb wetlands and 20x20 in tree wetlands, or applied across all types using a 0.1 ha (50 x20 m or 18 m circular) plot design. In each plot, a comprehensive list of vascular plants species was compiled, and their percent cover estimated by strata (minimally tree, shrub/sapling, herb). These data provided quantitative estimates of species abundance needed for calculating FQA metrics. Depending on the project, additional ecological data were collected on soil texture, pH, color, soil depth, depth of surface water. Plots were classified to state Natural Heritage Program types and tot the U.S. National Vegetation Classification. Other classifications include Hydrogeomorphic (HGM) setting, National Wetland Inventory (NWI) Information. All data were uploaded into NatureServe's Ecological Observations Database (EcoObs). EcoObs is currently managed by NatureServe staff and is in use by various member programs in the Network.

We compiled 5041 plots with sufficient location accuracy, and retained 4,726 plots with cover values, as these are needed for the Cover-weighted Mean C metric (see below). Plots were located across 8 of the 9 states, including Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Vermont. The Rhode Island data structure was sufficiently different that we were not able to include their data in this set of analyses.

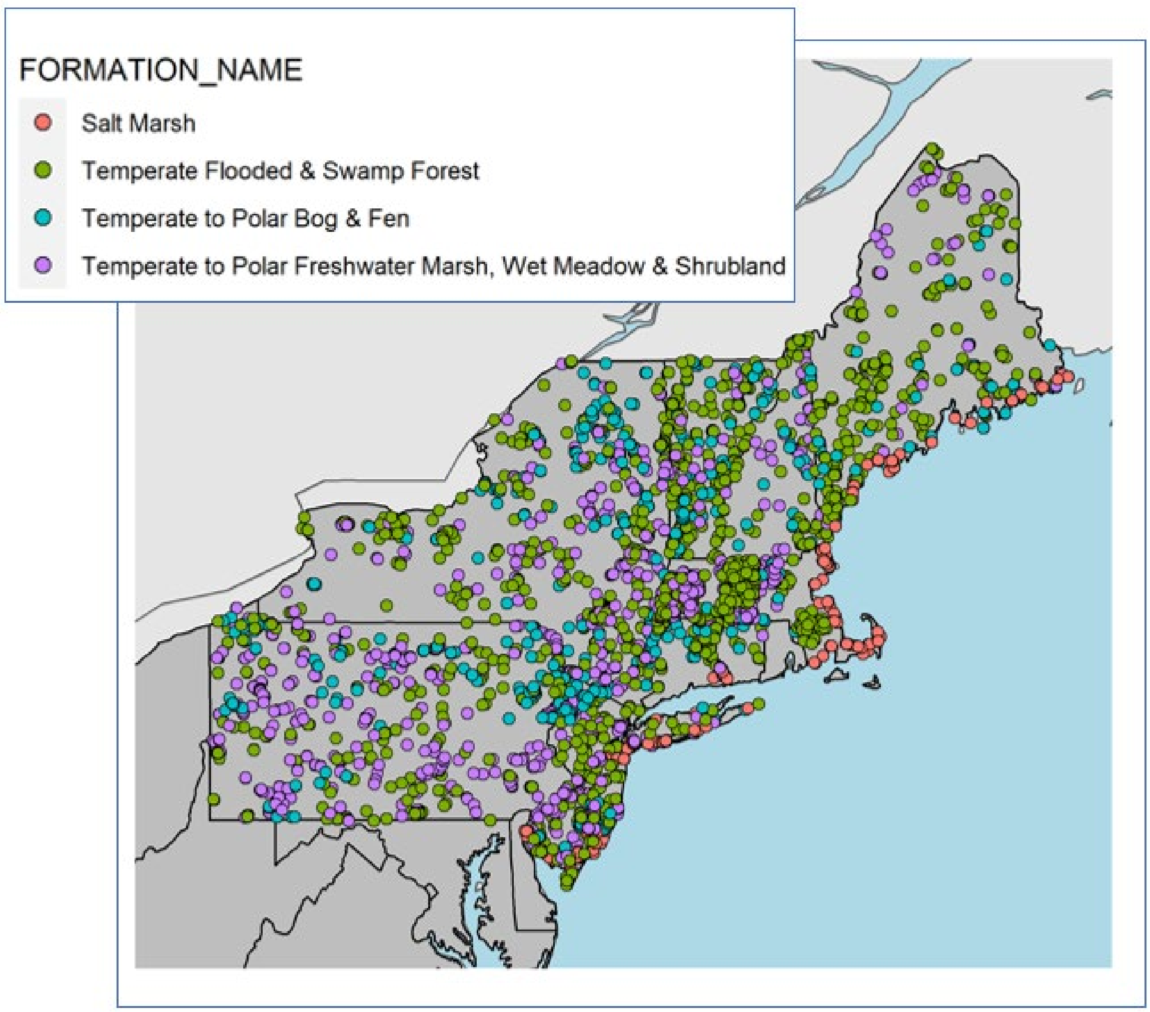


Figure 2. Plot data locations, labeled by the U.S. National Vegetation Classification wetland formation.

We standardized taxonomic nomenclature of all plant species across the nine-state region to the USDA Plants Database (USDA PLANTS, NRCS 2020). We used a version of USDA PLANTS that had been created for our development of ecoregional C value for each species in the region (Faber-Langendoen et al. 2021) (see below).

Our plot data set was an aggregation of available plot data. The data were not specifically designed to cover all wetland types or all levels of stress; thus, our analyses are limited by how well various types and levels of stressors were adequately sampled.

Wetland Types

The success of developing metrics of wetland condition or integrity depends on an understanding of the structure, composition, processes, and landscape connectivity that govern the wide variety of wetland types. Ecological classifications are helpful tools in categorizing natural variability within and among types, so that differences between occurrences with good integrity and poor integrity can be more clearly recognized (e.g., ecological and vegetation processes of floodplain forests are different from those of depressional bogs or tidal salt marshes). We used the U.S. National Vegetation Classification (USNVC), which is a multi-leveled ecological classification that classifies types from broad scale formations (Table 1) to fine-scale community types (e.g., Temperate Flooded & Swamp Forest formation to Central Appalachian-Northeast Silver Maple Floodplain Forest group) (ESA Vegetation Classification Panel 2015). The USNVC is a federal standard (FGDC 2008). State Natural Heritage Programs work closely with the USNVC to coordinate understanding of natural community types across the region (e.g., Appendix B in Thompson et al. 2019). Full descriptions of all wetland groups are available on usnvc.org and on NatureServe Explorer (natureserve.org/explorer).

For this study, we focused on the group level, a mid-scale level that provides types that are widely recognized by wetland managers across the region (e.g., in distinguishing the North Atlantic Coastal Bog & Fen from both acidic and alkaline boreal-subboreal bogs and fens) (see list of groups in Table 2 below). Each plot was assigned to an USNVC group using two sources of information. The first source for assignment was based on assignment of a plot to the USNVC by a state program ecologist. In this case, the USNVC type was assigned to the plot data either directly (typically at the finest scale of association) or it was assigned indirectly via a crosswalk between a state natural community type and a USNVC type. The assigned type was then rolled up to the group level. The second assignment process was used for plots that had no USNVC or state natural community assignment; for these plots, NatureServe staff used available plot information, such as vegetation, site factors, and ecoregional location, to assign plots to a USNVC group.

Wetlands dominated by invasive species are typically classified in the USNVC as separate groups from native wetland types because the native composition and ecological site factors have been strongly altered or converted into a new state. However, for our purposes, these ruderal types can also be considered the most degraded forms of native wetland groups; thus, for this study, we assigned all ruderal plots to the closest fitting natural NVC group type to bolster the plots available for assessing the full condition gradient.

Wetland Groups and Plots

There are 43 natural NVC wetland groups that occur in the 9-state region (excluding the six aquatic vegetation types, which were not included in this study). Of the 43 groups, there are 11 that are outliers or very localized in the region (e.g., boreal swamps, inland saline marshes, southern coastal plain wetlands), and had either no or very few plots. Of the remaining 32 groups, 26 groups had at least 15 plots overall, which we judged to be a minimum requirement to be included in our analyses. The 26 groups are nested within four USNVC formations, which largely correspond to the National Wetlands Inventory (NWI) class level (Cowardin et al. 1979). (see Table 1).

Table 1. The four USNVC formations the number of USNVC natural groups for which at least 15 plots were available. Plot counts are provided for USNVC formation and the equivalent National Wetlands Inventory (NWI) class and subclass (Cowardin et al. 1979). Group count for all states and for NJ is based on the groups for which at least 15 plots were available. Totals are reported for both the entire Northeast and for NJ. NJ plots numbers are separated out because they were used for pilot testing of our methods.

Formation Code	Formation Name	NWI class	All 9 states: No. groups	All 9 states: No. Plots	NJ: No. groups	NJ: No. plots
1.B.3	Temperate Flooded & Swamp Forest	PFO	9	1814	3	126
2.C.2	Temperate to Polar Bog & Fen	PML*	4	1039	2	141
2.C.4	Temperate to Polar Freshwater Marsh, Wet Meadow & Shrubland	PSS, PEM	10	1565	5	259
2.C.5	Salt Marsh	E2SS/E2EM	3	308	3	90
			26	4726	13	616

* Bogs and Fens may be classified by NWI to PEM or PSS where the moss layer is overtopped by herbs or shrubs.

NJ Pilot: There were 24 groups reported for NJ. After eliminating groups from our analyses that had less than 15 plots, we retained 13 groups with 619 plots for NJ (Table 2).

Northeast: There were 26 groups across the Northeast that had at least 15 plots, including the 13 groups analyzed in NJ (Table 2).

Table 2. Summary of groups and plot counts for the 26 Northeast groups. To be included in this study, a group had to have ≥ 15 plots. Group codes and names are from the USNVC (usnvc.org). Groups in NJ in bold and marked with # had sufficient plots to be included in the NJ pilot. Groups with plot counts shaded in grey indicate groups that had insufficient plot data in New Jersey for analyses. However, data for these NJ groups are available through the NE dataset.

FORMATION_NAME	Group Code	GROUP_NAME	CODE	NJ	NE
Flooded & Swamp Forest	G902	Central Appalachian-Northeast Acidic Swamp	G902	**7**	219
	G918	**Central Appalachian-Northeast Alkaline Swamp #**	G918	**19**	269
	G917	Central Interior-Great Lakes Flatwoods & Swamp Forest*	G917	**0**	15
	G045	Laurentian-Acadian Alkaline Swamp	G046	**7**	282
	G046	Laurentian-Acadian Acidic Swamp*	G045	**0**	139
	G653	Laurentian-Acadian Floodplain Forest	G653	**0**	227
	G667	Northeastern Forest Vernal Pool	G667	**0**	74
	G039	**Northern Coastal Plain Swamp #**	G039	**77**	197
	G673	**South Central-Appalachian-Northeast Floodplain Forest #**	G673	**30**	392
Marsh, Wet Meadow & Shrubland	G903	**Appalachian-Northeast Wet Meadow & Shrub Swamp #**	G903	85	538
	G753	Central Interior-Appalachian Riverscour Barrens & Prairie	G753	0	25
	G125	**Eastern North American Freshwater Marsh #**	G125	39	218
	G755	Eastern North American Scrub & Herb Riverbed Wetland	G755	2	281
	G904	Laurentian-Acadian Wet Meadow & Shrub Swamp	G904	0	149
	G925	Laurentian-Acadian-Northeast Riverscour Vegetation	G925	0	87
	G752	**North Atlantic Coastal Interdunal Wetland #**	G752	15	26
	G916	**North Atlantic Coastal Plain Pondshore #**	G916	89	102
	G914	**North Atlantic Coastal Tidal Freshwater Marsh #**	G914	31	59
	G189	North-Central & Northeastern Seep	G189	10	80
Bog & Fen	G805	**Central Appalachian-Northeast Alkaline Fen #**	G805	31	169
	G804	Eastern North American Boreal-Subboreal Alkaline Fen	G804	6	185
	G1172	Eastern North American Boreal-Subboreal Bog & Acidic Fen	G1172	5	555
	G1171	**North Atlantic Coastal Bog & Fen #**	G1171	110	130
Salt Marsh	G120	**Atlantic & Gulf Coastal Brackish Salt Marsh #**	G120	41	69
	G121	**Atlantic & Gulf Coastal High Salt Marsh #$**	G121	24	158
	G122	**Atlantic & Gulf Coastal Low Salt Marsh #$**	G122	25	81
		Total		616	4726

group in NJ with sufficient plots to be included in the NJ pilot.

*Correct name for this Group is: Acadian-Appalachian Red Spruce Acidic Swamp, but because we included black spruce swamps from the subboreal region, we feel plots represent the broader Laurentian-Acadian region.

$These two groups were recently merged to form one type in the North Atlantic region, separate from South Atlantic-Gulf.

FQA Metrics and Ecoregional Coefficients of Conservatism

Mean C and Cover-weighted Mean C metrics

Two FQA metrics have been widely used in local and state projects for conducting wetland condition assessments, namely Mean C and Cover-weighted Mean C (CwMean C) (DeBerry et al. 2015). These metrics have been shown to respond well to associated stressor levels affecting wetlands; that is, the metrics show a "stressor-dose response" to changes in stressor levels. The Mean C metric simply requires a comprehensive vascular plant species list within a fixed plot area or a mapped area of a wetland, and the mean C metric score is the mean of the C values across all species. The CwMean C requires an estimate of the percent cover for each species; the C value for each species is then weighted by its cover, thereby providing a CwMean C value. Because we wanted to compare the response of the two metrics, we only used plot data that had cover data.

Ecoregional C values

Typically, the two FQA metrics have been applied using state-based C values (e.g., Bried et al. 2012). Here, we benefitted from a recently completed database of ecoregional C (eC) values, posted on the Universal FQA Calculator website (Faber-Langendoen et al. 2021). That database contained 5,559 taxa across all 10 ecoregions in EPA R1 – R3, including 4,794 species, 73 hybrids, 192 subspecies and 540 varieties. All taxa were assigned an eC value using the criteria shown in Table 3.

Table 3. Guiding definitions for coefficients of conservatism, or C values, assigned to the Northeast flora (Faber-Langendoen et al. 2019a).

CoC	Criteria
0	Non-native with wide range of ecological tolerances. Often these are opportunistic of intact undisturbed habitats.
1 to 2	Native invasive or widespread native that is not typical of (or only marginally typical of) a particular plant community; tolerant of anthropogenic disturbance.
3 to 5	Native with an intermediate range of ecological tolerances and may typify a stable native community, but may also persist under some anthropogenic disturbance.
6 to 8	Native with a narrow range of ecological tolerances and typically associated with a stable community.
9 to 10	Native with a narrow range of ecological tolerances, high fidelity to particular habitat conditions, and sensitive to anthropogenic disturbance.

Ecoregions were defined using EPA (Omernik 1987, USEPA 2013) ecoregions. We used USDA PLANTS (2020) as a guide to assigning nonnative status to a species, but refined through our development of the ecoregional C value. That is, some species were native in the Northeast, but nonnative in a particular ecoregion.

Using the plot coordinates, we were able to determine which ecoregion the plot was in, and thereby to assign the ecoregional C (eC) value to each species in the plot. For example, if *Abies balsamea* (balsam fir) occurred in a plot in ecoregion 82, it's eC value was 3, whereas if it occurred in a plot in ecoregion 60, its eC value was 9. The eC values for balsam fir vary because in the southern part of its range, balsam fir is much more dependent on high quality natural areas to persist.

Calibration using Stressor Gradient

We calibrated our two FQA metrics in three steps:

- developed a stressor gradient for all plots.
- piloted the testing of the FQA metrics response to the stressor gradient in a well-curated set of wetland plots in New Jersey.
- extended the metric tests across the Northeast (PA and NJ to New York and the six New England states).

Stressor Gradient

To calibrate and compare our metrics using the "stressor-dose response" approach (Fig. 3), we developed a consistent and repeatable measure of overall stress for each plot, both in the surrounding landscape and on site.

