White Paper 1-Executive Summary of Historical NYS Aquatic Plant Surveys and Plant Metrics

New York State is blessed with both an abundance of high quality and accessible lakes- more than 12,000 lakes, ponds and reservoirs larger than an acre in size- and an abundance of information about these lakes. Water quality data have been collected on more than 3000 lakes, ponds, and reservoirs through at least one local, regional or statewide monitoring program by agencies, academicians, and the public, nearly 1500 drinking water supplies are monitored by local and state agencies, and fisheries data are available on several thousand stocked lakes. While most of these lakes were sampled to evaluate lake water quality, trends and support of lake uses, these lakes were also surveyed for evaluating other lake conditions, including aquatic plant communities. However, most of the aquatic plant survey data from these programs has not been systematically evaluated.

White Paper 1 evaluates aquatic plant survey information on about 2000 lakes surveyed over nearly a century, with a focus on data collected in the 1920s and 1930s through the New York state Biological Surveys, in the 1980s through the Adirondack Lake Survey Corporation, and more recent data collected by the Adirondack Watershed Institute and other lakes using standardized survey methods referred to as PIRTRAM. These data, particularly those collected by several consultants in about 50 lakes using PIRTRAM surveys, were also used to identify and evaluate several lake metrics, and to propose modifications to these metrics that can be used to conduct aquatic life assessments, evaluate the impact or need for management, and determine the impact of invasive species introductions.

This White Paper was separated into seven smaller White Papers, with accompanying data files and an index of tables and figures available to facilitate further review, refinement and discussion:

White Paper 1A- Summary of Major NYS Aquatic Plant Surveys since the mid-1920s
White Paper 1B- Elements of Aquatic Plant Surveys
White Paper 1C- Tools Used to Evaluate NYS Aquatic Plant Survey Data
White Paper 1D- Evaluation of Species Richness in NYS Lakes
White Paper 1E- Evaluation of Plant Lists and Individual Plant Species in NYS Lakes
White Paper 1F- Evaluation of Coefficients of Conservatism in NYS Lakes
White Paper 1G- Evaluation of Floristic Quality in NYS Lakes

This Executive Summary provides bullet point summaries of the most important findings and recommendations in each White Paper, as well as indices identifying the pertinent section discussing each bullet point. Some additional notes to be considered when reviewing these summaries:

1. Survey data for all but the PIRTRAM lakes were hand copied from paper or on-line PDF reports, and therefore some transcription errors may have occurred.
2. Although granular aquatic plant survey data were available for some PIRTRAM lakes for many consecutive years, frequency-corrected and abundance-corrected assessments were not conducted for all lakes each year (i.e. each lake-year), since the key findings for each evaluation were apparent using only a subset of these lake-years data. However, at least one year for each PIRTRAM lake was included in these analyses.
3. Several of the tools used in these White Papers and proposed modifications to traditional species richness calculations and floristic quality indices are unique to these White Papers

and therefore should be evaluated by others for future consideration. **As such, these White Papers should be considered working drafts and each may be further refined pending input from other researchers, receipt of new data, or additional analyses**. Data files and other information for these lakes are available from the author of these White Papers.

4. The author wishes to thank Chris Doyle (previously SOLitude Lake Management), Bob Johnson (Racine-Johnson Aquatic Ecologists), and Larry Eichler (retired DFWI) for providing PIRTRAM data and support, the Adirondack Watershed Institute (AWI) for on-line availability of their surveys, and NYSFOLA for hosting these White Papers.

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November 2021, November 2022

White Paper 1A- Summary of Major NYS Aquatic Plant Surveys since the mid 1920s

- Although more than 3000 lakes, ponds and reservoirs have been sampled in New York state, many of these waterbodies were not surveyed for aquatic plants, at least in sufficient detail to evaluate aquatic plant communities in these lakes (WP1A, Section 1).
- Four large scale monitoring efforts, however, included aquatic plant surveys sharing enough common characteristics to afford a long-term evaluation of aquatic plant communities and their associated changes, as well as providing a basis for evaluating several aquatic plant community measures. These four monitoring efforts spanned nearly 100 years, and involved nearly 2000 ponded waters, including many lakes surveyed in multiple programs over this time. These programs were as follows; the size and distribution of the surveyed lakes appear to represent a good cross-section of the size and geographic distribution of New York state lakes overall, particularly those that are most heavily used and under threat from invasion by invasive species (WP1A, Section 2):
    - The New York State Biological Surveys (NYS BioSurveys) from 1926 to 1938 involved more than 300 lakes throughout the state surveyed by the Conservation Department one time with submergent, floating leaf and emergent plants identified to species level and relative abundance of each plant reported. Individual survey points or survey site densities (the number of survey points within a defined littoral area) were not reported, so site-level corrections for plant frequency or abundance are not possible (WP1A, Section 2.1).
    - The Adirondack Lake Survey Corporation (ALSC) study of more than 1500 Adirondack and high elevation downstate lakes from 1984 to 1987 surveyed for aquatic plants in all habitats. Plants were identified to genera, but relative abundance, individual survey point data, and survey site densities were not reported. Therefore these data cannot be corrected for plant frequency or abundance. (WP1A, Section 2.2)
    - PIRTRAM aquatic plant surveys of about 50 lakes surveyed, often over several years and for some lakes annually for more than a decade, from the late 1990s to the late 2010s, by New York state lake managers from Allied Biological, Inc. (now SOLitude Lake Management), Racine-Johnson Aquatic Ecologists, Darrin Freshwater Institute, and the NYSDEC (usually DOW in Albany or DFW in Region 1, including lake association surveys overseen by the NYSDEC). All surveys included granular survey site data (information for each plant at each site) from sites distributed throughout the littoral zone, generally using overlay grids roughly consistent with NYSDEC permitting requirements. Submergent plants were generally identified to species level and floating leaf and emergent plants were generally identified to genera, and enumerated using relative abundance categories. These lakes were distributed throughout the state, and broadly follow the geographic and size distribution of “major” lakes throughout the state, but generally were limited to lakes subject to or considered for plant management actions (WP1A, Section 2.3).