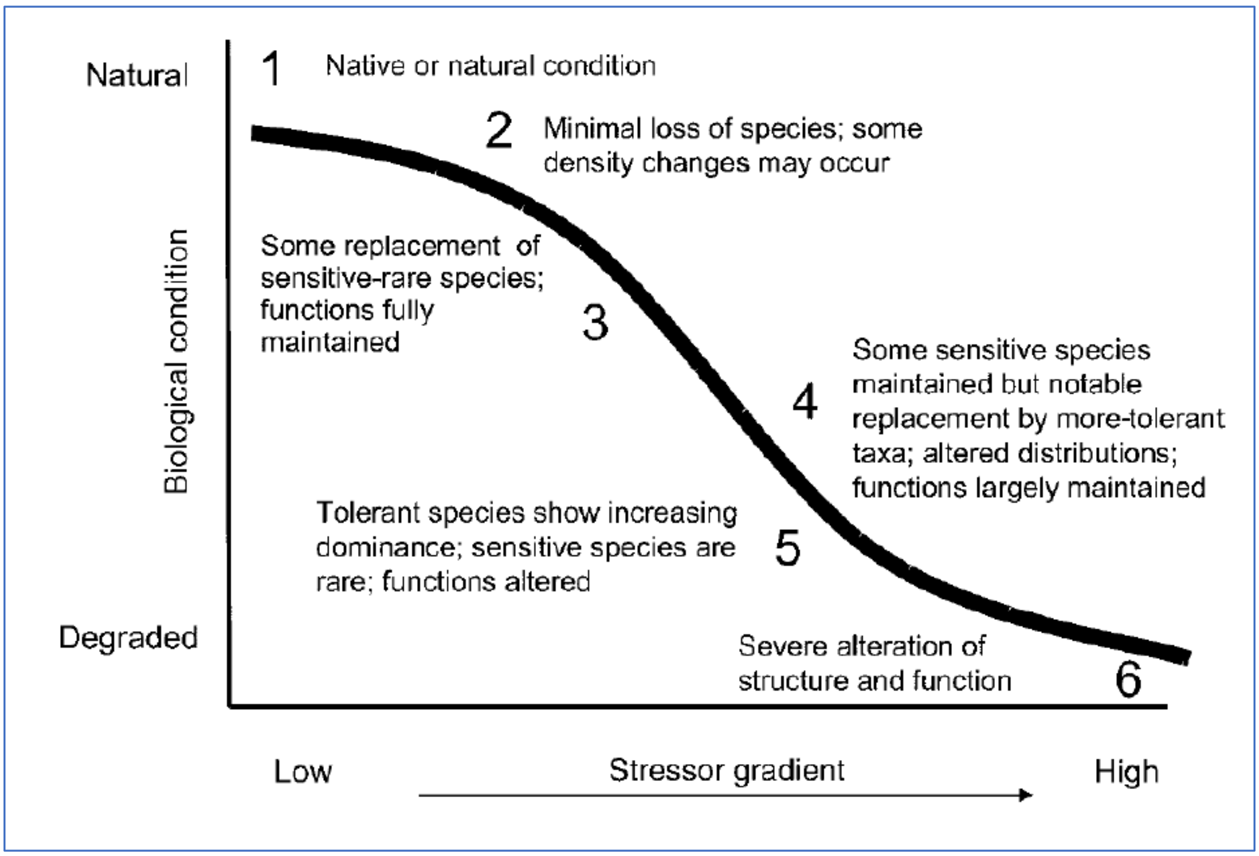


Figure 3. A conceptual model of the Biological Condition Gradient (reprinted from Davies and Jackson 2006).

Measures of surrounding landscape stressors have proven to be an important explanatory variable in evaluating wetland condition (Brooks et al. 2006, Mack 2006, Mita et al. 2007, Stein et al. 2009, Comer and Faber-Langendoen 2013, Hak and Comer 2017, Walz and Faber-Langendoen 2018, Kutcher and Forrester 2018, Faber-Langendoen et al. 2019b). We used the Land Use Index ("LAN2") that was developed for the Ecological Integrity Assessment of Faber-Langendoen et al. (2016, 2019b) to assess stressors associated with land uses in the surrounding landscape. The index measures the intensity of human dominated land uses in the surrounding landscape. Each plot was buffered by 40 m, then the LAN2 index applied out to 500 m (Fig. 4).

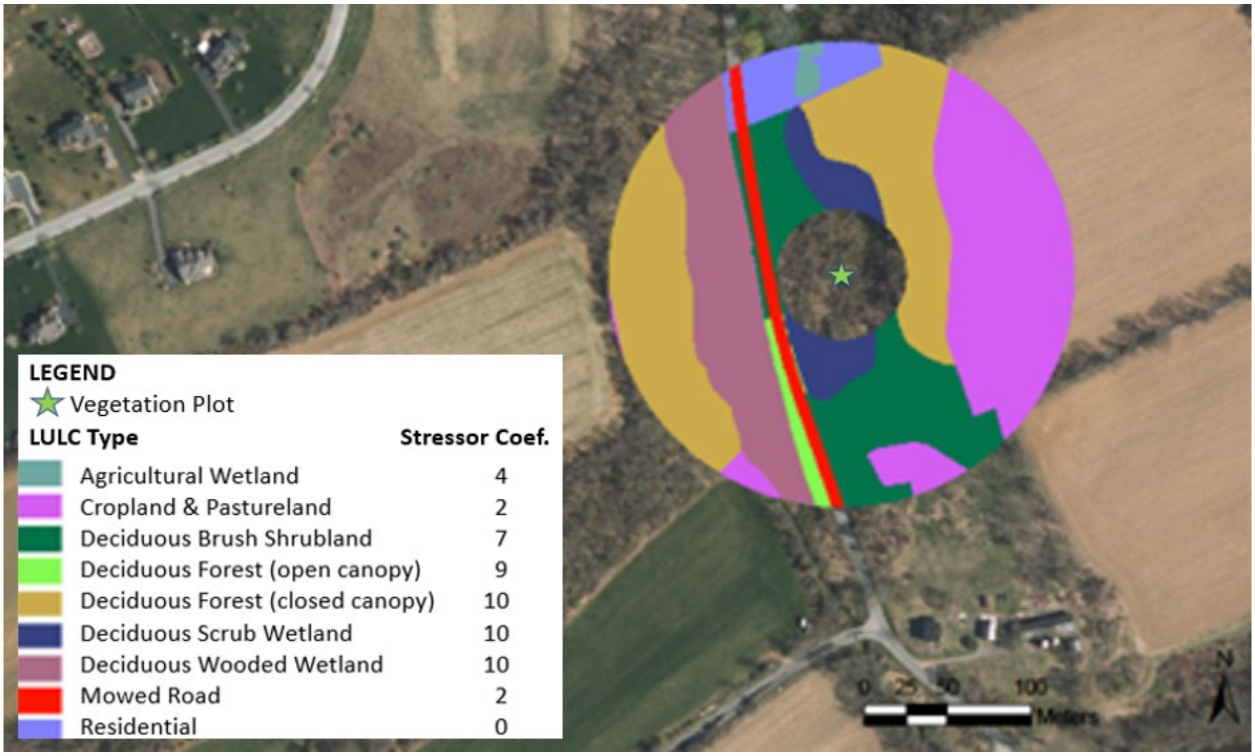


Figure 4. Example application of the Land Use Index (See also Appendix 2). Plot location is indicated by a green star, around which a 40 m radius is used to define the Assessment Area (AA). The Land Use Index is applied in the area defined by a 500 m radius around the AA: First each LULC is mapped within the 500 m area; second, a preestablished Stressor Coefficient is assigned to the land cover and used to weight the areas of the LULC type's contribution to the Index. Land Use Land Cover (LULC) types are presented in alphabetic order (Adapted from Walz and Faber-Langendoen 2018).

Assessing on-site stressors was more challenging, given that our primary source of data were vegetation plots, many of which did not have a stressor assessment of the site being sampled. However, the presence and abundance of nonnative plant species are often indicative of stressor levels. For example, nonnative Phragmites in salt marshes is a vegetative response to a variety of stressors/ disturbances such as filling, land clearing, hydrologic alteration, and nutrient loading associated with coastal development (Kutcher et al. 2022). Thus, our onsite metric of stressor levels was the percent cover of all nonnative plant species in a plot.

We used our two metrics of stressor levels to generate three stressor categories, as follows:

- Good (low to no stressors)/Reference Condition:
    - **LAN2 $\geq$ 80** and < **5.0% nonnatives**
- Fair (moderate levels of stressors):

    - **LAN2 ≥40 – 79.9** and **< 10% cover nonnatives** OR > **LAN2 ≥ 80** and **5-9.9% nonnatives** cover
- Poor (high levels of stressors):
    - **< 40 LAN 2** or **≥10% cover nonnatives**.

In New Jersey, we used the New Jersey Department of Environmental Protection's (NJDEP) polygon-based photo-interpreted imagery of Land Use Land Cover (LULC) to calculate the LAN2 Index. Within the state, the photo-interpreted LULC mapping is judged to be more accurate than the satellite-based National Land Cover Dataset (NLCD) (Yang et al. 2018), based on the experience of New Jersey field crews when visiting wetland sites and their surrounding landscape. We compared the LAN2 scores based on the NJ LULC with that of the scores based on NLCD, because the NLCD layer was available across the rest of the Northeast and therefore could be applied to the entire study area.

FQA Metric Response to Stressor Gradient

Mean C: As described above, our method for identifying a set of stressor categories for the plots included the percent cover of nonnatives. But because Cover-weighted Mean C (CwMean C) metric also uses percent cover of nonnatives as part of its calculation, its score is partially autocorrelated with the stressor categories. For that reason, we emphasized the use of Mean C as the test of how well floristic quality responds to the stressor categories. But we also provided the CwMean C score because it is widely used to assess wetland condition, and as we show below, the differences in response between the two metrics were minimal.

Discriminatory power is the ability of the FQA metrics to distinguish levels of stressors, i.e., Good, Fair, Poor. For each NVC wetland group, we compared how well the two C metrics were able to distinguish stressor levels using box-and-whisker plots and one-way analysis of variance (ANOVA). We first tested whether there was an overall significant difference among the means (F test), and second, to see which of the three Stressor levels could be distinguished. We applied the Tukey's HSD Test to calculate these pairwise comparisons between groups, with corrections for multiple testing and adjusting p-values when testing multiple comparisons. Finally, comparisons were scanned using Notched Boxplots. If the two boxes' notches do not overlap, this is "strong evidence" that their medians differ (Chambers et al. 1983, p. 62).

Having selected group with at least 15 plots for the group, we then tested thresholds for Good, Fair, Poor, but flagged all thresholds where there were < 10 plots in a category, as these are of lower confidence (Bourdaghs et al. 2012, Marti et al. 2019); we also combined Fair + Poor to help increase sample size; even then, a category may have < 10 plots, as frequently occurred in the NJ pilot (Table 2 above).

New Jersey and Northeast: We first tested our approach on the New Jersey data set. Here, plots were largely collected by a single program, were consistent in their data collection methods, and plots were all assigned to the USNVC by state experts. We identified Mean C thresholds for Good, Fair, and Poor for each NVC wetland group, where the data permitted (i.e., provided there were at least 10 plots in each of the three stressor categories).

Based on successful application of our methodology in NJ, we expanded our analysis to the full range of wetland data and NVC groups across the Northeast. We then compared the Mean C threshold scores identified across the Northeast with that of New Jersey. We also tested whether metric ratings differed significantly between Mean C and CwMean C for each wetland type.

Threshold Ratings

To develop threshold ratings (benchmarks) for FQA, researchers have used either the 10th and 90th percentiles (Bourdaghs 2012) or 25th and 75th percentiles between stressor categories (Kutcher and Forrester 2018, Marti and Bernthal 2018, 2019). Because our plot data were aggregated across multiple projects and our estimates of stressors were not strongly field based, we used the 25th percentile as our threshold for Good, then inferred that Excellent would be the 75th percentile of Good. Because our data are stronger for Fair than Poor sites, our percentiles for Poor are likely an underestimate of high stress; thus, we used the 10th percentile of the Poor Category, when available.

In summary, we used the following criteria for estimating thresholds (Fig. 5):

- Excellent = > 75th percentile of Good
- Good = 75th - 25th percentile of Good
- Fair = 25th percentile of Good to 10th percentile of Fair& Poor or Poor
- Poor = < 10th percentile of Fair& Poor or Poor

All statistical analyses were performed using the R software (2021).

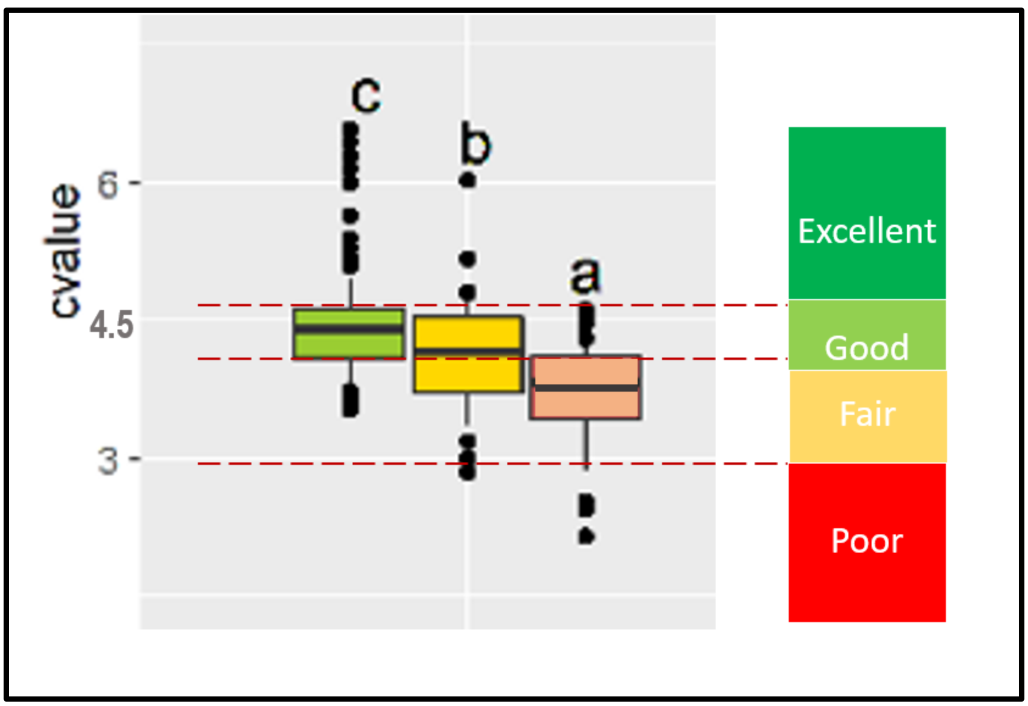


Figure 5. Use of boxplots to guide estimation of thresholds for metric scores. X-axis represents the three stressor categories: green = good, yellow = fair, and tan = poor. Mean C value is shown on the axis. Threshold categories derived from the boxplots are shown on the right.

RESULTS

Assigning Stressor Categories

New Jersey Stressor Categories

We applied our criteria for stressor levels to all plots in the 13 New Jersey wetland groups, using the NJ LULC imagery for the LAN2 index. Our plot data set was largely skewed towards Good/Reference Condition. That is, over-all the number of plots in each of the three categories analyzed was Good- 57% (352 plots), Fair – 22% (135 plots), Poor – 21% (129 plots).

The correlation between LAN2 Index scores using NJ LULC and NLCD was high ($r^2 = 0.71$, $p < 0.0001$), which gave us confidence in using the NLCD as the source of data for the calculation of the LAN2 index at the regional scale (Fig. 6). When both sets of stressor categories were assigned to NJ plot data, there were minimal differences in the counts of plots assigned to good vs. fair or poor plots (20 plots or 3.2% changed categories).

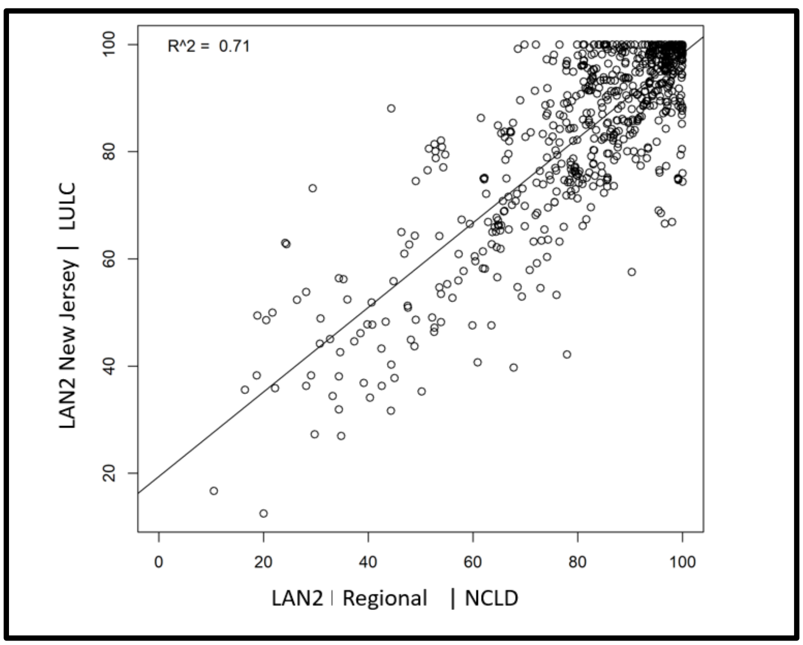


Figure 6. Comparison of LAN2 Index scores between NJ Land Cover Land Use and National Land Cover Land Use. The LAN2 Index for NJ was based on state Land Use Land Cover (LULC) map, which is based on aerial photo interpretation. The LAN2 Index for the region scores were based on the National Land Cover Database (NLCD). Data points are from the 616 plots used for the New Jersey FQA metric analyses.

Northeast Stressor Categories:

As with the NJ dataset, we found that our regional plot data set of was largely skewed towards Good/Reference Condition. That is, the total number of plots in each of the three categories was as follows: Good – 55%, Fair - 22% Poor – 22%. This skew was not surprising, given that the datasets largely came from individual Heritage Programs, whose mandate focuses on exemplary occurrences of all natural community types, as well as the best remaining examples of at-risk types. However, this limited our ability to confidently identify thresholds for each stressor category. At minimum, we assessed Reference /Good from Non-Reference/Fair-Poor, but where data permitted, we assessed all three categories of Good, Fair, and Poor.

FQA Metric Response to Stressor Gradient

New Jersey Metric Analyses

Of the 13 wetland groups found in NJ, only 4 had sufficient plots in each stressor category (i.e., $\geq$ 10 plots) to compare Good/Reference Condition versus Fair & Poor / Non-Reference condition; but all had sufficient plots to calculate Good/Reference condition scores. All results are reported in Table 4, and Figure 2. All 13 groups had sufficient data in the regional study to generate metric ratings in each of the three stressor categories (Table 2).

For forested wetlands, swamps had Mean C scores for Reference stands between 5.19 and 5.44, whereas floodplain forests had Mean C scores of 4.42 (Table 4). CwMean C values were very similar.

In the Marsh, Wet Meadow & Shrubland formation, freshwater marshes and coastal plain pond shore had Mean C values for Reference Condition between 6.02 and 6.62, as compared to wet meadow-shrub swamps and interdunal wetlands, whose reference Conditions were 4.28 and 4.94 (Table 4). CwMean C values for Reference Condition were largely comparable, except that CwMean C values were higher for the interdunal wetlands (4.85 vs 5.41) and tidal freshwater marshes (4.94 vs 5.50).

For Bog & Fen Formation, the North Atlantic Coastal Bog Mean C score for Reference Conditions (Good) was considerably lower (6.16) than the Central Appalachian-Northeast Alkaline Fen (8.61) (Table 4). CwMean C values were very similar.

The Brackish Salt Marsh scored lower for Reference Condition (5.45) than either the High Salt Marsh (6.72) or Low Salt Marsh (7.11). Table 4). CwMean C values were very similar.

For all groups, the difference between Reference Conditions (Good) versus Non-Reference (Fair or Fair & Poor) were accentuated using CwMean C. But our results for CwMean C are influenced by potential autocorrelation between the criterion of using percent cover of nonnatives to define our stressor categories and the CwMean C metric [see Methods above].

Table 4. New Jersey Metric Ratings. A summary of metric scores (mean values) for Mean C and Cover-weighted (CwMean C) metric scores for 13 NVC wetland groups in NJ. Groups marked in Bold and with a # have at least 10 plots per stressor category to confidently assess metric response to stressor categories.

		Mean C			Cw Mean C			Plot No.	
FORMATION	**GROUP_NAME**	**Good**	**Fair & Poor**		**Good**	**Fair & Poor**		**Good (n)**	**Fair & Poor (n)**
Flooded & Swamp Forest	Central Appalachian Northeast Alkaline Swamp	5.19	4.19		5.13	3.76		4	15
	Northern Coastal Plain Swamp #	5.44	4.86		5.28	4.43		47	30
	South Central Appalachian Northeast Floodplain Forest	4.43	3.46		4.59	3.57		1	29
Marsh, Wet Meadow and Shrubland	**Appalachian Northeast Wet Meadow & Shrub Swamp #**	4.28	4.03		4.69	3.90		38	47
	Eastern North American Freshwater Marsh	6.02	2.98		5.95	1.83		2	37
	North Atlantic Coastal Interdunal Wetland	4.82	4.44		5.41	3.87		13	2
	North Atlantic Coastal Plain Pondshore #	6.62	4.81		6.99	5.52		76	13
	North Atlantic Coastal Tidal Freshwater Marsh	4.94	4.80		5.55	5.03		7	24
Bog & Fen	Central Appalachian Northeast Alkaline Fen	8.61	5.13		8.75	5.76		2	29
	North Atlantic Coastal Bog & Fen #	6.16	5.57		6.72	5.55		95	15
Salt Marsh	Atlantic & Gulf Coastal Brackish Salt Marsh	5.45	4.89		5.61	4.94		28	13
	Atlantic & Gulf Coastal High Salt Marsh	6.72	6.48		7.89	6.41		19	5
	Atlantic & Gulf Coastal Low Salt Marsh	7.11	6.30		7.18	6.82		19	6
	Total Plots							351	265

Northeast Metric Analyses

For the 26 Northeast wetland groups, 16 had sufficient plots to compare all 3 categories of Good, Fair and Poor. For the other 10, we were able to assess Reference Condition versus Fair & Poor combined.

Note that now all 13 NJ wetland groups now have robust data sets from across the region to strengthen the threshold ratings initially established within the state, due to additional regional data (cf. Table 2).

Metric ratings for both Mean C and CwMean C are provided in Table 5, and mean C boxplots are provided in Figure 7. Nineteen of the 26 groups showed a decline in metric ratings as stressors increased, but 7 of the groups declines were inconsistent (Table 5), with ratings in the Fair or Poor category higher than Good or Fair categories. All but one of the 7 groups showing this inconsistency also had < 10 plots in that category, suggesting that these results were largely based on inadequate sample sizes. Although we show the mean values across all 3 categories in Table 5, for future statistical analyses, we combined the Fair & Poor categories for all groups where < 10 plots were available in each of these categories (see Fig. 7).

For forested wetlands, floodplain forests had mean C scores for Reference stands between 4.4 and 4.5 (Table 5, Fig. 7a). Circumneutral to alkaline swamps scores ranged from 4.7 to 5.0; acid swamps consistently had scores of 5.4, and Great Lakes flatwoods and swamps scored 5.9. CwMean C values were very similar.

In the Marsh, Wet Meadow & Shrubland formation, riverbed and riverscour wetlands had low scores for reference conditions (3.7 to 4.1), whereas freshwater marshes, wet meadows, and shrublands had scores between 4.3 and 4.7 Table 5, Fig. 7b). Interdunal wetlands, tidal freshwater marshes, and coastal plain pond shore had the highest scores at 4.9, 5.1, and 6.5, respectively. CwMean C values were very similar.

For Bog & Fen Formation, the North Atlantic Coastal Bog Mean C score was higher (6.1) than the Central Appalachian-Northeast Alkaline Fen (5.6) (cf. New Jersey scores in Table 4, where this fen type scored 8.6), but boreal-subboreal bogs had the highest score at 6.4 (Fig. 7c). CwMean C values were very similar to Mean C values.

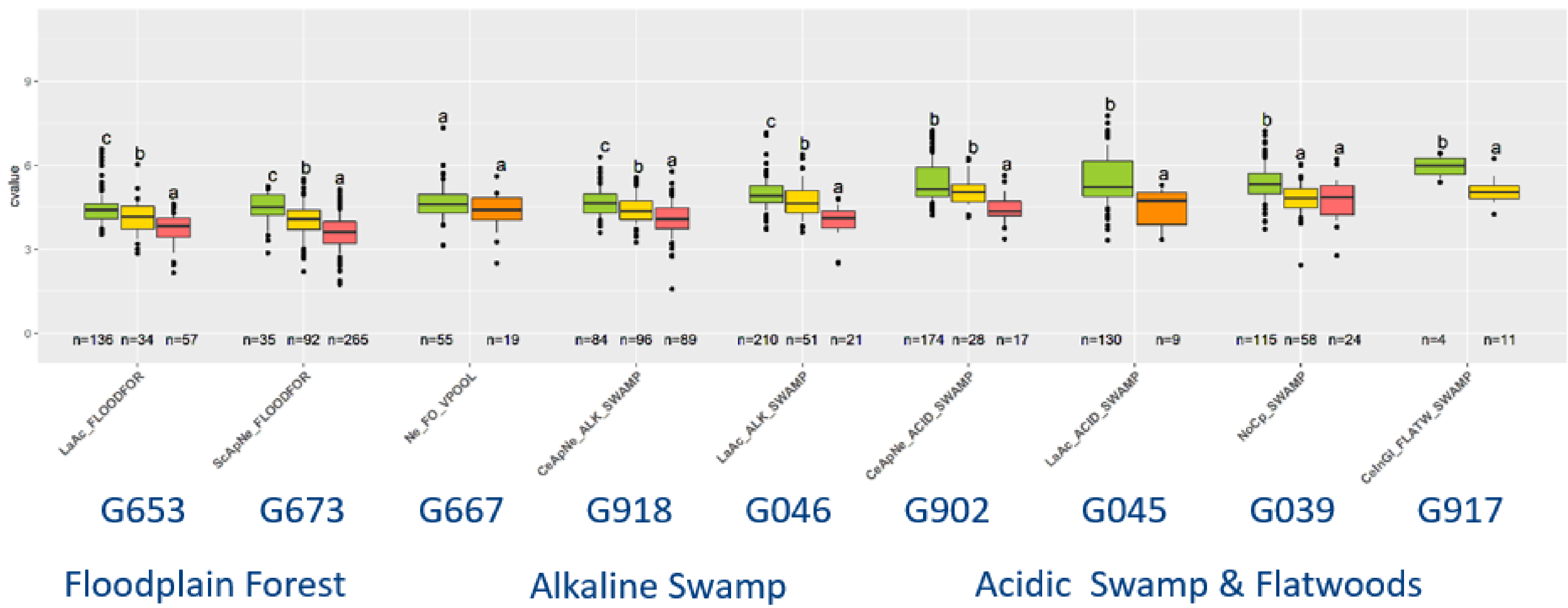
The Brackish Salt Marsh scored lower (5.2) than either the High Salt Marsh (6.6) or Low Salt Marsh (7.3) (Fig. 7d). CwMean C values were very similar.

For all groups, the difference between Reference Conditions (Good) versus Non-Reference (Fair or Fair & Poor) were accentuated using CwMean C; that is to say, differences in CwMean C values were larger between Good versus Fair or Fair & Poor than for Mean C. But our results for CwMean C are influenced by partial autocorrelation between the criterion of using percent cover of nonnatives to define our stressor categories and the CwMean C metric.

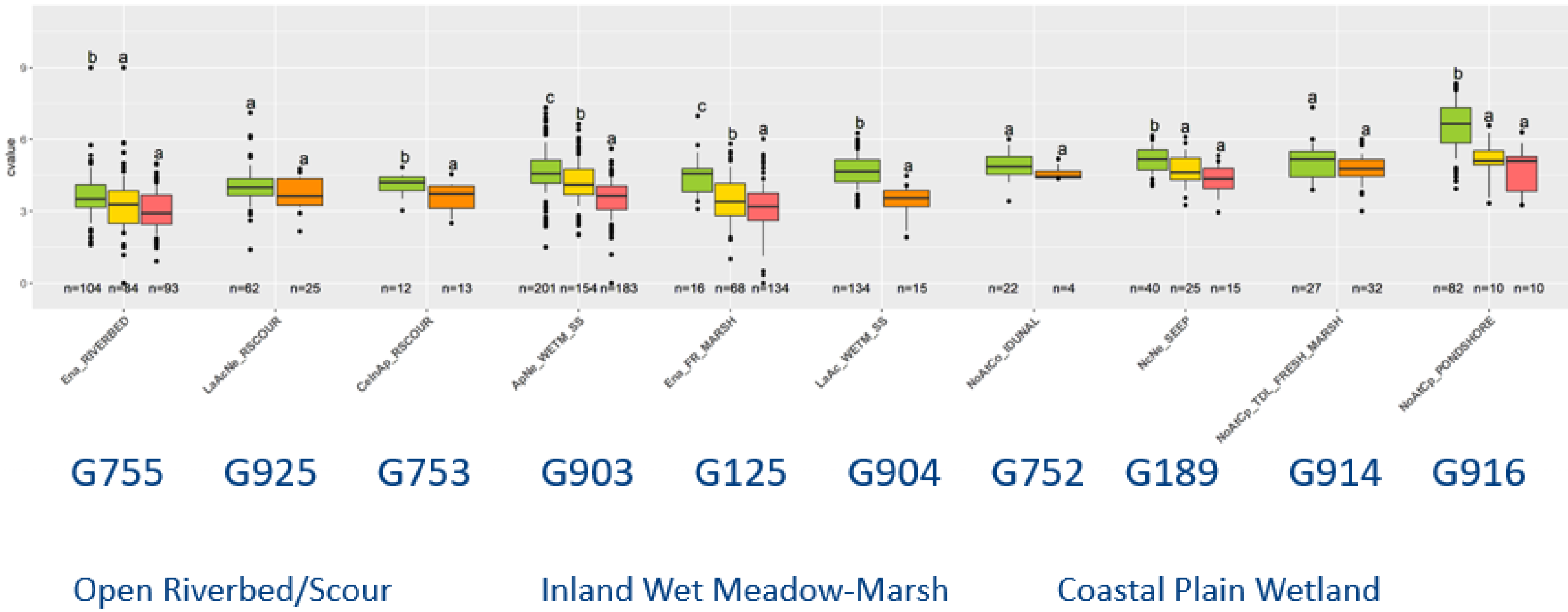
Table 5. Northeast. Summary of metric scores for native wetland types (NVC group level) for the Northeast. 16 of 26 groups (marked in bold and #) had sufficient plots to assess metric ratings across all three stressor categories. Metric ratings in red have < 10 plots. Gray cells indicates that the Metric scores do not follow a consistent declining response from Good to Fair to Poor (or Fair & Poor). See Appendix 6 for numerical statistical significance values.