- The Adirondack Watershed Institute (AWI) conducted aquatic plant surveys on nearly 100 lakes, primarily moderate to large lakes with boat access (private or public) from 2012 to 2016. These lakes were surveyed at varying times with combinations of "serpentine" rake toss samples and visual assessments of more concentrated plant beds, with single relative abundance values assigned to each plant observed in both categories. Therefore, while the former (serpentine rake tosses) can be compared directly to PIRTRAM data if assumed to represent the entire littoral zone, the latter (plant bed evaluations) assume a single relative abundance assignment for each plant for the entire plant bed. While this combination of survey sites allows for evaluation of species richness and perhaps individual plants or plant lists, it is less useful in evaluating floristic quality when corrected for frequency or abundance (WP1A, Section 2.4).

- These programs can be briefly characterized as seen in Table 3.1 from White Paper 1A.

WP1A Table 3.1: Summary of Historical Aquatic Plant Survey Programs in New York State

Program	Years	# Lakes	Spatial Extent	Siting Method	Plant Collection	Evaluation Abundance	Plant ID	Habitats
NYS BioSurvey	1926-38	305	Unkn	Unkn	Rake toss, visual	Relative abundance	Species	All
ALSC	1984-87	1559	Unkn	Unkn	Unkn	None	Genera	All
PIRTRAM	1997-2019+	50%	Entire littoral	Point intercept	Rake toss, visual	Relative abundance or frequency	Species*	Mostly floating & submergent
AWI	2012-16	91	Entire littoral	Serpentine search	Rake toss, visual	Relative abundance	Species*	Mostly floating & submergent

+ PIRTRAM surveys mostly between 2006 and 2012
% multiple years of surveys conducted on some lakes (i.e. multiple lake-years)
*see White Paper 1B for specifics regarding species level v. genera level IDs for PIRTRAM and AWI lakes

The various permutations of each monitoring program summarized in Table 3.1 and White Paper 1A allow for the use of these data in some of the following White Papers (WP1A, Section 3):

- White Paper 1D (Species Richness)- NYS BioSurvey data, PIRTRAM data, AWI data
- White Paper 1E (Individual Plants and Plants Lists)- all programs, with all long-term trend evaluations involving NYS BioSurvey lakes data
- White Paper 1F (Coefficients of Conservatism, or C Values) and White Paper 1G (Floristic Quality Indices)- NYS BioSurvey, PIRTRAM, and AWI data can be used for generating uncorrected C values and FQI values, but only PIRTRAM data can be used for generating C and FQI values corrected for plant frequency and/or plant abundance

White Paper 1B- Elements of Aquatic Plant Surveys

- Comprehensive aquatic plant surveys must address most of the elements described below; the four major NYS monitoring programs described in White Paper 1A satisfy many of these elements in similar ways:
  - *Spatial extent*- the PIRTRAM and AWI surveys focus on most of, to the entirety of, the littoral zone (defined in White Paper 1C). While documentation of the spatial extent of the NYS BioSurveys and ALSC program aquatic plant surveys is not available, it is assumed that these surveys also focused of the littoral zone (WP1B, Section 1.1).
  - *Methods for determining survey locations*- PIRTRAM lakes are surveyed using overlay grids defining point-intercept sites, with some limited visual observations for some floating leaf or emergent plants. AWI surveys include both visual observations and random points derived from serpentine boat surveying. Methods for determining survey locations within NYS BioSurvey and ALSC lakes are no longer available (WP1B, Section 1.2).
  - *Plant collection methods*- two sided rakes were the primary plant collection method used in the PIRTRAM and AWI surveys, supplemented by some combination of nets, hand collections, and (for identifications not requiring voucher specimen) visual observations. Plant collection methods for the NYS BioSurvey and ALSC lakes are not known, but given that all habitats were well represented in these surveys, it is assumed that a deep retrieval tool (like a two sided rake) was used, along with other surface methods (WP1B, Section 1.3).
  - *Plant frequency and abundance*- plant frequency- defined here as the number of surveyed sites within the lake containing each plant- was reported only in lakes with plant survey results reported for all individual sites. This includes all of the PIRTRAM lakes, with limited results from AWI lakes. Plant abundance “scores” were defined on a lakewide basis for NYS BioSurvey lakes, and at individual sites within surveyed lakes through PIRTRAM and incompletely in the AWI lakes. Plant abundance scales appeared to be comparable between these programs, broadly consistent with the “scores” developed by the US Army Corps of Engineers and Cornell University (WP1B, Section 1.4).
  - *Plant identifications*- aquatic plant identification expertise resided in the sampling teams or associated colleagues for all of the monitoring programs highlighted in White Paper 1B, with more recent surveys using Crowe and Hellquist to support these identifications. It is assumed, but not verifiable, that historical programs (NYS BioSurvey and ALSC) used equivalent identification keys, and that plant identifications for all programs were accurate and comparable. Species level identification was provided for all NYS BioSurvey lakes, and for most submergent macrophytes found in the PIRTRAM and AWI surveys. Plants were identified to genera in the ALSC program, and in most submergent macroalgae and most floating leaf and emergent macrophytes in the PIRTRAM and AWI programs (WP1B, Section 1.5).

- *Other factors*- these include timing, plasticity, and plant habitats (WP1B, Section 1.6).
    - *Timing*- All of the surveys cited in White Paper 1A were conducted in late summer. This optimized plant frequency and abundance data, but may have impacted the ability of surveyors to find early season plants.
    - *Plasticity*- This is addressed in these surveys by both assigning a single species or genera label to all indistinguishable species (thereby slightly reducing species richness)- such as *Elodea canadensis* and *Elodea nuttallii*, and by conducting all surveys within a narrow seasonal timeframe.
    - *Aquatic plant habitats*- The results from the NYS BioSurvey and ALSC lakes were reported as documented- all habitats identified to species level in the NYS BioSurvey and to genera level in the ALSC. Emergent plants were incompletely assessed in the PIRTRAM and AWI surveys, and therefore were not included in most analyses. Since some floating leaf macrophytes and submergent macroalga were reported only to genera in PIRTRAM and AWI surveys, the NYS BioSurvey plants were "corrected" to genera only when results were compared across programs.
- The PIRTRAM program elements outlined in White Paper 1B include many of the aquatic plant survey elements that serve to best evaluate species richness (White Paper 1D), individual plants and plant lists (White Paper 1E), and floristic quality (White Paper 1F), and were at one time required by the NYSDEC and other agencies to use some aquatic plant management actions. However, some of the higher-level identifications found in the NYS BioSurvey could also be included in the PIRTRAM program elements if resources, including aquatic plant identification expertise, permit these enhancements. Other aquatic plant monitoring elements are discussed in the aforementioned White Papers (WP1B, Section 2).