			MeanC				Cw MeanC				Plot Counts (n)		
Formation	**Group Code**	**GROUP_NAME**	**Good**	**Fair**	**Poor**	**Sig_ Diff**	**Good**	**Fair**	**Poor**	**Sig_ Diff**	**Good**	**Fair**	**Poor**
Flooded & Swamp Forest	G902	**Central Appalachian-Northeast Acidic Swamp #**	5.37	5.11	4.92	*	5.32	5.04	3.31	*	174	28	17
	G918	**Central Appalachian-Northeast Alkaline Swamp #**	4.66	4.41	4.06	*	4.53	4.34	3.74	*	84	96	89
	G917	Central Interior-Great Lakes Flatwoods & Swamp Forest	5.94	5.10		*	6.09	5.18		*	4	11	0
	G045	Laurentian-Acadian Acidic Swamp	5.37	4.59	4.10	*	5.50	4.63	4.06	*	130	6	3
	G046	**Laurentian-Acadian Alkaline Swamp #**	4.95	4.70	4.01	*	4.92	4.60	3.68	*	210	51	21
	G653	**Laurentian-Acadian Floodplain Forest #**	4.43	4.12	3.68	*	4.63	4.53	3.69	*	136	34	57
	G667	Northeastern Forest Vernal Pool	4.62	4.31	4.20	NS	4.56	4.50	1.75	NS	55	17	2
	G039	**Northern Coastal Plain Swamp #**	5.35	4.81	4.75	*	5.41	4.55	4.17	*	115	58	24
	G673	**Southcentral-Appalachian-Northeast Floodplain Forest #**	4.46	4.03	3.59	*	4.71	4.67	3.55	*	35	92	265
Freshwater Marsh, Wet Meadow & Shrubland	G903	**Appalachian-Northeast Wet Meadow & Shrub Swamp #**	4.58	4.18	3.52	*	4.85	4.44	3.22	*	201	154	183
	G753	Central Interior-Appalachian Riverscour Barrens & Prairie	4.09	3.63	3.52	NS	4.88	4.88	4.37	NS	12	8	5
	G125	**Eastern North American Freshwater Marsh #**	4.33	3.47	2.99	*	3.93	3.12	2.00	*	18	68	134
	G755	**Eastern North American Scrub & Herb Riverbed Wetland #**	3.68	3.29	3.03	*	4.70	4.20	3.18	*	104	84	93
	G904	Laurentian-Acadian Wet Meadow & Shrub Swamp	4.67	3.64	3.19	*	5.00	3.87	3.01	*	134	7	8
	G925	Laurentian-Acadian-Northeast Riverscour Vegetation	4.06	3.93	3.25	NS	4.23	4.22	3.66	NS	62	18	7

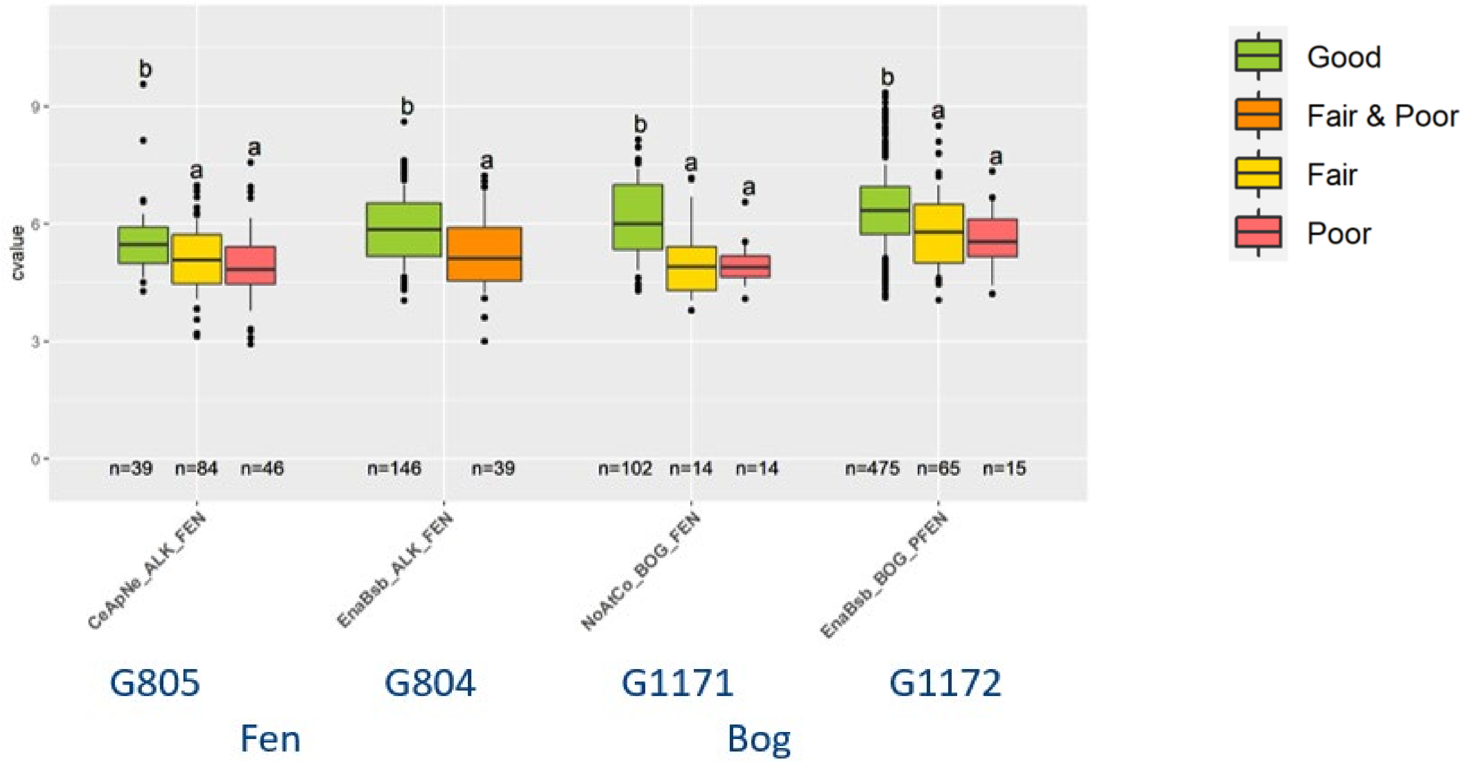
			MeanC				Cw MeanC				Plot Counts (n)		
Formation	**Group Code**	**GROUP_NAME**	**Good**	**Fair**	**Poor**	**Sig_ Diff**	**Good**	**Fair**	**Poor**	**Sig_ Diff**	**Good**	**Fair**	**Poor**
	G752	North Atlantic Coastal Interdunal Wetland	4.91	4.41	5.18	NS	5.61	4.04	6.36	NS	22	3	1
	G916	**North Atlantic Coastal Plain Pondshore #**	6.54	5.09	4.78	*	6.90	5.62	5.15	*	82	10	10
	G914	North Atlantic Coastal Tidal Freshwater Marsh	5.07	4.73	4.97	NS	5.10	5.25	3.63	NS	27	29	3
	G189	**North-Central & Northeastern Seep #**	5.14	4.71	4.31	*	5.36	4.84	4.29	*	40	29	15
Bog & Fen	G805	**Central Appalachian-Northeast Alkaline Fen #**	5.57	5.11	4.92	*	5.92	6.01	5.13	*	39	84	46
	G804	Eastern North American Boreal-Subboreal Alkaline Fen	5.87	5.29	5.10	*	6.33	6.28	5.13	NS	146	32	7
	G1172	**Eastern North American Boreal-Subboreal Bog & Acidic Fen #**	6.36	5.85	5.59	*	6.59	6.05	5.80	*	475	65	15
	G1171	**North Atlantic Coastal Bog & Fen #**	6.12	5.06	4.96	*	6.63	5.84	4.67	*	102	14	14
Salt Marsh	G120	**Atlantic & Gulf Coastal Brackish Salt Marsh #**	5.21	4.70	4.61	NS	5.06	4.92	4.08	NS	45	14	10
	G121	**Atlantic & Gulf Coastal High Salt Marsh #**	6.57	6.93	6.27	NS	7.03	7.39	6.24	*	98	41	19
	G122	Atlantic & Gulf Coastal Low Salt Marsh	7.32	7.54	5.32	*	7.27	7.47	5.40	*	63	11	7
TOTAL PLOTS											2611	1060	1055



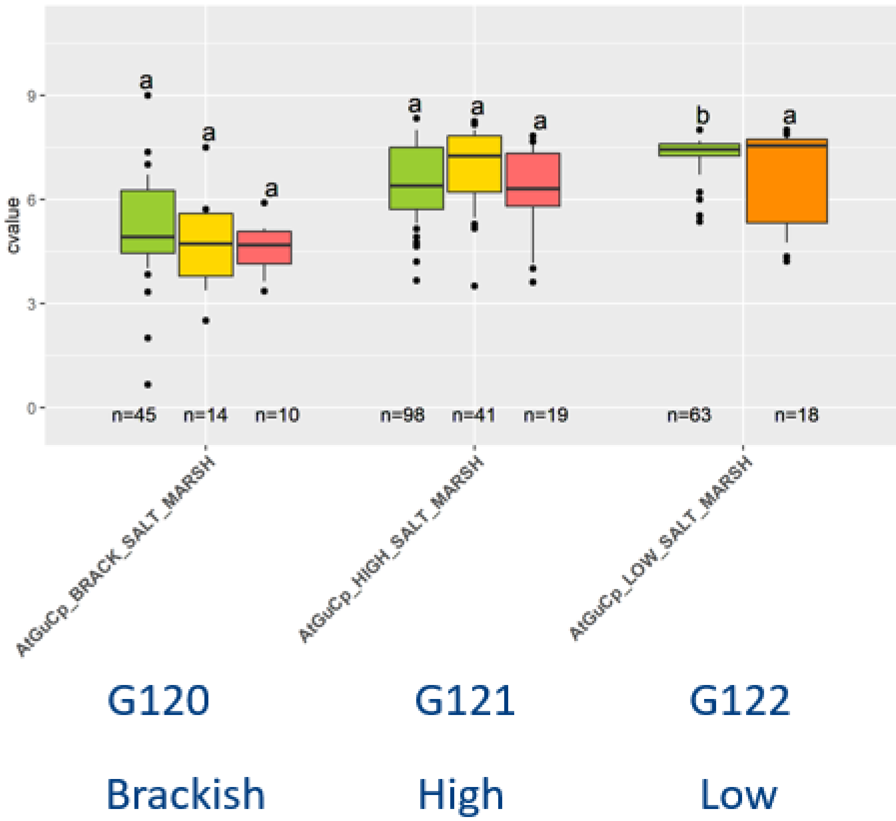
a) Flooded & Swamp Forests. Mean C.



b) Marsh, Wet Meadow and Shrubland. Mean C.



c) Bog & Fen. Mean C



d) Salt Marsh. Mean C

Figure 7. Northeast results comparing Mean C values for the various wetlands, organized by Formation. 7a) Flooded & Swamp Forests, 7b) Marsh, Wet Meadow and Shrubland, 7c) Bog and Fen, 7d) Salt Marsh. Wetland types are ordered by score of Good category In each figure, the smaller case letters (a, b, c) indicate whether the means between the stressor categories are significantly different, i.e., categories that share a letter do not have significantly different mean values. Group codes (G###) provide link to the Group names, as shown in Table 5.

Comparison of New Jersey and Northeast Metric Ratings

Our tests comparing the metric scores for the Good category between the New Jersey and the Northeast metric rating are provided in Table 6. Of the 13 groups, 4 showed significant differences between Northeast and NJ Mean C values and 2 showed differences for CwMean C. Of the 4 NJ groups, 3 had < 10 plots to provide Good scores, suggesting that the main reason for the differences was lack of sufficient plot data.

Table 6. Comparison of NJ and Northeast Metric scores for plots assigned to Good condition. Diff shows the difference in Metric score between the Northeast and the NJ, and the *indicates those that are significantly different ($p < 0.05$). Values in red indicate that the scores are based on < 10 plots within the Stressor category. See Appendix 7 for numerical statistical significance values**.**

			MEAN C			CW MEANC			No. Plots	
Formation	Group Code	GROUP_NAME	Good Northeast	Good _NJ	Diff	Good_ Northeast	Good_ NJ	Diff	North east	NJ
Flooded & Swamp Forest	G918	Central Appalachian-Northeast Alkaline Swamp	4.66	5.19	0.53*	4.53	5.13	0.60*	84	4
	G039	Northern Coastal Plain Swamp	5.35	5.44	0.09	5.41	5.28	0.13	115	47
	G673	South Central Appalachian-Northeast Floodplain Forest	4.47	4.43	-	4.72	4.59	-	35	1
Marsh, Wet Meadow & Shrubland	G903	Appalachian-Northeast Wet Meadow & Shrub Swamp	4.64	4.28	0.36*	4.90	4.69	0.20	201	38
	G125	Eastern North American Freshwater Marsh	4.48	6.02	1.54*	4.23	5.95	1.72	16	2
	G752	North Atlantic Coastal Interdunal Wetland	4.91	4.82	0.09	5.61	5.41	0.20	22	13
	G916	North Atlantic Coastal Plain Pondshore	6.54	6.62	0.09	6.90	6.99	0.08	82	76
	G914	North Atlantic Coastal Tidal Freshwater Marsh	5.07	4.94	0.13	5.10	5.55	0.45	27	7
Bog & Fen	G805	Central Appalachian-Northeast Alkaline Fen	5.58	8.61	3.04*	5.92	8.75	2.84*	39	2
	G1171	North Atlantic Coastal Bog & Fen	6.12	6.16	0.04	6.63	6.72	0.09	102	95
Salt Marsh	G120	Atlantic & Gulf Coastal Brackish Salt Marsh	5.21	5.45	0.24	5.06	5.61	0.55	45	28
	G121	Atlantic & Gulf Coastal High Salt Marsh	6.57	6.72	0.15	7.03	7.89	0.86*	98	19
	G122	Atlantic & Gulf Coastal Low Salt Marsh	7.32	7.11	0.21	7.27	7.18	0.09	63	19

Threshold Ratings for Northeast Wetland Groups

A summary of the thresholds (benchmarks) for all 26 northeast wetland groups is provided for Mean C (Table 7) and for CwMean C (Table 8). These thresholds are based on the specified quartiles from box and whisker plots (see Methods). We combined thresholds [we merged cells] where threshold scores were based on categories with < 10 plots, typically for Fair versus Poor thresholds. But for comparisons with future studies (see also Table 9), we provide the Poor threshold in square brackets.

Table 7. Thresholds for Mean C Metric by Wetland Group for Northeast. E=Excellent, G=Good, F=Fair, P=Poor. Where thresholds lacked sufficient plot data (i.e., where categories contained < 10 plots, the cells are merged. For comparisons with future studies, we provide the Poor threshold in square brackets (& marked in red font).

			MEAN C			
Formation	Group Code	GROUP_NAME	E	G	F	P
Flooded & Swamp Forest	G902	Central Appalachian-Northeast Acidic Swamp	> 5.9	5.9-4.9	4.9-3.8	< 3.8
	G918	Central Appalachian-Northeast Alkaline Swamp	> 5.0	5.0-4.3	4.3-3.3	< 3.3
	G917	Central Interior-G. Lake Flatwood & Swamp Forest	> 6.3	6.3-4.7		< 4.7
	G045	Laurentian-Acadian Acidic Swamp	> 6.2	6.2-4.9	< 4.9	[3.4]
	G046	Laurentian-Acadian Alkaline Swamp	> 5.3	5.3-4.7	4.7-3.6	< 3.6
	G653	Laurentian-Acadian Floodplain Forest	> 4.6	4.6-4.1	4.1-2.9	< 2.9
	G667	Northeastern Forest Vernal Pool	> 5.0	5-4.3	< 4.3	[3.6]
	G039	Northern Coastal Plain Swamp	> 5.7	5.7-5.0	5.0-4.0	< 4.0
	G673	Southcentral-Appalachian-Northeast Floodplain Forest	> 4.9	4.9-4.2	4.2-2.8	< 2.8
Freshwater Marsh, Wet Meadow & Shrubland	G903	Appalachian-Northeast Wet Meadow & Shrub Swamp	> 5.1	5.1-4.2	4.2-2.6	< 2.6
	G753	Central Interior-Appalachian Riverscour Barrens & Prairie	> 4.4	4.4-3.9	< 3.9	[2.7]
	G125	Eastern North American Freshwater Marsh	> 4.8	4.8-3.8	3.8-1.1	< 1.1
	G755	Eastern North American Scrub & Herb Riverbed Wetland	> 4.1	4.1-3.1	3.1-2.0	< 2.0
	G904	Laurentian-Acadian Wet Meadow & Shrub Swamp	> 5.1	5.1-4.2	<4.2	[2.2]
	G925	Laurentian-Acadian-Northeast Riverscour Vegetation	> 4.4	4.4-3.6	<3.6	[3.2]
	G752	North Atlantic Coastal Interdunal Wetland	> 5.3	<5.3	[4.5,	4.4]
	G916	North Atlantic Coastal Plain Pondshore	> 7.3	7.3-5.9	5.9-3.3	< 3.3
	G914	North Atlantic Coastal Tidal Freshwater Marsh	> 5.5	5.5-4.4	<4.4	[4.0]
	G189	Northcentral & Northeastern Seep	> 5.6	5.6-4.7	4.7-3.5	< 3.5
Bog & Fen	G805	Central Appalachian-Northeast Alkaline Fen	> 5.9	5.9-5.0	5.0-3.8	< 3.8
	G804	Eastern North American Boreal-Subboreal Alkaline Fen	> 6.5	6.5-5.2	< 5.2	[4.2]
	G1172	Eastern North American Boreal-Subboreal Bog & Acidic Fen	> 6.9	6.9-5.7	5.7-4.4	< 4.4
	G1171	North Atlantic Coastal Bog & Fen	> 7.0	7.0-5.3	5.3-4.4	< 4.4
Salt Marsh	G120	Atlantic & Gulf Coastal Brackish Salt Marsh	> 6.2	6.2-4.4	4.4-3.6	< 3.6
	G121	Atlantic & Gulf Coastal High Salt Marsh	> 7.5	7.5-5.7	5.7-4.2	<4.2
	G122	Atlantic & Gulf Coastal Low Salt Marsh	> 7.6	7.6-7.3	<7.3	[4.8]

Table 8. Thresholds for Cover-Weighted Mean C Metric by Wetland Group. E = Excellent, G = Good, F = Fair, and P = Poor. Where thresholds lacked sufficient plot data (i.e., where categories contained < 10 plots, the cells are merged. But for comparisons with future studies, we provide the Poor threshold in square brackets (and marked in red font).

			CW MEAN C			
Formation	**Group Code**	**GROUP_NAME**	**E**	**G**	**F**	**P**
Flooded & Swamp Forest	G902	Central Appalachian-Northeast Acidic Swamp	> 6.1	6.1-4.6	4.6-2	< 2.0
	G918	Central Appalachian-Northeast Alkaline Swamp	> 5.0	5.0-4.0	4-2.7	< 2.7
	G917	Central Interior-Great Lakes Flatwoods & Swamp Forest	> 6.3	6.3-5.9		< 4.6
	G045	Laurentian-Acadian Acidic Swamp	> 6.4	6.4-4.6	< 4.6	[3.9]
	G046	Laurentian-Acadian Alkaline Swamp	> 5.4	5.4-4.5	4.5-3.3	< 3.3
	G653	Laurentian-Acadian Floodplain Forest	> 5.0	5.0-4.2	4.2-2.7	< 2.7
	G667	Northeastern Forest Vernal Pool	> 5.0	5.0-4.0	< 4.0	[2.8]
	G039	Northern Coastal Plain Swamp	> 6.0	6.0-4.7	4.7-2.6	< 2.6
	G673	Southcentral-Appalachian-Northeast Floodplain Forest	> 5.2	5.2-4.4	4.4-2.3	< 2.3
Freshwater Marsh, Wet Meadow & Shrubland	G903	Appalachian-Northeast Wet Meadow & Shrub Swamp	> 5.7	5.7-4.1	4.1-2.2	< 2.2
	G753	Central Interior-Appalachian Riverscour Barrens & Prairie	> 5.1	5.1-4.6	< 4.6	[2.7]
	G125	Eastern North American Freshwater Marsh	> 4.8	4.8-3.4	3.4-1.5	< 1.5
	G755	Eastern North American Scrub & Herb Riverbed Wetland	> 5.0	5.0-3.5	3.5-1.6	< 1.6
	G904	Laurentian-Acadian Wet Meadow & Shrub Swamp	> 5.6	5.6-4.3	< 4.3	[2.4]
	G925	Laurentian-Acadian-Northeast Riverscour Vegetation	> 4.7	4.7-3.7	< 3.7	[1.6]
	G752	North Atlantic Coastal Interdunal Wetland	> 6.1	< 6.1	[5.0,	3.8]
	G916	North Atlantic Coastal Plain Pondshore	> 7.8	7.8-6.3	6.3-1.1	< 1.1
	G914	North Atlantic Coastal Tidal Freshwater Marsh	> 5.8	5.8-4.1	< 4.1	[4.0]
	G189	North-Central & Northeastern Seep	> 5.9	5.9-4.7	4.7-3.7	< 3.7
Bog & Fen	G805	Central Appalachian-Northeast Alkaline Fen	> 6.3	6.3 5.2	5.2-2.0	< 2.0
	G804	Eastern North American Boreal-Subboreal Alkaline Fen	> 6.9	6.9-5.9	< 5.9	[4.6]
	G1172	Eastern North American Boreal-Subboreal Bog & Acidic Fen	> 7.1	7.1-6.2	6.2-4.8	< 4.8
	G1171	North Atlantic Coastal Bog & Fen	> 7.7	7.7-5.7	5.7-3.9	< 3.9
Salt Marsh	G120	Atlantic & Gulf Coastal Brackish Salt Marsh	> 6.7	6.7-3.6	3.6-2.4	< 2.4
	G121	Atlantic & Gulf Coastal High Salt Marsh	> 7.9	7.9- 6.0	6.0-3.9	< 3.9
	G122	Atlantic & Gulf Coastal Low Salt Marsh	> 7.5	7.5-7.0	< 7.0	[3.9]

Finally, we compared our thresholds for CwMean C with those reported elsewhere in the literature, specifically for Wisconsin (Marti and Benthal 2019) and Minnesota (Bourdaghs 2012). We identified wetland types in those studies that are most comparable to ours. All our threshold ratings for Excellent and Poor were within 1 point of those reported by those authors (Table 9).

Table 9. Comparison of Thresholds in this study with Wisconsin and Minnesota. Wisconsin data from Marti and Benthal (2019); Minnesota data from Bourdaghs (2012). NWMF = Northern Wet-mesic forest, CS = Conifer Swamp, NHS = Northern Hardwood Swamp, HS = Hardwood Swamp, FF = Floodplain Forest. Multiple values are reported for Marti and Benthal, who developed metrics by wetland type by three ecoregions in central and southern Wisconsin (not all types occur in each ecoregion). E = Excellent, G = Good, F = Fair, and P = Poor.

			Cw Mean C				WI		MN	
Formation	**Group Code**	**GROUP_NAME**	**E**	**G**	**F**	**P**	**E**	**P**	**E**	**P**
Flooded & Swamp Forest	G918	Central Appalachian-Northeast Alkaline Swamp	> 5.0	5.0- 4.0	4-2.7	< 2.7	SHS> 4.7	< 2.0		
	G045	Laurentian-Acadian Acidic Swamp	> 6.4	6.4- 4.6	< 4.6	[3.9]	NTS> 7.1	< 4.5	CS > 5.6	3.6
	G046	Laurentian-Acadian Alkaline Swamp	> 5.4	5.4- 4.5	4.5-3.3	< 3.3	NHS>6.2	<3.5	HS > 4.6	2.5
	G653	Laurentian-Acadian Floodplain Forest	> 5.0	5- 4.2	4.2-2.7	< 2.7	FF > 4.0/4.4	< 2.2/2.2	FF > 3.3	2.1
Freshwater Marsh, Wet Meadow & Shrubland	G125	Eastern North American Freshwater Marsh	> 4.8	4.8- 3.4	3.4-1.5	< 1.5	EM > 5.7/6.6/5.2	< 2.0/0.8/1.7	SM>4.9	1.6
	G904	Laurentian-Acadian Wet Meadow & Shrub Swamp	> 5.6	5.6- 4.3	< 4.3	[2.4]	SM > 6.3/6.0, SC > 5.1/5.7/5.5	SM < 3.7/<1.9, SC < 3.1/1.6/1.8	FM > 4.2, SC >4.5	FM < 1.3, SC < 3.2
Bog & Fen	G804	Eastern North American Boreal-Subboreal Alkaline Fen	> 6.9	6.9-5.9	< 5.9	[4.6]	CF > 7.0	< 3.5	CF >6.4	< 4.7
	G1172	Eastern North American Boreal-Subboreal Bog & Acidic Fen	> 7.1	7.1-6.2	6.2-4.8	< 4.8			OB/CB > 7.3	< 5.4

DISCUSSION

Calibrating FQA Metrics using Stressor Gradient

Calibration using a Stressor Gradient

Our methodology followed standard methods for calibrating metrics – the Biological Condition Gradient of Davies and Jackson (2006)- whereby an independent stressor rating is used to assess the biological response (FQA metric) of the wetland type to the stressor rating. Although our information about stressor levels was limited to a land use index and to abundance of nonnative species, it had the advantage of being consistent across multiple data sets and regions. However, we recognize that studies that more rigorously stratify plots across the region and develop site-based assessments of stressors will provide a more robust assessment of how wetlands response to increasingly degrading factors, ultimately leading to their collapse. Thus, although not necessary in routine applications of rapid assessments, we encourage the collection of stressor data to assist with the interpretation of ecological integrity and as a means of guiding management activities to maintain or improve ecological condition.

Calibrating FQA Metrics across a Large Region with Ecoregional C Values

Our study is rare in that we calibrated our FQA metrics at the regional scale, which was possible because we had access to a comprehensive set of ecoregional C (eC) values across the entire 9-state region (Faber-Langendoen et al 2019a, Faber-Langendoen et al. 2021). Previous studies have largely been restricted to a subregion within a state or across a state, drawing from state-based C-values. This has limited utility for watershed-based assessments that require a set of metrics that can be used regardless of jurisdiction. The only other study we are aware of that uses ecoregional C values is that of EPA's National Wetland Condition Assessment (Serenbetz 2016), which uses a Vegetation Multi-metric Index (VMMI) calibrated by wetland type across major ecoregions. That methodology does not, however, provide a comprehensive set of C values for all wetland (let alone upland) plant species. Because of the availability of an ecoregion set of C-values across the Northeast, we were able to compile a very large data set of over 4,700 plots and assign eC values to each species in each plot.

Calibrating FQA Metrics by Wetland Type

We also were able to compile a very large data set across the Northeast region (over 4,700 plots), such that a wide variety of wetland types were included. Previous studies often have more limited plot data sets, limiting their ability to characterize the diversity of wetland types. We used the U.S. National Vegetation Classification (USNVC) because it is being rigorously peer reviewed across the entire U.S., is a federal standard, and types are carefully crosswalked to or directly used as part of state Natural Heritage Program classifications, which regularly survey and track information on exemplary and rare occurrences of wetland types (e.g., Thompson et al. 2019). We focus on the NVC group level, because comprehensive information is becoming available for all USNVC groups, including through comprehensive mapping of USNVC groups by LANDFIRE (Comer et al. 2022), and protection status by USGS (McKerrow et al. 2021). The USNVC also shares the same classification approach as the Canadian NVC, thereby providing a North American perspective on all wetland types (Faber-Langendoen et al. 2018). Thus, state and regional assessments in the Northeast can draw from a wealth of information at state, national, and international levels.

Although USNVC groups are a mid-level of the USNVC (that is, finer-scaled wetland types exist at the alliance and association levels), they are a finer-scale unit when compared to NWI or HGM types, raising concerns that they both demand a lot of classification expertise and perhaps require more detail than is needed for a wetland condition assessment. Our study included 43 wetland types across 9 states, with 26 common groups. In any given state, depending on whether it had both freshwater and estuarine wetland types, the number of common wetland groups will vary from approximately 10 (inland states) to around 20 (inland and coastal). Many of these types have distinct hydrologic and floristic composition, important for guiding mitigation and restoration efforts. Given the available level of information and guidance available on applying the USNVC, we feel the benefits of working at the group level outweigh the costs.

Mean C versus Cover-weighted Mean C

Because our development of the stressor gradient required that we used the cover of nonnatives as a criterion for the level of stress on a plot (which is also part of the Cover-weighted Mean C (CWMean C), we were unable to adequately compare the response of the Mean C metric and CWMean C metrics. The comparisons we did make suggest they are comparable in their response. This agrees with the findings of Kutcher and Forrester (2018). These authors note the value of including species abundance as part of the metric, particularly in cases where a single or a few nonnative species dominate and the remaining natives have only low cover. Incorporating cover does require extra sampling effort, but use of relatively broad cover classes does not require much more effort and are effective in describing the essential structural and functional characteristics of the vegetation. Cover data also aid in identifying the wetland type; indeed, at the extremes of highly abundant nonnatives, these cover data may indicate when a native wetland type has essentially collapsed and transformed into a novel ecosystem type.

Threshold Ratings by Wetland Type

A major finding of our research was the ability to produce wetland specific threshold ratings using boxplots as guides. Although our data were uneven, both by wetland type and by stressor category, our data were remarkably consistent with other research findings, particularly those conducted in Wisconsin (Marti and Benthal 2019) and Minnesota (Bourdaghs 2012). Our thresholds are provisional for northeast wetland types, given our heterogeneous datasets and the general assessment of stressor categories. We look forward to more rigorous tests of our findings for those groups we were unable to develop thresholds for across all stressor levels (see Tables 8, 9).

FQA as a Rapid and Intensive Wetland Method

Wetland scientists continue to look for a suite of assessment tools that include both rapid assessment (Level 2) and intensive (Level 3) methods. The FQA metrics presented here are typically considered more intensive, because of the botanical skills required to gather the data. In addition, the need to calibrate the metrics by wetland community type (such as the USNVC group level) requires additional expertise in delineating wetland types as part of the sampling protocol. Conversely, applying these tools adds much more "grain" to the assessment. Wetland managers will benefit from the mix of rapid assessment methods that continue to be developed (e.g., Kutcher et al. 2022) alongside the improvement of intensive methods, such as the FQA metric.

Ecological Integrity and the Role of FQA for Wetland Condition Assessments

Our results add to a growing body of knowledge that indicate the value of FQA metrics in describing wetland condition. Vegetation integrates and reflects the cumulative impacts of multiple stressors, and the FQA metrics tested here provides a well-developed methodology for documenting the vegetation response. The FQA metric approach is relatively straightforward to understand, making it a practical tool that managers and researchers can use to communicate their findings. Indeed, EPA's National Wetland Condition Assessment (Serenbetz 2016) uses floristic response as a primary tool for assessing the condition of the nation's wetland.

That said, FQA alone does not describe all aspects needed to describe wetland condition. Degradation of hydrologic functions may not be fully captured, nor may various structural features, such as woody regeneration, coarse woody debris, or old growth conditions. If managers are looking for guidance to assess resilience of wetlands to a variety of stressors, a fuller assessment may be needed, such as those conducted to assess ecological integrity and other wetland values. For example, Kutcher et al. (2022) developed a rapid salt marsh assessment, called MarshRAM, that produces five indices reflecting (1) ecological and cultural value, (2) surrounding landscape condition, (3) the intensity of human disturbances, (4) marsh platform integrity, and (5) landward migration potential. Similarly, many wetland condition assessments assess the combination of vegetation, hydrology, soils, and landscape context that together describe the wetlands integrity (e.g., Collins et al. 2006, Fennessy et al. 2007, Unnasch et al. 2009, Faber-Langendoen et al. 2019). This is, in part, because rarely are wetland assessments conducted simply to get a rating of its condition; rather, the goal is to guide management and, at a site level, to reduce known stressors that may be degrading a wetland.

The Role of FQA Metrics in Wetland Monitoring, Mitigation, and Restoration

Our development of thresholds of FQA metric response to the stressor gradient can provide guidance to ongoing monitoring and assessment programs, where knowledge of reference conditions (Good and Excellent ratings in Tables 8 and 9) can guide interpretation of the status of wetlands in a watershed, state, or region. Similarly, these thresholds can guide restoration and mitigation efforts by helping set standards for restoration success or, in the case of mitigation, compliance. Most mitigation efforts are guided by a five-year plan, and it is entirely possible that a project shows the right trajectory in the early years, but ultimate achievement of a desired threshold may or may not prove elusive (Fig. 10).