White Paper 1C- Tools Used to Evaluate NYS Aquatic Plant Survey Data

- Several tools have been developed for evaluating species richness (White Paper 1D), generating plant lists and evaluating individual plants (White Paper 1E), coefficients of conservatism (White Paper 1F), and floristic quality (White Paper 1G). The tools used to evaluate species richness are introduced in White Paper 1C, and the development and application of these tools are explored in more detail in the aforementioned White Papers for New York state lakes (WP1C, Section 2.1).
- Species richness and Coefficients of Conservatism tools (WP1C, Section 2; WP1D, Section 3, WPID Sections 2 and 3):
    - Recommended survey site densities- to minimize large differences in survey site densities between surveyed lakes and to facilitate comparisons within survey programs and between programs over time, a standardized survey site density is recommended. Based on existing PIRTRAM surveys, achievable survey sizes, historical NYSDEC survey requirements, and the spatial distribution of rake toss grids, White Paper 1C recommends survey sites at an actual or projected density of 1 site per littoral hectare. A much "tighter" survey site density of 4 sites per littoral acre can be used to evaluate maximum species richness, but this density is realistically not achievable given the very high resource demands in such a survey (WP1C, Section 2.2-2.3).
    - Projecting species richness- several tools are introduced and deployed in estimating projected species richness (pSR) from values observed in actual surveyed sites (= observed species richness, or oSR). These include subsampling methods involving modified bootstrap analysis to estimate cumulative species richness at various survey site intervals, and ANOVA analyses to determine variance associated with each cumulative species richness estimates. The same tools are also used to determine the optimal number of survey sites and computational runs needed to reach stability in calculating species richness (using an inflection point that represents the number of sampling sites required to shift from a high degree of change (in species richness) per unit effort to a low degree in change in species richness). This process can be used to define the optimal number of survey sites to conduct efficient surveys (finding nearly all plant species with a minimal survey effort), to find AIS or protected plants, or other objectives, discussed in White Papers 1D, 1E and 1F (WP1C, Section 2.4-2.5)- note- computational run analysis may not be necessary to evaluate oSR, pSR.
    - Projecting maximum species richness- the tools described above are used to develop regressions between survey site densities and estimated cumulative species richness. These regressions can be extrapolated to estimate pSR associated with the recommended survey site density of 1 site per littoral hectare. The same tools can also be used to estimate the smallest number of survey sites (and associated cumulative species richness estimates for each site) required to accurately calculate pSR (WP1C, Section 2.5 through 2.8).
- Coefficients of Conservatism Only Tools

- The traditional C value system (C_{ny}) suffers from several issues, related to uncertainties in plant identification associated with incomplete collections and expertise, inability to observe plants *in situ*, high plasticity, inconsistencies between historical programs, merging of all exotic species into a single C value, and lack of corrections for plant frequency or abundance. Many of these issues can be addressed by adopting a modified C value (C_m) system that ranges from -5 to 5, with all exotic species assigned differing negative values based on invasiveness, nuisance species assigned a value of +1, protected plants assigned a value of +5, and all other plants assigned a value of +3 (WP1C, Section 3.2, WP1F, Section 3).
- Whether analysts accept or reject the recommendation to switch from the New York C_{ny} value system to a modified C_m value system, the computed mean C values are likely more accurate when corrected for plant frequency, defined as the number or percentage of surveyed sites with specific individual plants present. Frequency corrections for mean C_m can be done on an absolute or relative sense, as discussed at length in White Paper 1F. Absolute frequency corrections are easily applied to subsampled data- that is, frequency corrections of cumulative mean C_m values for each survey site density- and are recommended for use by analysts, although (as discussed in White Paper 1G) frequency-corrected mean C_m and FQI scoring criteria have not been established
- White Paper 1F also provides information about abundance corrections for mean C_m values, also available on an absolute or relative basis. And as with frequency corrections, abundance corrections are best applied to subsampled data required to develop mean C_m projections (as discussed above). The resulting scoring criteria for abundance-corrected mean C_m values and associated FQI values require further assumptions about the optimal amount of aquatic plants for a lake. Although these assumptions are discussed and applied in White Paper 1F and 1G, additional work may be needed in this area.

- Tools used to generate plant lists and floristic quality component (species richness and C values) and scores are discussed at length within White Paper 1D (Species Richness), White Paper 1E (plant lists and individual plants) and White Paper 1F (Coefficients of Conservatism). However, the same subsampling and bootstrapping methods summarized above used for evaluating and projecting cumulative species richness at any survey site density can also be used for evaluating and projecting coefficients of conservatism.

White Paper 1D- Evaluation of Species Richness in NYS Lakes

1. Species richness in historical NYS monitoring programs (WP1D, Section 1)
   - Species richness is one component of floristic quality evaluations, based on the equation $FQI = \bar{C} \; x \; \sqrt{N}$, *and* $\bar{C} = \Sigma C \,/\, N$; where N = number of unique plant species in a lake (= species richness)
   - Species richness is defined as the number of unique aquatic plant species in a lake survey.
   - Observed species richness (oSR) was highest in lakes sampled in the NYS BioSurveys from the 1920s-30s, and lowest in lakes surveyed in the more contemporary programs (WP1D, Section 2).
   - As noted in White Papers 1A through 1C, some of this difference reflects species-level identifications in all habitats in the NYS BioSurveys, but species-level identifications only in (most) submergent macrophytes, and not submergent macroalgae or floating leaf and emergent macrophytes in the PIRTRAM and AWI programs. However, even when the NYS BioSurveys results were "corrected" to document the same identification levels as these contemporary programs, species richness was still highest in the 1920s-30, whether inside or outside the Adirondacks (WP1D, Section 2.1).
   - Annual variability in oSR, independent of management-driven change, was 10-30% (WP1D, Section 2.2);
2. Long term changes in species richness
   - Long-term change in oSR exceeded annual variability, perhaps several standard deviations higher, outside the Adirondacks from the 1920s to the present. This change was apparent whether looking at all lakes surveyed in each program, or just those lakes commonly surveyed in multiple programs (over time) (WP1D, Section 2.3, 2.5).
   - Long-term changes in observed genera richness (oGR) from the NYS BioSurvey to the ALSC (and in oSR from the 1920s-30s to the present AWI surveys) were in the range of annual variability, and did not appear to be influenced significantly by AIS introduction or acidification (WP1D, Section 2.3, 2.5).
   - The difference between lakes inside and outside the Adirondacks is likely consistent with increasing shoreline and lake usage, eutrophication, and a higher rate of AIS introduction outside the Adirondack Park than in lakes inside the Park (WP1D, Section 2.3, 2.5).
3. Projected species richness and sampling needed to estimate pSR (WP1D, Section 3)
   - Using methods introduced in White Paper 1C, projected species richness (pSR) estimates maximum species richness based on a standardized high (but achievable) survey site density of 1 site per littoral hectare, and built off subsampled regressions of projected oSR data. pSR is preferred to oSR, given many issues with generating an accurate oSR, but requires granular survey site data (presence or relative abundance data from each survey site) available only in the PIRTRAM lakes (WP1D, Section 3.1).
   - PIRTRAM data shows a very strong correlation between pSR and oSR, with pSR generally exceeding within 1% of oSR and most of the deviation between oSR and pSR associated with very high survey site densities (relative to a standardized 1 site per littoral hectare). Given the abundance of oSR data, a strong overall relationship between oSR and pSR, and the lack of granular data to support converting oSR to pSR data, oSR data