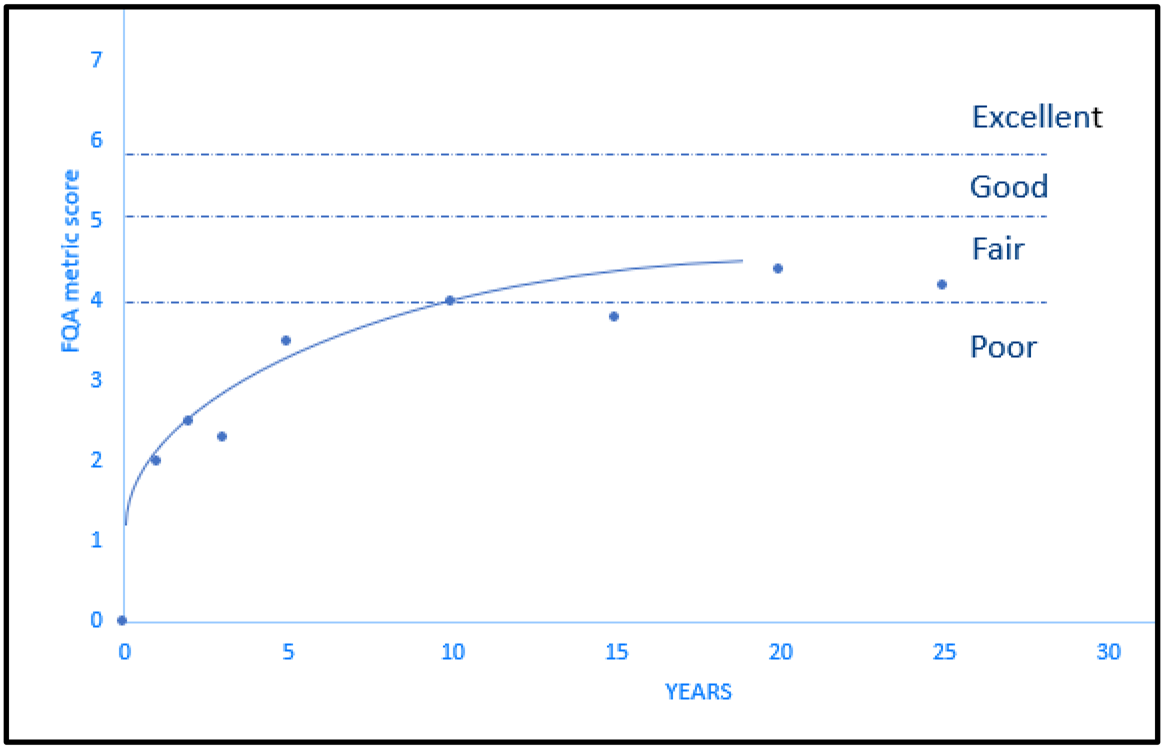


Figure 10. Tracking FQA metric to Assess Mitigation Success. The hypothetical graph shows trend in FQA metric over time in a mitigation project relative to potential benchmarks (dotted lines). The thresholds are based on Mean C values for Northern Coastal Plain Swamp (G039) (see Table 7). Thresholds for Cover-weighted Mean C are initially lower (P/F=2.6) but otherwise comparable F/G=4.7, G/E=6.0 (Table 8).

FQA metrics are an important component of mitigation and restoration assessments, and best used in combination with a fuller set of metrics that inform vegetation, soils, hydrology, and landscape context that together provide a reliable guides to the success or compliance of wetland mitigation and restoration. The practical value of FQA metrics in helping inform mitigation and restoration projects should not be understated, precisely because the FQA metrics tested here provides a well-developed methodology for documenting the vegetation response. We encourage embedding these metrics within current state wetland monitoring and assessment programs to facilitate standard evaluations of wetlands across the northeast.

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APPENDICES

APPENDIX 1. Members of the Technical Advisory Committee

Name	Agency or Organization
Alafat, Beth	Environmental Protection Agency
Bishop, Jordan	NEIWPCC
Connors, Beth	Maine Department of Environmental Protection
DiFranco, Jeanne	Maine Department of Environmental Protection
Friesner, Richard	NEIWPCC
Golembiewski, Brian	Connecticut Department of Energy and Environmental Protection
Hohn, Charlie	Vermont Department of Environmental Conservation
Kucher, Tom	Rhode Island Natural History Survey
Murphy, Carol	Rhode Island Department of Environmental Management
McHugh, Mike	Massachusetts Department of Environmental Protection
Nichols, William	New Hampshire Natural Heritage Bureau
Puryear, Kristen	Maine Natural Heritage Program
Rhodes, Lisa	Massachusetts Department of Environmental Protection
Shappell, Laura	New York Natural Heritage Program
Tilton, Maryann	New Hampshire Department of Environmental Services
Wernerehl, Bob	Massachusetts Natural Heritage & Endangered Species Program

APPENDIX 2. Land Use Index (LAN2)

Definition: This metric measures the intensity of human dominated land uses in the surrounding landscape, including options for sub-metrics for the inner sub-zone, or buffer (0–100 m) and outer sub-zone (100–500 m).

Metric Type: Stressor.

Tier: 1 (remote sensing).

Measurement Protocol: The Land Use Index metric is measured by documenting the surrounding land use(s) within the inner and outer landscape areas. The assessment should be completed in the office using remote sensing imagery, such as aerial photographs or satellite imagery, then, where feasible, verified in the field, using roads or transects to verify land use categories. Ideally, both field data as well as remote sensing tools are used to identify an accurate percent of each land use within the landscape area, but remote sensing data alone can be used.

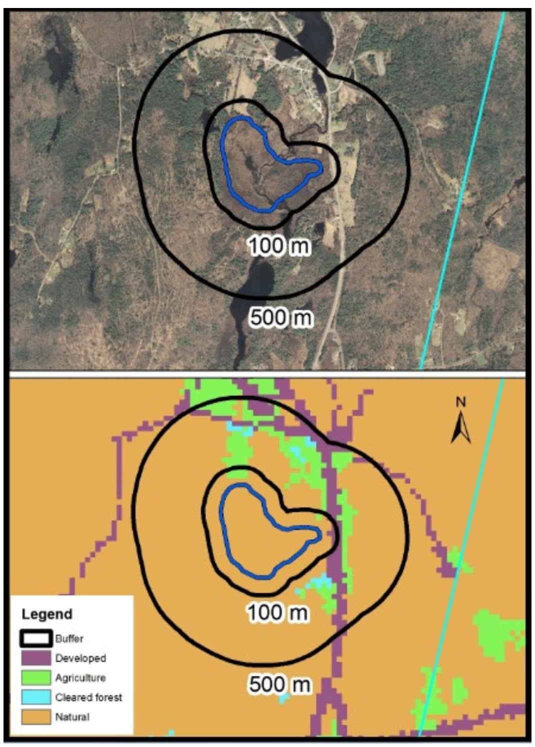


Figure A2.1. Application of land use coefficients to assess the Land Use Index metric (Nichols and Faber-Langendoen 2012). Here, the Land Use Index is calculated for the inner sub-zone (0–100 m) and the outer sub-zone (100–500 m) of a polygon. In this study, we used a plot/point and a single 500 m zone . The percent area of each land use is recorded in Table A2.1 , and a weight is assigned to the land use based on the degree of non-naturalness. In this case, because the land uses are very general, Developed gets a weight = 1, Agriculture = 3, Cleared Forest = 5, and Natural = 10.

Table A2.1. Table for recording Land Uses using a standard list.

Surrounding Land Use Index: Worksheet : Land Use Categories	**Land Use Categories-Aggregated**	**Coef-ficient**	**Zone** (0-500 m)	
			% Area	**Score**
Paved roads / parking lots	Developed – High to Moderate Intensity	0		
Domestic, commercial, or publicly developed buildings and facilities (non-vegetated)	Developed – High to Moderate Intensity	0		
Gravel pit / quarry / open pit / strip mining	Developed – High to Moderate Intensity	0		
Unpaved roads (e.g., driveway, tractor trail, 4-wheel drive, logging roads)	Developed – High to Moderate Intensity	1		
Agriculture: tilled crop production	Agriculture – Cultivated Crop, Annual	2		
Intensively developed vegetation (golf courses, lawns, etc.)	Developed – Low Intensity	2		
Vegetation conversion (chaining, cabling, roto-chopping, clearcut)	Vegetation – Highly Altered	3		
Agriculture: permanent crop (vineyard, orchard, nursery, hayed pasture, etc.)	Agriculture – Cultivated Crop – Perennial	4		
Intense recreation (ATV use / camping / popular fishing spot, etc.)	Vegetation – Highly Altered	4		
Military training areas (armor, mechanized)	Vegetation – Highly Altered	4		
Heavy grazing by livestock on pastures or native rangeland	Vegetation – Highly Altered	4		
Heavy logging or tree removal (50-75% of trees >30 cm dbh removed)	Vegetation – Moderately Altered	5		
Commercial tree plantations / holiday tree farms	Vegetation – Mod. Altered	5		
Recent old fields and other disturbed fallow lands dominated by ruderal and exotic species	Vegetation – Mod. Altered	5		
Dam sites and flood disturbed shorelines around water storage reservoirs and motorized boating	Vegetation – Mod. Altered	5		
Moderate grazing of native grassland	Vegetation – Mod. Altered	6		
Moderate recreation (high-use trail)	Vegetation – Mod. Altered	7		
Mature old fields and ruderal forests with natural composition on former fallow lands	Vegetation – Mod. Altered	7		
Selective logging or tree removal (<50% of trees >30 cm dbh removed)	Vegetation – Lightly Altered	8		
Light grazing or haying of native rangeland	Vegetation – Lightly Altered	9		
Light recreation (low-use trail)	Vegetation – Lightly Altered	9		
Natural area / land managed for native vegetation	Vegetation – No/ Minimally Altered	10		
	A $\geq$9.5, B = 8.0–9.5%, C = 4.0–7.9%, D = <4.0%	**Total Land Use Score**	-	
		Total Land Use Rating		

To calculate a Total Land Use Score, estimate the percent of each Land Use type and then assign the corresponding coefficient (Table 9) into the following equation:

Sub-land use score = $\sum LU \times PC/100$

LU = Land Use Score for Land Use Type

PC = % of adjacent area in Land Use Type

For example, if 30% of the Landscape area was under moderate grazing (0.3 * 6.6 = 1.8), 10% composed of unpaved roads (0.1 * 1.0 = 0.1), and 60% was a natural area (e.g., no human land use) (0.6 * 10.0 = 6.0), the LAN2 Score = 0.79 (0.18 + 0.01 + 0.60). The score can then be rated using A2.2

Metric Rating:

Table A2.2. Land Use Index metric rating.

Metric Rating	***Average Land Use Score: ALL WETLANDS***
EXCELLENT (A)	9.5–10
GOOD (B)	8.0–9.4
FAIR (C)	4.0–7.9
POOR (D)	<4.0

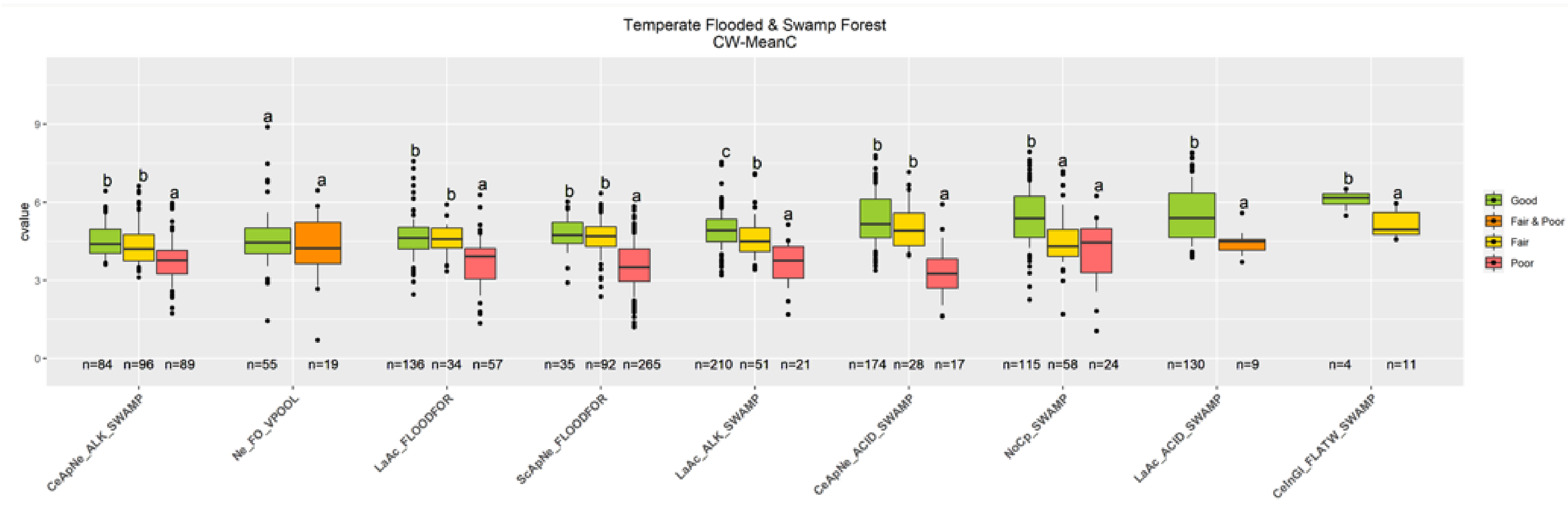
APPENDIX 3. Plot Count Of Each Group By State

FORMATION_NAME	GROUP_NAME	CODE	CT	MA	ME	NH	NJ	NY	PA	VT	Totals
Temperate Flooded & Swamp Forest	Central Appalachian-Northeast Acidic Swamp	G902	5	77	21	19	7	31	66	8	**234**
	Central Appalachian-Northeast Alkaline Swamp	G918	28	96	2	10	21	103	9	2	**271**
	Central Interior-Great Lakes Flatwoods & Swamp Forest	G917	0	0	0	0	0	0	5	10	**15**
	Laurentian-Acadian Alkaline Swamp	G046	7	58	55	36	7	29	0	90	**282**
	Laurentian-Acadian Acidic Swamp	G045	2	29	23	10	0	34	22	19	**139**
	Laurentian-Acadian Floodplain Forest	G653	1	0	118	38	0	46	0	25	**228**
	Northeastern Forest Vernal Pool	G667	0	0	1	0	0	50	0	23	**74**
	Northern Coastal Plain Swamp	G039	29	33	21	20	77	11	7	0	**198**
	South Central-Appalachian-Northeast Floodplain Forest	G673	53	2	0	4	29	65	243	0	**396**
Temperate to Polar Freshwater Marsh, Wet Meadow & Shrubland	Appalachian-Northeast Wet Meadow & Shrub Swamp	G903	22	144	2	7	87	120	153	10	**545**
	Central Interior-Appalachian Riverscour Barrens & Prairie	G753	0	0	0	0	0	0	25	0	**25**
	Eastern North American Freshwater Marsh	G125	6	0	0	5	39	126	32	12	**220**
	Eastern North American Scrub & Herb Riverbed Wetland	G755	0	0	0	49	2	55	173	3	**282**

FORMATION_NAME	GROUP_NAME	CODE	CT	MA	ME	NH	NJ	NY	PA	VT	**Totals**
	Laurentian-Acadian Wet Meadow & Shrub Swamp	G904	0	0	38	59	0	39	0	14	**150**
	Laurentian-Acadian-Northeast Riverscour Vegetation	G925	0	0	6	31	0	29	20	2	**88**
	North Atlantic Coastal Interdunal Wetland	G752	0	0	0	1	15	10	0	0	**26**
	North Atlantic Coastal Plain Pondshore	G916	0	0	2	8	89	3	0	0	**102**
	North Atlantic Coastal Tidal Freshwater Marsh	G914	8	1	1	0	31	9	9	0	**59**
	North-Central & Northeastern Seep	G189	0	0	0	10	10	12	128	2	**162**
Temperate to Polar Bog & Fen	Central Appalachian-Northeast Alkaline Fen	G805	17	0	0	0	31	40	74	7	**169**
	Eastern North American Boreal-Subboreal Alkaline Fen	G804	14	7	10	40	6	56	10	42	**185**
	Eastern North American Boreal-Subboreal Bog & Acidic Fen	G1172	59	39	55	99	5	106	150	42	**555**
	North Atlantic Coastal Bog & Fen	G1171	2	0	0	9	110	2	7	0	**130**
Salt Marsh	Atlantic & Gulf Coastal Brackish Salt Marsh	G120	12	4	2	0	43	9	0	0	**70**
	Atlantic & Gulf Coastal High Salt Marsh	G121	0	47	61	0	25	26	0	0	**159**
	Atlantic & Gulf Coastal Low Salt Marsh	G122	0	19	0	0	25	37	0	0	**81**
Totals			**265**	**558**	**418**	**455**	**668**	**1059**	**1137**	**311**	**4871**