are used for timeline comparisons for individual lakes if pSR data are not available (WP1D, Section 3.2-3.4).

- **Truncated surveys, involving as few as 15 sites for small lakes and 25 sites for large lakes, may be sufficient to calculated pSR within 5% of the actual value**, with a relatively low variance. Note that these sites should be well distributed throughout the littoral zone to improve accuracy, and that larger survey sizes (survey site densities) may be needed to meet aquatic plant survey objectives outlined in White Papers 1E, 1F and 1G. These truncated surveys appear to be sufficient to find 80-100% of all plants captured using a standardized survey site density of 1 site per littoral hectare (WP1D, Section 4).
- Aquatic plant surveys for which the standardized 1 site per littoral hectare density results in fewer than 15-25 sites should compute species richness from this density, while large lakes should project species richness (using granular survey site data) from this density.

4. Factors influencing species richness; note that even those findings supporting existing expectations would benefit from further evaluation with larger datasets (WP1D, Section 5)
    - **Site frequency and number of survey sites** increase species richness, even when the size of the littoral area (or lake area) is held static in NYS lakes. This is due to the higher number of opportunities (survey sites) for finding additional plant species associated with higher site frequency. This finding forms the basis for recommending a standardized survey site density (= 1 sites per littoral hectare) for calculating pSR (WP1D, Section 5.2).
    - Species richness appears to increase with increasing **littoral area** in NYS lakes, especially when considering lakes with similar lake area and trophic status. However, pSR does not appear to increase with increasing lake area when littoral areas do not change. This is as expected and consistent with an increase in species richness due to more opportunities (site frequency above, littoral area here) to find additional plants (WP1D, Section 5.3).
    - NYS lakes with lower **lake productivity**- oligotrophic and mesotrophic- appear to exhibit higher species richness, as expected given the relationship between trophic state and water transparency, water transparency and selectivity for AIS, and AIS presence and reduced space for native plants (see White Paper 1E) (WP1D, Section 5.4).
    - **Latitude** does not appear to significantly influence species richness, at least in the range of latitudes found in northern and southern NYS lakes (WP1D, Section 5.5).
    - **Public access** does not appear to strongly influence species richness, at least in the AWI and PIRTRAM lakes, although transport of plants, particularly AIS, through public access points may influence the frequency and abundance of individual species (discussed in White Paper 1E) and floristic quality (discussed in White Paper 1F) (WP1D, Section 5.6).
    - Likewise, the **presence of AIS** does not appear to strongly influence species richness in AWI or PIRTRAM lakes, consistent with the public access findings cited above. However, **high frequency or dominance by AIS** may exert a stronger influence on individual plants (White Paper 1E) or floristic quality (White Paper 1F) (WP1D, Section 5.7).

- **Plant management** may slightly increase species richness, but any increases outside the range of normal variability may be limited to smaller lakes with significant AIS populations and suppression of native plant communities (in other words, lakes with low species richness prior to management). Unmanaged lakes appear to have higher species richness, but this may be a consequence of species richness (those with higher richness are less likely to be managed) than a consequence of management (WP1D, Section 5.8).

5. There are no well defined measures exist for using species richness (oSR or pSR) for evaluating the quality of the aquatic plant community or aquatic life, or even developing a species richness score. Such scores could be developed by either comparing lakes to statistical (regressed mean values and some measure of variance) ranges of species richness values relative to littoral area, including:

    - Representative cross sections of lakes, such as surveyed through the NYS BioSurvey, as seen in White Paper 1D, Table 6.3
    - Reference lakes (not yet assigned) to either existing NYS BioSurvey or AWI lakes, or to-be surveyed lakes using monitoring strategies outlined in these White Papers

    WP1D Table 6.3- Observed Species Richness (oSR) Scores Based on Figure 6.3

Lake Area	Expected oSR	Poor oSR	Fair oSR	Good oSR
0-10 ac	11.6	< 4.9	4.9 - 18.2	> 18.2
10-25 ac	14.6	< 6.8	6.8 - 22.4	> 22.4
25-50 ac	16.4	< 5.6	5.6 - 27.2	> 27.2
50-100 ac	17.7	< 6.7	6.7 - 28.7	> 28.7
100-200 ac	18.7	< 6.6	6.6 - 30.8	> 30.8
200-400 ac	19.5	< 7.7	7.7 - 31.2	> 31.2
400-600 ac	20.2	< 6.4	6.4 – 34.0	> 34.0
600-2000 ac	20.7	< 5.6	5.6 - 35.9	> 35.9
>2000 ac	21.3	< 9.3	9.3 - 33.2	> 33.2

    However, since it is not known if the historical NYS BioSurvey lakes are typical of minimally impacted reference lakes, and since the existing NYS BioSurvey and AWI lakes cannot be used to calculate projected species richness (pSR) values at a standardized survey site density of 1 site per littoral hectare (due to the lack of granular survey site data), **it is recommended that species richness-specific metrics be developed in the future using reference waterbodies. (**WP1D, Section 6)

6. Species richness scores would be defined by values relative to the expected species richness based on these regressions and either standard deviations or prediction intervals- for example, for reference lakes, “very good” species richness values would exceed the regression value by at least one standard deviation or be above the upper (50%) prediction interval (WP1D, Section 6.3-6.4).