APPENDIX 4. Northeast Wetland Groups: Boxplots for Cover-weighted Mean C

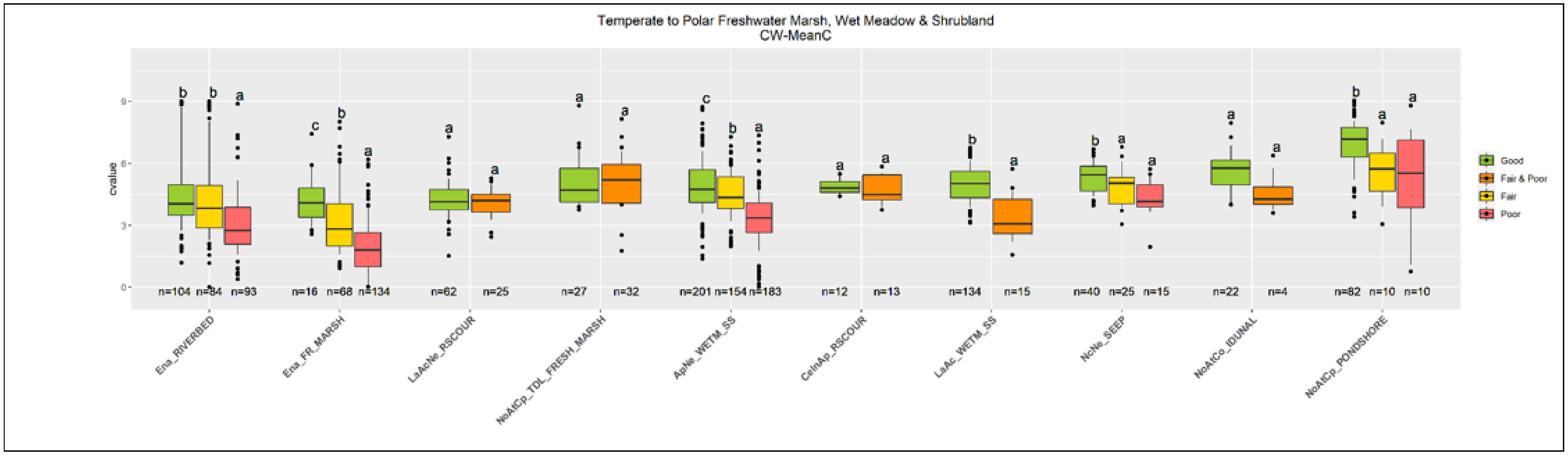
a) Flooded & Swamp Forests, b) Marsh, Wet Meadow and Shrubland, c) Bog and Fen, d) Salt Marsh. Wetland types are ordered by score of Good category. In each figure, the smaller case letters (a, b, c) indicate whether means between stressor categories are significantly different, i.e., categories with same letter do not have significantly different mean values.



G918 G667 G653 G673 G046 G902 G039 G045 G917

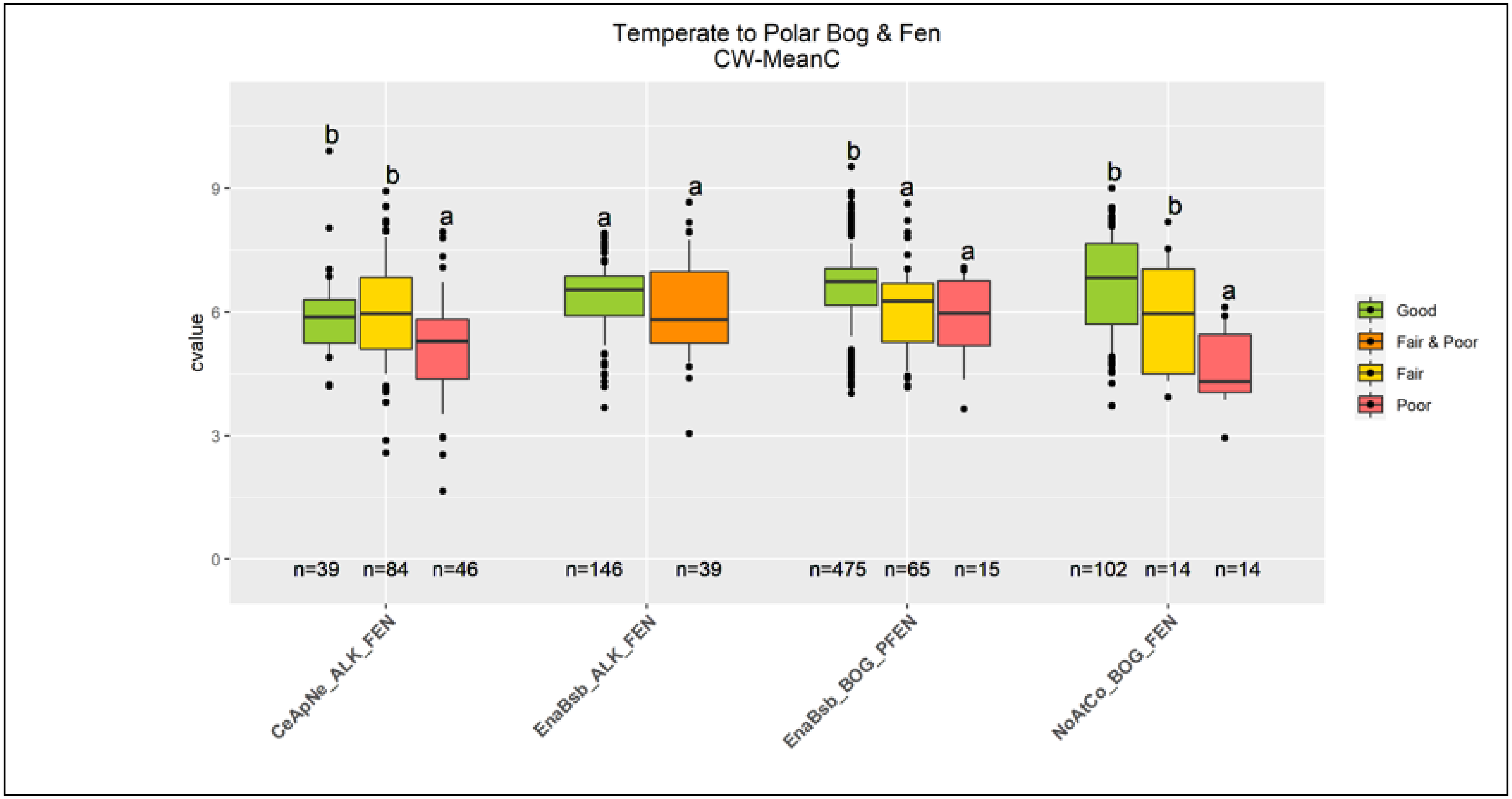
Alkaline Swamp and Floodplain Forest Acidic Swamp & Flatwoods

a)



G755 G125 G925 G914 G903 G753 G904 G189 G752 G916

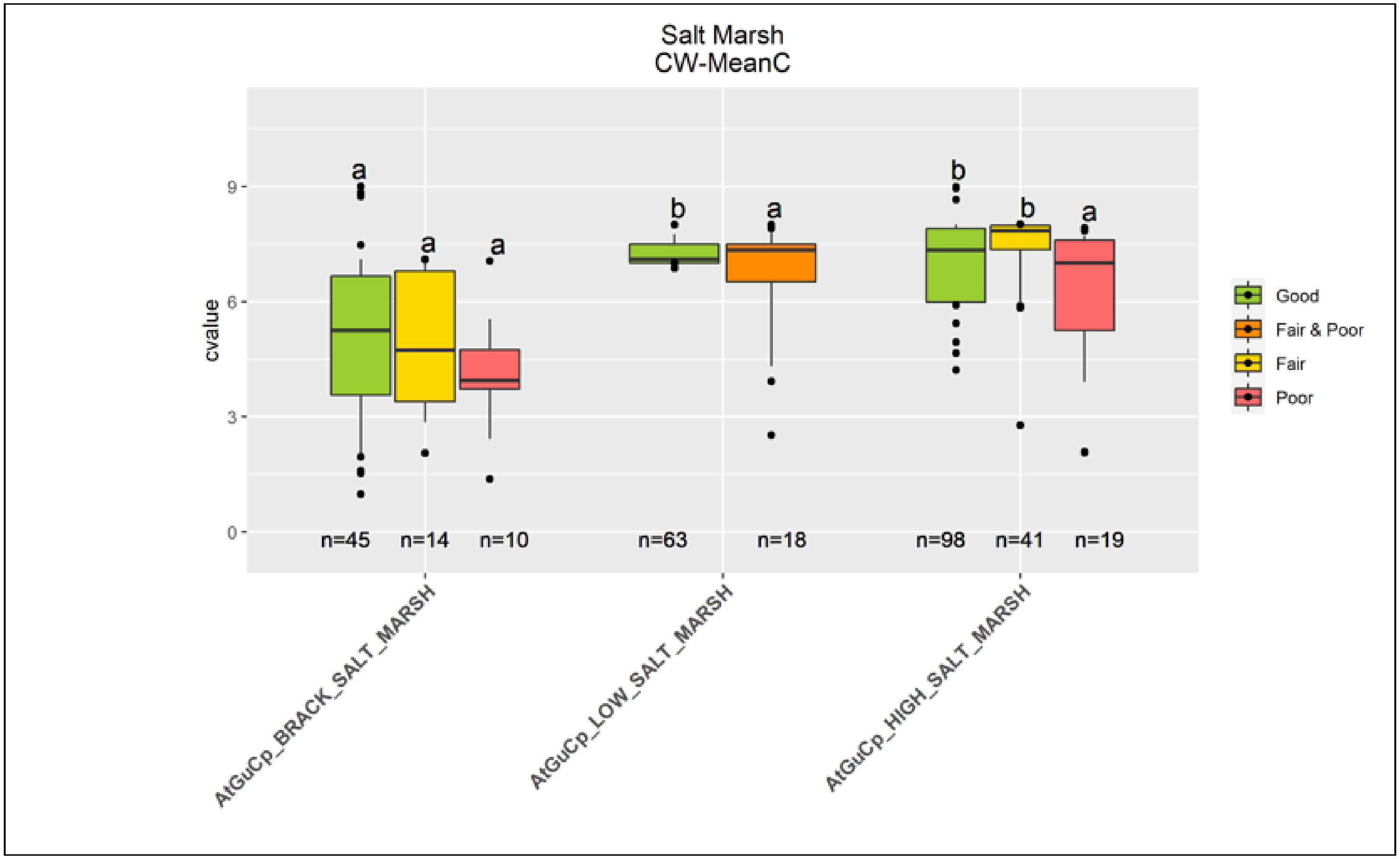
b)



G805 G804 G1172 G1171

Fen Bog

c)

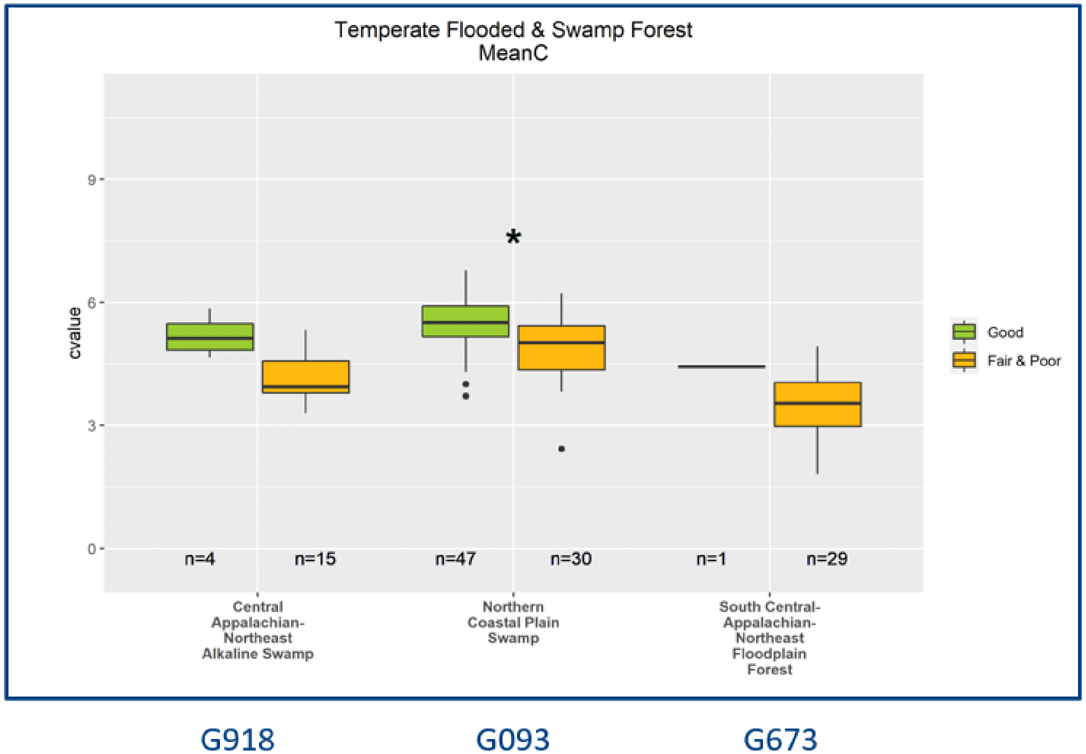


G120 Brackish | G122 Low | G121 High

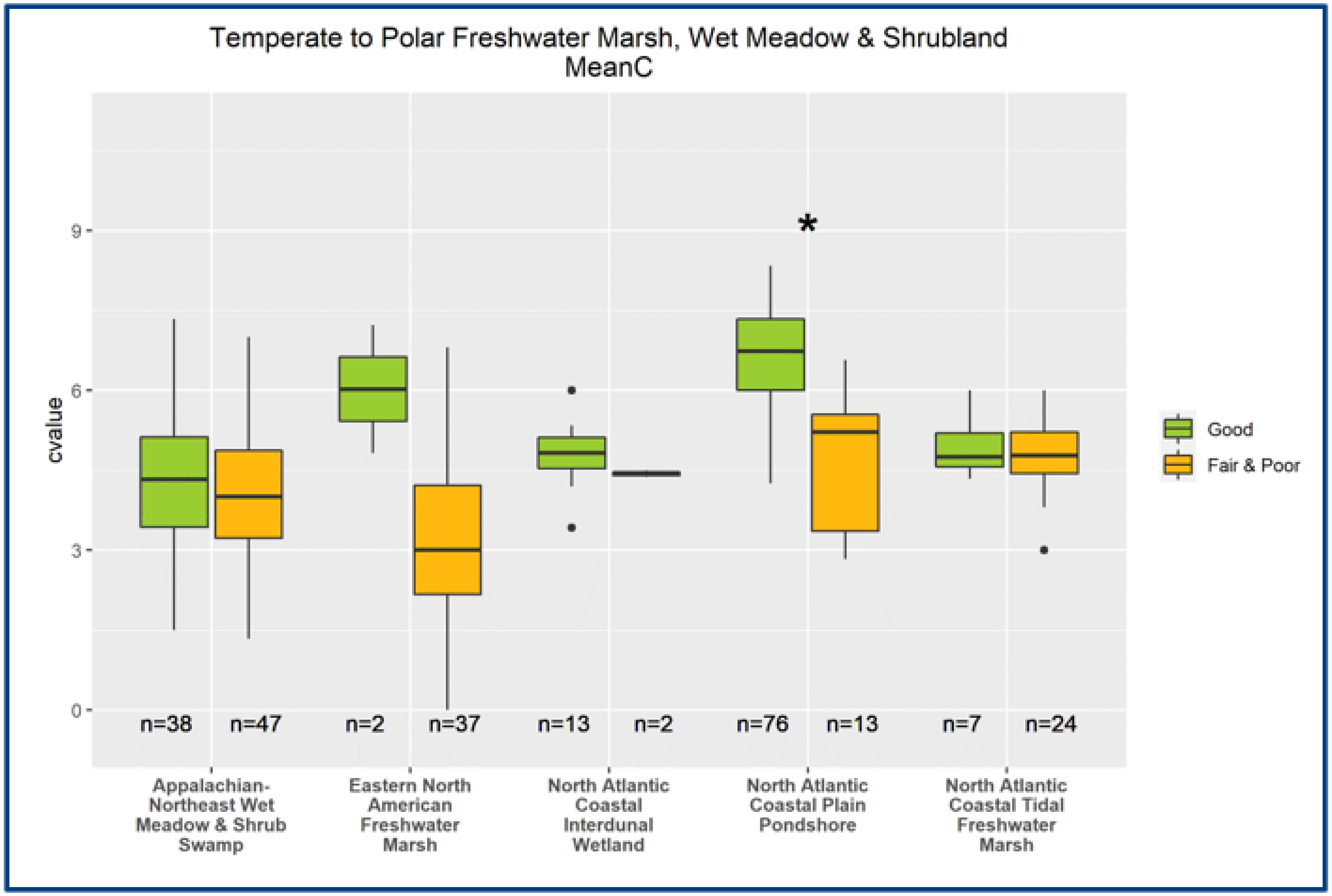
d)

APPENDIX 5. New Jersey Wetland Groups: Boxplots for Mean C

New Jersey results comparing Mean C values for the various wetlands, organized by Formation. a) Flooded & Swamp Forests, b) Marsh, Wet Meadow and Shrubland, c) Bog and Fen, d) Salt Marsh. In each figure, the * indicates whether the means between the stressor categories are significantly different, i.e., categories marked with an * have significantly different mean values at p <0.1.

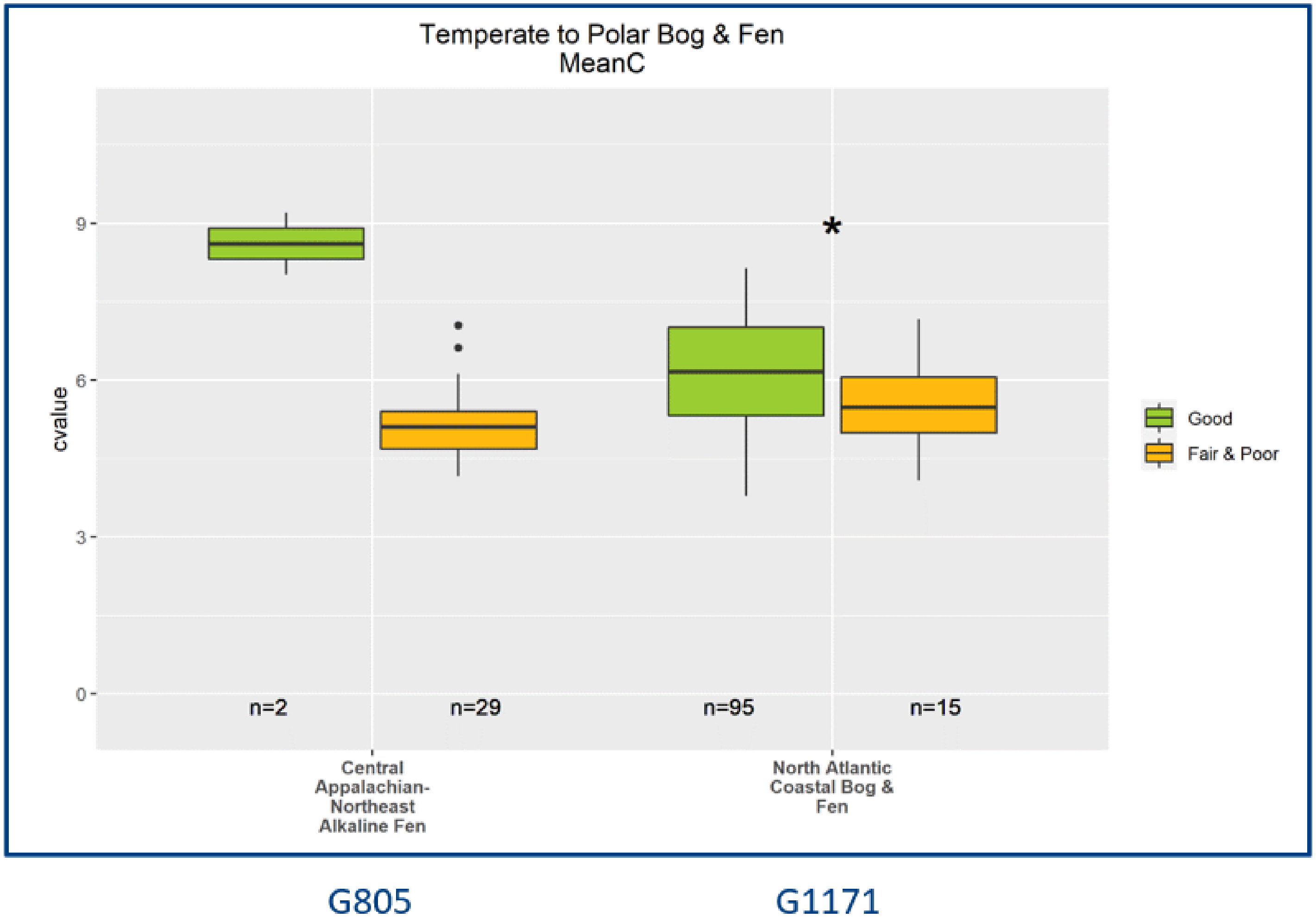


a)



G903 G125 G752 G916 G925

b)


Temperate to Polar Bog & Fen
MeanC
cvalue
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6
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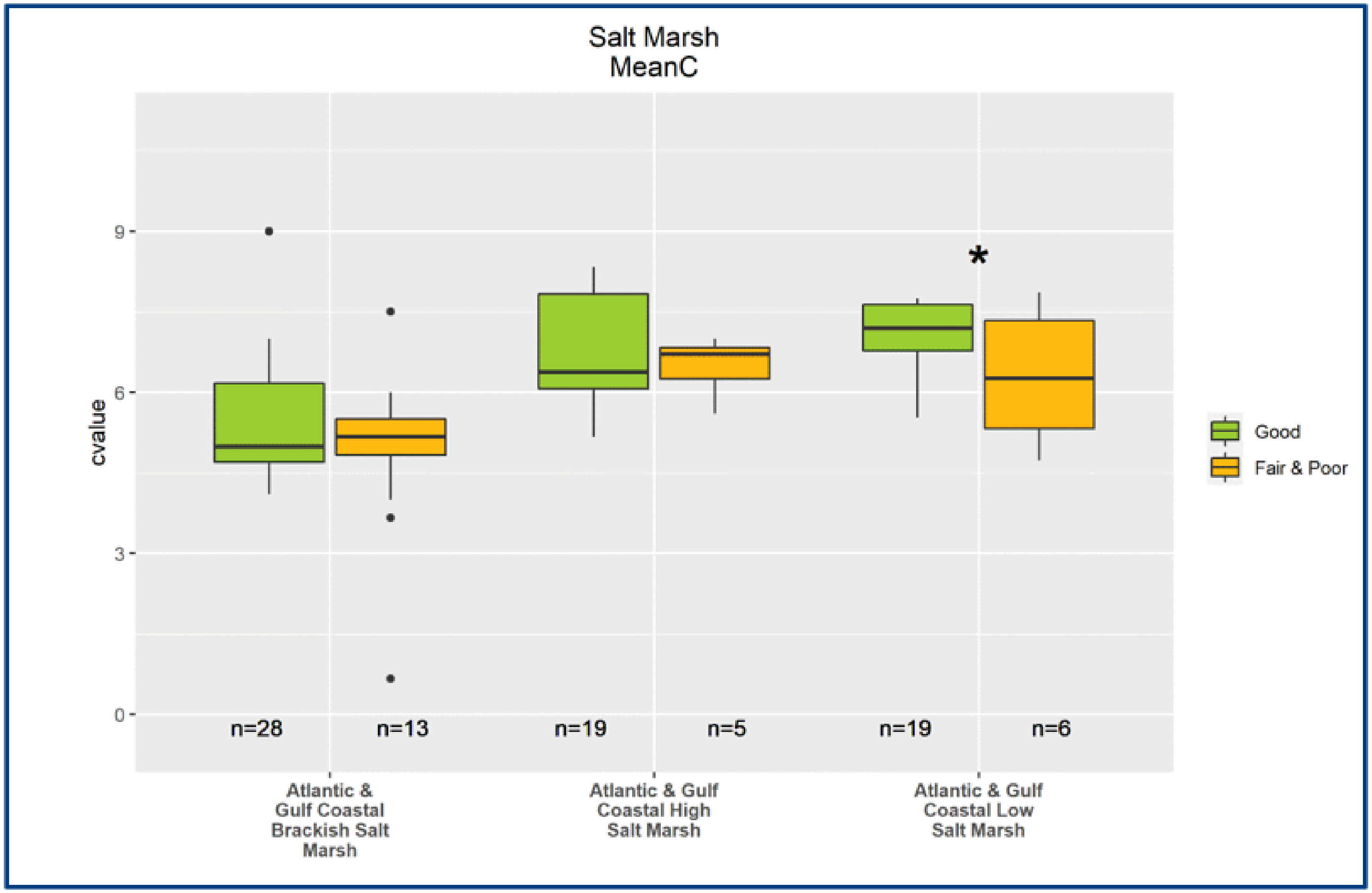
0
*
n=2
n=29
n=95
n=15
Central Appalachian-Northeast Alkaline Fen
North Atlantic Coastal Bog & Fen
Good
Fair & Poor
G805
G1171

c)



G120 G121 G122

d)

APPENDIX 6. Statistical Significance Values for Table 5.

Formation	Group Code	GROUP_NAME	MEANC Good	MEANC Fair	MEANC Poor	MEANC *Sig_ Diff*	MEANC *Pval*	CW-MeanC Good	CW-MeanC Fair	CW-MeanC Poor	CW-MeanC *Sig_ Diff*	CW-MeanC *Pval*
Flooded & Swamp Forest	G902	Central Appalachian-Northeast Acidic Swamp #	5.37	5.11	4.92	*	<0.001	5.32	5.04	3.31	*	<0.001
	G918	Central Appalachian-Northeast Alkaline Swamp #	4.66	4.41	4.06	*	<0.001	4.53	4.34	3.74	*	<0.001
	G917	Central Interior-Great Lakes Flatwoods & Swamp Forest	5.94	5.1		*	0.0134	6.09	5.18		*	0.009
	G045	Laurentian-Acadian Acidic Swamp	5.37	4.59	4.1	*	0.029	5.50	4.63	4.06	*	<0.001
	G046	Laurentian-Acadian Alkaline Swamp #	4.95	4.7	4.01	*	<0.001	4.92	4.6	3.68	*	0.006
	G653	Laurentian-Acadian Floodplain Forest #	4.43	4.12	3.68	*	<0.001	4.63	4.53	3.69	*	<0.001
	G667	Northeastern Forest Vernal Pool	4.62	4.31	4.2	NS	0.17	4.56	4.5	1.75	NS	0.350
	G039	Northern Coastal Plain Swamp #	5.35	4.81	4.75	*	<0.001	5.41	4.55	4.17	*	<0.001
	G673	Southcentral-Appalachian-Northeast Floodplain Forest #	4.46	4.03	3.59	*	<0.001	4.71	4.67	3.55	*	<0.001
Freshwater Marsh	G903	Appalachian-Northeast Wet Meadow & Shrub Swamp #	4.58	4.18	3.52	*	<0.001	4.85	4.44	3.22	*	<0.001
	G753	Central Interior-Appalachian Riverscour Barrens & Prairie	4.09	3.63	3.52	NS	0.115	4.88	4.88	4.37	NS	0.199
	G125	Eastern North American Freshwater Marsh #	4.33	3.47	2.99	*	<0.001	3.93	3.12	2	*	<0.001
	G755	Eastern North American Scrub & Herb Riverbed Wetland #	3.68	3.29	3.03	*	0.001	4.70	4.2	3.18	*	<0.001
	G904	Laurentian-Acadian Wet Meadow & Shrub Swamp	4.67	3.64	3.19	*	<0.001	5.00	3.87	3.01	*	<0.001
	G925	Laurentian-Acadian-Northeast Riverscour Vegetation	4.06	3.93	3.25	NS	0.451	4.23	4.22	3.66	NS	0.248
	G752	North Atlantic Coastal Interdunal Wetland	4.91	4.41	5.18	NS	0.394	5.61	4.04	6.36	NS	0.490
	G916	North Atlantic Coastal Plain Pondshore #	6.54	5.09	4.78	*	<0.001	6.90	5.62	5.15	*	<0.001
	G914	North Atlantic Coastal Tidal Freshwater Marsh	5.07	4.73	4.97	NS	0.2117	5.10	5.25	3.63	NS	0.106
	G189	North-Central & Northeastern Seep #	5.14	4.71	4.31	*	<0.001	5.36	4.84	4.29	*	<0.001
Bog & Fen	G805	Central Appalachian-Northeast Alkaline Fen #	5.57	5.11	4.92	*	0.048	5.92	6.01	5.13	*	0.007
	G804	Eastern North American Boreal-Subboreal Alkaline Fen	5.87	5.29	5.1	*	0.01	6.33	6.28	5.13	NS	0.210
	G1172	Eastern North American Boreal-Subboreal Bog & Acidic Fen #	6.36	5.85	5.59	*	<0.001	6.59	6.05	5.8	*	<0.001
	G1171	North Atlantic Coastal Bog & Fen #	6.12	5.06	4.96	*	<0.001	6.63	5.84	4.67	*	<0.001
Salt Marsh	G120	Atlantic & Gulf Coastal Brackish Salt Marsh #	5.21	4.7	4.61	NS	0.254	5.06	4.92	4.08	NS	0.362
	G121	Atlantic & Gulf Coastal High Salt Marsh #	6.57	6.93	6.27	NS	0.756	7.03	7.39	6.24	*	0.017
	G122	Atlantic & Gulf Coastal Low Salt Marsh	7.32	7.54	5.32	*	<0.001	7.27	7.47	5.4	*	<0.001

APPENDIX 7. Statistical Significance Values for Table 6.

Formation	Group Code	GROUP_NAME	MEAN C Good Northeast	MEAN C Good_NJ	MEAN C Diff	MEAN C pval	CWMEANC Good Northeast	CWMEANC Good_NJ	CWMEANC Diff	CWMEANC pval
Flooded & Swamp Forest	G918	Central Appalachian-Northeast Alkaline Swamp	4.66	5.19	0.53*	0.024	4.53	5.13	0.60*	0.045
	G039	Northern Coastal Plain Swamp	5.35	5.44	0.09	0.42	5.41	5.28	0.13	0.46
	G673	South Central Appalachian-Northeast Floodplain Forest	4.47	4.43	-		4.72	4.59	-	
Marsh, Wet Meadow & Shrubland	G903	Appalachian-Northeast Wet Meadow & Shrub Swamp	4.64	4.28	0.36*	0.015	4.9	4.69	0.2	0.27
	G125	Eastern North American Freshwater Marsh	4.48	6.02	1.54*	0.035	4.23	5.95	1.72	0.14
	G752	North Atlantic Coastal Interdunal Wetland	4.91	4.82	0.09	0.7	5.61	5.41	0.2	0.6
	G916	North Atlantic Coastal Plain Pondshore	6.54	6.62	0.09	0.58	6.9	6.99	0.08	0.66
	G914	North Atlantic Coastal Tidal Freshwater Marsh	5.07	4.94	0.13	0.73	5.1	5.55	0.45	0.34
Bog & Fen	G805	Central Appalachian-Northeast Alkaline Fen	5.58	8.61	3.04*	<0.001	5.92	8.75	2.84*	<0.001
	G1171	North Atlantic Coastal Bog & Fen	6.12	6.16	0.04	0.82	6.63	6.72	0.09	0.61
Salt Marsh	G120	Atlantic & Gulf Coastal Brackish Salt Marsh	5.21	5.45	0.24	0.38	5.06	5.61	0.55	0.19
	G121	Atlantic & Gulf Coastal High Salt Marsh	6.57	6.72	0.15	0.57	7.03	7.89	0.86*	0.011
	G122	Atlantic & Gulf Coastal Low Salt Marsh	7.32	7.11	0.21	0.16	7.27	7.18	0.09	0.32