White Paper 1E- Evaluation of Plant Lists and Individual Plant Species in NYS Lakes

1. Plant lists of most frequent or most abundant individual species or (in ALSC lakes) genera. Detailed summaries are provided in White Paper 1E, Section 5.
    a. The NYS BioSurvey lakes surveyed in the 1920s and 1920s were largely dominated by emergent and some floating leaf plants inside the Adirondack Park, particularly yellow water lily, bulrush and spikerush, and water quality-sensitive submergent plants (ribbon leaf and floating leaf pondweed) were found in many lakes. This may reflect the relative lack of shoreline development and good water quality characteristics in these lakes. Outside the Adirondacks, submergent plants were as common as plants in other habitats, particularly those submergent plants that can thrive in lakes with poor water quality (coontail, and slender naiad) and those plants also common to the Adirondacks. Exotic plants were very uncommon, and were often more abundant than frequent, including significant beds but not isolated plants. Nuisance native plants were often more abundant than common outside the Park, but not inside the Adirondacks. Small pondweed was the only plant that was more frequent than abundant throughout the state, indicating isolated plants rather than plant beds (WP1E, Section 1).
    b. The ALSC lakes surveyed in the mid-1980s were dominated by emergent and floating leaf genera in both the Adirondacks and downstate region (particularly yellow water lily, sedges, and bur reed), but evaluation of the sensitive of these plants to water quality conditions and lake acidification is limited by the lack of species-level identifications for these plants. There was only some overlap in the most commonly reported plants in the Adirondacks compared to the non-Adirondack lakes in the ALSC, with only *Potamogeton* and *Nuphar* among the (five) most common plants in both regions. Bladderwort was more common in the Adirondacks, while milfoil (presumably Eurasian watermilfoil) and cattails more common in the downstate region (WP1E, Section 2).
    c. Submergent and floating leaf plants dominated the PIRTRAM surveys, likely due to the exclusion of emergent plants in many of these surveys. Invasive plants, particularly Eurasian watermilfoil, and nuisance native plants, particularly coontail, white water lily, common waterweed, and muskgrass, were among the most common and most abundant plants. Regional invasive plants- fanwort, variable watermilfoil, water chestnut and brittle naiad, were more likely to be abundant than common, perhaps due to the regional infestation patterns for these plants. These findings may have been a consequence of surveying lakes with excessive invasive or native plant growth, but also may indicate the susceptibility of these lakes to AIS and nuisance native plants (WP1E, Section 3).
    d. Emergent and floating leaf plants, particularly bur reed, water lilies, and watershield, identified only to genera, were the most common and abundant plants in the AWI surveys. Pondweeds and bladderwort were the most reported submergent plants. Variable leaf watermilfoil was the most common and abundant invasive plant, and with Eurasian watermilfoil, was more abundant than

common. Eelgrass, quillwort, and variable pondweed were more common than abundant (WP1E, Section 4).

2. Long term changes in plant lists and individual species, looking at both regional changes (in all lakes in historical and contemporary programs within a region) and changes in lakes commonly surveyed in both. Detailed summaries are provided in White Paper 1E, Section 5.
    a. Whether evaluating long-term changes in all lakes surveyed in the NYS BioSurvey and ALSC or just those lakes commonly surveyed in both programs, emergent and floating leaf genera increased from the 1920s-30s to the 1980s, while submergent genera decreased. The latter may be in response to lake acidification over this period, although other factors (lakeshore development, increasing use, climate change) may have influenced this change. Shoreline development may have more greatly affected the downstate ALSC lakes than the Adirondack lakes (WP1E, Sections 1, 2, and 5).
    b. By far the plants increasing the most from the 1920s-30s NYS BioSurvey to the present day PIRTRAM, whether considering frequency or abundance, were invasive plants- Eurasian watermilfoil, curly leafed pondweed, and brittle naiad. Starry stonewort and hydrilla have become more significant in recent years. Some of the plants that decreased in frequency or abundance over this period are water quality sensitive plants, protected plants, or "lesser" species within genera dominated by invasive plants (for example, some of the small native milfoils). Emergent plants appeared to decrease significantly between these surveys, particularly outside the Adirondacks, but this may instead demonstrate that emergent plants were under-reported in the PIRTRAM surveys (WP1E, Sections 1, 3 and 5).
    c. There was a relatively even balance of increasing and decreasing plant species (frequency and abundance) from the 1920s-30s Adirondack lakes to the present AWI surveys, but only when considering all lakes in both datasets. When considering only the 44 lakes included in both surveys, far more plants decreased than increased in frequency or abundance over this period, with the two exotic milfoils and other exotic and nuisance plants among the few plants that increased. This may have significant implications for future spread of regional or new invasive plants into the Adirondacks, since these data suggest AIS can grow explosively and crowd out native plants, including an apparent loss of protected plants. Bur reed increased in frequency, but not abundance, but it is not known if this is an artifact of the different methodologies in the surveys (WP1E, Sections 1, 4, and 5).
3. After accounting for different sampling methodologies and relatively small numbers of commonly surveyed lakes, the primary changes in NYS plant communities over the last century appear to be the introduction of AIS, particularly Eurasian watermilfoil and curly-leafed pondweed among the statewide invasives, water chestnut, fanwort and variable watermilfoil among the regional invaders, and hydrilla and starry stonewort among the new invaders. There also seemed to be a reduction in emergent plant species

and genera, and in non-nuisance native plants and protected plants, but these datasets may not be adequate to quantify these losses. However, this decrease in some submergent plant species may be associated with the spread of Eurasian watermilfoil and other AIS (WP1E, Section 5).

White Paper 1F- Evaluation of Coefficients of Conservatism in NYS Lakes

1. Traditional FQIs and Traditional C values are associated with the NY C value system
   - Coefficients of conservatism, or C values is a component of floristic quality indices (FQIs, which are most often calculated using the equation

     $FQI = \bar{C}\ x\ \sqrt{N},\ and\ \bar{C} = \Sigma C / N$; where C = coefficient of conservatism (C_{ny} values) for each unique species and $\bar{C}$ = mean C value (WP1F, Section 2.1)
   - Most FQI equations use a “traditional” C value system in which C values are assigned to each aquatic plant using values provided by Natural Heritage Program (WP1F, Sections 2 and 3)
2. There are several problems with the use of the traditional C value system ($=C_{ny}$), related to inconsistencies or challenges in plant collection and identification, plant plasticity, survey intensity and timing, interpretation of FQI values, and other factors. A simplified, or modified, C value system ($=C_m$) using the same range but assigning negative values to exotic species and distinguishing nuisance from protected native plants, confers many advantages and addresses many of the logistic problems with the use of C_{ny} values. The modified C_m system ranges from -5 (most invasive plants) to +5 (protected plants), with all exotic plants assigned one of three negative values, and nuisance native plants assigned lower (C_m = 1) values than benign beneficial native plants (C_m = 3). (WP1F, Sections 2 and 3)
3. All New York state aquatic plants can be assigned to one of these modified C_m values, based on regulatory definitions for exotic and protected plants, and by lake manager consensus for nuisance native plants. These are summarized in Table 3.2 found in White Paper 1F (WP1F, Sections 2 and 3):
4. There is a strong correlation between C_m and C_{ny} values, and these data recommend the use of the modified C_m system for computing floristic quality and otherwise evaluating the relationship between C values and several static and dynamic features in NYS lakes.

WP1F Table 3.2: Modified C Values (C_m) for Aquatic Plants in New York State

Category	***Modified C_m Value***	***Representative Plants***
Protected Plants	+5	Water marigold, Farwellii’s milfoil, Fineleaf pondweed, Lesser bladderwort
Beneficial Native Plants	+3	Slender naiad, Bur reed, Stonewort, most pondweeds, Common waterweed, Duckweed, Watershield
Nuisance Native Plants	+1	Purple bladderwort, Coontail, Largeleaf pondweed, Watermeal, Water lilies, Leafy pondweed
Exotic Plants with “Low” Invasiveness	-1	Water shamrock, Pond water starwort, Brittle naiad, Twoleaf waterweed
Exotic Plants with “High” Invasiveness	-3	Brazilian elodea, Fanwort, Curlyleaf pondweed, Yellow floating heart, Parrotfeather
Exotic Plants with “Very High” Invasiveness	-5	Eurasian watermilfoil, Water chestnut, European frogbit, Hydrilla, Starry stonewort

Note- starry stonewort, charaphytes, and aquatic mosses have been assigned C_m values even though C values were not assigned to these non vascular aquatic plants. However, filamentous algae was not assigned either a C value or a C_m value. Reference: Kishbaugh, 2020.

The primary reasons for recommending the use of the modified C_m system include (WP1F, Section 3.2 – 3.3):

- Maintaining a wide range of C values throughout the aquatic plant community
- Delineating levels of invasiveness and defining all exotic plants has having negative floristic value, taking advantage of existing regulatory definitions
- Generating FQI values that are generally < 0 when plant communities are comprised primary of exotic plants, consistent with "AIS are bad" messaging and offering an easy to understand scaling of floristic quality values
- Highest C_m values assigned to protected plants, also consistent with existing regulatory definitions
- Lower sensitivity to inaccurate identifications of difficult to identify or partially retrieved plants, with most plants by default assigned a single C_m value (=3), thereby greatly reducing identification and training challenges
- Greater accuracy in defining floristic quality scores from various FQI criteria
- Greater opportunities for developing and comparing interstate FQI values

5. Observed C_m values (and community mean C_m values) can be determined for the NYS BioSurvey, AWI and PIRTRAM lakes, although differences in habitat assessments (generally species level ID for submergent plants, genera level ID for floating or emergent plants) need to be corrected to facilitate comparisons across programs. These data show a decrease in mean C_m values over time outside of the Adirondacks, perhaps due to AIS introduction, more extensive lake use and shoreline development, and climate change. This may foretell a future change in Adirondack lakes. (WP1F, Section 3.3)
6. Observed C_m data do not change in response to increasing littoral areas, unlike the pattern observed in species richness (and by extension FQI). (WP1F, Section 3.3)
7. C_m values, like species richness values, should be projected to a standardized survey site density of 1 site per littoral hectare to facilitate comparison across programs and from year to year in lakes, to minimize extrapolation errors associated with projections to a higher standardized density, and to improve the likelihood of surveyors surveying all (1 site per littoral hectare) survey sites. Unlike species richness, which increases to an asymptotic value as survey sites increase, the relationship between cumulative mean C_m and survey sites is less consistent, further pointing to the need for a standardized evaluation. (WP1F, Section 4)
8. Mean C_m values improve in accuracy when corrected for relative frequency and especially for relative abundance. Plant frequency is evaluated using the following equation:

   Equation 5.3.2: $C_{m\_uf\_}$ *= sum of (all sites counts x* C_m *value for species) / (number of plant species x number of survey sites*), where "u" refers to unbounded frequency

   A lake-by-lake comparison of uncorrected mean C_m values and frequency-corrected mean C_m values show that corrected values appear to more accurately characterize the floristic quality of plants within these lakes. Lakes with a high frequency of invasive plants had negative mean C_{m_uf} values, as expected, particularly when uncorrected mean C_m values were positive. (WP1F, Section 5.3)

9. Plant abundance is evaluated by converting narrative descriptions (“trace”, “sparse”, “moderate”, and “dense”) to $\log_5$ equivalent values (1, 5, 25, and 125, respectively), as seen in Table 6.3.1 drawn from White Paper 1F. These correction factors are used in Equation 6.3.1 in White Paper 1F: (WP1F, Section 6.3)

   Equation 6.3.2: C_{m_ua} = *sum of (all sites abundance x* C_m *value for species) / (number of plant species x number of taxa)*

   WP1F Table 6.3.1: Plant Abundance Categories Used in NYS Plant Surveys

Density Category	Estimated Quantity from Average of 1-2 Rake Tosses	Approximate Biomass	Assigned Score
No plants (Z)	Nothing	0 g/m^2	0
Trace (T)	Fingerful (of plants)	up to 0.1 g/m^2	1
Sparse (S)	Handful	0.1 to 20 g/m^2	5
Medium (M)	Rakeful	20 to 100 g/m^2	25
Dense (D)	Can’t Bring In Boat	100 to 400 g/m^2	125

   Reference: Kishbaugh, 2020; Johnson, 2008

   As with plant frequency corrections, mean C_m values corrected for plant abundance were compared with both uncorrected and frequency-corrected mean C_m values. These comparisons showed further improvements in aquatic plant community evaluations when these mean C_m values were corrected for plant abundance. Those abundance-corrections resulted in lakes with a high abundance of invasive plants having negative mean C_{m_ua} values; it is reasonable to assume that this represents a more accurate assessments. (WP1F, Sections 6.3 and 6.4)

10. Truncated surveys can also be used to estimate mean C_m values (corrected or uncorrected). Using the methods outlined in White Paper 1C, truncated surveys of 15 site in small lakes and 40 sites in large lakes (and extrapolated cumulative mean C_m regressions generated from subsampled data) result in highly accurate estimates of mean C_m values at the standardized survey site density of 1 site per littoral hectare (WP1F, Section 6.5)

11. C value scores can be generated from uncorrected and corrected mean C_m values using the Florida aquatic plant community designations identifying the percentage of sensitive, tolerant, native and exotic plants in

   Table 7.1.1- Typical Aquatic Plant Community Designations

Aquatic Plant Community Designation	Description
Outstanding	67% “sensitive”, 0% “tolerant”, 90% “native”, 0% “invasive”
Excellent	20% “sensitive”, 20% “tolerant”, 85% “native”, 0% “invasive”
Fair	15% “sensitive”, 35% “tolerant”, 70% “native”, 10% “invasive”
Poor	0% “sensitive”, 50% “tolerant”, 60% “native”, 25% “invasive”
Very Poor	0% “sensitive”, 40% “tolerant”, 40% “native”, 40% “invasive”

   From Fore, L.S. et al, 2007

"outstanding", "excellent", "fair", "poor" and "very poor" floristic quality lakes- these designations are shown in Table 7.1.1 above drawn from White Paper 1F. Some of these categories need to be collapsed as these mean C_m values are corrected for aquatic plant frequency or abundance. Table 7.1.2, Table 7.2.1 and Table 7.3.3, all also included in White Paper 1F, show the mean C_m thresholds associated with these aquatic plant designations (or collapsed designations) for uncorrected, frequency corrected and abundance corrected mean C_m values, respectively. (WP1F, Section 7.1)

12. The application of the mean C_m scoring system summarized in Tables 7.1.2, 7.2.1 and 7.3.3 above to the PIRTAM lakes (lake-years) results in an increasing percentage of lakes with poor aquatic plant community assessments as the mean C_m values are corrected for plant frequency and for plant abundance. A summary of these results in shown in Table 7.3.4 above drawn from White Paper 1F. These generally appear to be consistent with expectations, since nearly all of the PIRTRAM lakes were surveyed either in response to or in anticipation of aquatic plant management activities. More lakes (lake-years), particularly those with perceived favorable aquatic plant community assessments, would need to be evaluated to determine if mean C_m values should be corrected for aquatic plant frequency or abundance. (WP1F, Section 7.3)

Table 7.3.4- % PIRTRAM Lakes Meeting C_m Criteria from Table 7.1.2 (C_m), Table 7.2.1 (C_{m_uf}), and Table 7.3.3 (C_{m_ua})

	C_m Evaluation using Criteria Above				
	Outst.	Exc.	Fair	Poor	V.Poor
% Lakes Using C_{m_ua}	3% (Good)		31%	64% (Poor)	
% Lakes Using C_{m_uf}	0%	6%	35%	12%	47%
% Lakes Using C_m	0%	10%	48%	24%	19%

Legend- Outst = Outstanding, Exc = Excellent; Cm = modified C value system

Therefore, the recommended mean C_m thresholds for Good (or Outstanding or Excellent) lakes, Fair lakes, and Poor (or Very Poor) lakes, whether mean C_m values are uncorrected or corrected for plant frequency or abundance, are provided in Table 8.1 drawn from White Paper 1F. (WP1F, Section 8.1)

Table 8.1- Recommended Mean C_m Thresholds and Aquatic Plant Community Designations Based on Uncorrected and Corrected Values

	Outstanding	Excellent	Fair	Poor	Very Poor
Mean C_m (uncorrected)	> 4.0	2.6-4.0	1.4-2.6	0.0-1.4	< 0
Mean C_{m_uf} (freq corr)	> 2.4	0.8-2.4	0.3-0.8	0-0.3	< 0
Mean C_{m_uf} (abund corr)	> 8.0 (Good)		0.0-8.0	< 0 (Poor)	

White Paper 1G- Evaluation of Floristic Quality Indices (FQIs) in NYS Lakes

1. White Papers 1D and 1F summarize the key components of FQI- Coefficients of conservatism, or C values, and species richness, based on the equation

   $FQI = \bar{C} \times \sqrt{N}$, *and* $\bar{C} = \Sigma C / N$; where C = coefficient of conservatism (C_{ny} values) for each unique species and $\bar{C}$ = mean C value, and N = species richness (WP1G, Section 3)
2. While FQIs can be generated from equations including observed species richness and (observed) New York C (C_{ny}) values for each plant, the information presented in White Papers 1D and 1F indicate that modified FQIs (mFQI) will be more accurate when both species richness and modified mean coefficients of conservatism are projected to a standardized survey site density of 1 site per littoral hectare (resulting in pSR and projected mean C_m values, respectively). (WP1G, Section 3)
3. Uncorrected mFQIs- derived from pSR and mean C_m uncorrected for frequency or abundance- are generally low in PIRTRAM lakes, with the very few negative mFQI alues associated with lakes (lake years) dominated by highly invasive species. There was little variability in uncorrected mFQI from year to year in managed lakes or in (unmanaged) lakes with multiple years of survey data. (WP1G, Section 3.3).
   - Uncorrected mFQI "scores" (labels for ranges of mFQI values) can be derived from the Swink-Wilhelm thresholds defining "natural areas", "high" and "low" vegetative quality in wetlands given several assumptions about (a) maximum species richness derived from subsample regressions projected to a survey site density of 4 sites per littoral acre, (b) the relationship between max species richness and projected (to a 1 site per littoral hectare density) species richness; and (c) the relationship between mean max C_{ny} and mean max $C_{m.}$ Fortunately, these associations are very high in the NYS lakes dataset. The resulting uncorrected mFQI scores derived from the Swink-Wilhelm thresholds indicate "natural areas" could be defined as an mFQI > 16, and "high" vegetative quality could be defined as an mFQI > 7. A metric combining mean C_m thresholds (White Paper 1F) and the mFQI thresholds cited here can be used to account for both species richness and individual plant quality. (WP1G, Section 3.4)
   - Application of these combined mFQI and uncorrected mean C_m scores to NYS lakes data indicate a slightly more favorable than expected assessment of floristic quality, particularly when applied to the NYS BioSurvey and AWI datasets (albeit using less accurate oSR and observed mean C_m values). About 85% of the PIRTRAM lakes (lake years) would be cited as "fair" or better. It is likely that these more favorable assessments reflect the use of uncorrected data. (WP1G, Section 3.5)
4. mFQI values corrected for plant frequency are also low, as expected given the expected condition of the evaluated (PIRTRAM) lakes. Most of the differences in frequency-corrected mFQI values, relative to uncorrected values, corresponded to lakes with higher frequencies of invasive or nuisance native plants. (WP1G, Section 4.3)
   - Frequency-corrected mFQI scores can be derived from modifying the uncorrected mFQI thresholds and associated scores by the (fairly strong) relationship between uncorrected and frequency-corrected mean C_m values. The resulting frequency-

corrected mFQI scores indicate "natural areas" could be defined as an mFQI > 6, and "high" vegetative quality could be defined as an mFQI > 2. As with plant frequency, a metric combining mean C_m thresholds (White Paper 1F) and the frequency-modified mFQI thresholds cited here can be used to account for both species richness and individual plant quality. (WP1G, Section 4.4)

- Application of these combined mean C_m and frequency-modified mFQI scores to NYS lakes data indicate a degradation in assessments of floristic quality, consistent with the expectation that frequency-based assessments would account for higher percentages of invasive or nuisance native plants in these lakes. The percentage of lake years evaluated as "fair" or better dropped to less than 65% when frequency corrections were applied to these values. It is likely that, while this trend is moving in the right direction (i.e. less favorable assessments), the most accurate assessments of these lakes would be less favorable. An evaluation of individual lakes (lake years) indicates that the frequency-corrected assessments more accurately represent aquatic plant communities in these lakes. (WP1G, Section 4.5)

5. mFQI values adjusted for plant abundance exhibit a wider range than seen with frequency-corrected values, consistent with the wide range of plant abundance levels found in these lakes. All lakes dominated by invasive species exhibit negative mFQI values, and these lower values appear to be even more accurate characterization of actual aquatic plant communities in these lakes. (WP1G, Section 5.3)
    - As with abundance corrections for mean C_m values noted in White Paper 1F, abundance corrections for mFQI require estimates of optimal plant coverage (abundance). In addition, given the uncertainty associated with these estimates, the aquatic plant community designation categories for abundance-corrected mFQI is collapsed into three categories- "good", "fair" and "poor", and the assignment of all negative mFQI values as indicative of unfavorable conditions. Combining all of these assumptions and adjustments, these data indicate that an abundance-corrected mFQI of 32 corresponds to "good" conditions, with an mFQI of 0 separating "fair" and "poor" aquatic plant community conditions. And as with frequency-corrected mFQI assessments, the abundance-corrected mFQI assessments can be combined with the mean C_m assessments to improve the overall assessment of lake conditions. (WP1G, Section 5.4)
    - Application of these combined mean C_m and abundance-modified mFQI scores to NYS lakes data indicate a further degradation in assessments of floristic quality, consistent with the expectation that frequency-based assessments would account for higher abundance of invasive or nuisance native plants in these lakes. The percentage of lake years evaluated as "fair" or better dropped to about 60% when abundance corrections were applied to these values, with only 5% of the lake years characterized as "fair to good". This appears to more closely represent conditions on the ground, although these combined mFQI- mean C_m thresholds and associated assessment scores should continue to be evaluated with additional lakes data. An evaluation of individual lakes (lake years) indicates that the abundance-corrected assessments even

more accurately represent aquatic plant communities in these lakes than does frequency-based assessments. (WP1G, Section 5.5)

6. An evaluation of about 15 individual lakes with long-term aquatic plant survey data suggest that abundance-corrected mFQI values (compared to uncorrected mFQI values) most accurately characterize lake conditions, although frequency-corrected values are nearly as accurate and can be used in the absence of abundance data for surveyed lakes. Combined metrics- using both mFQI and mean C_m thresholds associated with aquatic plant community designations- also appear to most accurately characterize aquatic plant communities in these lakes. (WP1G, Sections 6 and 7)

WP1G Table 8.2- Matrix Comparing mFQI (or Species Richness) Scores to Aquatic Life Assessments

mFQI or Mean C_m Score	Aquatic Life or Habitat "Condition" Assessment	Aquatic Life Use Assessment
Very Poor	Poor	Stressed
Poor		
Fair	Fair	Threatened
Good	Good	Fully Supported

7. mFQI (and mean C_m) values can be used to evaluate the efficacy of aquatic plant management actions, particularly if compared to normal annual variability in these mFQI values, the impacts of AIS introduction, and regional comparisons for those states or regions using the same modified C value and corrected FQI systems supported by granular survey site data (WP1G, Section 8).

8. These mFQI and mean C_m scores can also be used to conduct aquatic life assessments required by state agencies in assessing designated uses or waterbody conditions. Table 8.2 (drawn from and discussed in detail in White Paper 1G) shows an example conversion matrix that can be used to derived aquatic life assessments from mFQI and/or mean C_m scores. (WP1G, Section 9)

9. Recommendations to improve the proposed modified FQI system are outlined in White paper 1G (as are comparable recommendations to improve the proposed modified mean C_m system in White Paper 1F). The modified FQI system, corrected for relative plant frequency and abundance, and evaluated against mFQI scoring criteria, would benefit significantly from regional support, particularly in the areas of (WP1F, Section 10):
   - Consensus on assignment of individual plants to modified C values categories
   - Adoption of specific relative abundance scales, such as the $\log_5$ scale proposed in these White Papers
   - Appropriate mFQI and mean C_m values to distinguish the difference between "fair" and "poor" condition lakes.
   - Identification of optimal plant coverage (abundance) associated with each plant type (sensitive, tolerant, native, exotic) for each aquatic plant community designation (outstanding/excellent, good, fair, poor/very poor)
   - Identification and surveying of reference (unimpacted) waterbodies used to identify modified FQI values associated with representative reference conditions