Using Lichens as Indicators of Hydrology in Mixed Pond-Cypress (*Taxodium ascendens*) - Pine (*Pinus* sp.) Wetlands in Central Florida

Major Paper

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For My Wife, Tracy, and My Children, Maddi and Caden,
Who Sacrificed Much So I Could Complete My Graduate Program.

Acknowledgments

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Introduction

Lichens as Indicators of Hydrology

Lichens have long provided a means to date historical, naturally-occurring events because they are long-lived, have a relatively slow radial growth rate, and have different species-specific tolerances to inundation (Benedict 2009). These attributes have proven particularly useful in a number of studies pertaining to stage height in aquatic systems (Santesson 1939, Gregory 1976, Hale 1984). For example, by using growth rates of saxicolous (i.e. 'on rock') lichen lines, Timoney and Marsh (2004) were able to determine the approximate year that lakes within a Canadian watershed began to recede. These investigators relied upon Hale's work (1983) on lichen growth rates to formulate their dating method. Hale observed that foliose forms grow approximately 1 to 6 mm/year and crustose forms 0.5 to 2.5 mm/year. Timoney and Marsh (2004) measured the diameter of lichen thalli on tombstones in cemeteries near the study area and established a size/age curve based on the size of the thalli and the date on each tombstone. Then, they measured lichen thalli in trimlines on cliff faces at several lakes throughout the watershed. After accounting for recolonization lag time, the size/age curve was applied to the lichens in the trimline, which allowed for an inference to be made about how long it had been since water levels had last reached the trimline.

Similarly, in forested wetland systems, elevations of past water levels can be inferred by 'reading' the history of lichen lines on tree boles. An understanding of the relationship between lichen lines and recurring water elevations is particularly important at sites for which there are either no hydrodata, or no hydrodata exist for the time period of interest. At one such site, in one of the few studies of lichen lines ever published in central Florida, Hale (1984) observed a corticolous (i.e. 'on bark') lichen line 'move' up a bald-cypress (*Taxodium distichum*) tree bole over time. The apparent upward migration of the lichen line was in response to consecutively higher flooding events along the Peace River in Polk County, Florida. Hale's study was the first published work in Florida that associated sustained, elevated water levels with chlorosis, exfoliation, and disintegration of lichens on trees. He found that in order to form a lichen line, water must remain at an elevated level for at least seven days to sufficiently kill lichen thalli below that level.

Similarly, in a study in south Florida, Griffin (Professor Emeritus, Department of Botany, University of Florida, Gainesville) submerged lichen samples and recorded the time necessary to kill thalli. He found that lichens could not tolerate more than five days of inundation (Clewell et al. 2009). Since lichen growth rates are generally slow, one may then infer that lichen lines are indicative of high water events in the distant decadal past. Indeed, as demonstrated by Timoney and Marsh (2004), this may be the case in some systems. However, because of variation in recolonization lag time, growth rates, and tolerance to inundation between lichen growth forms and species, some lichen lines may be indicative of annual recurring water elevations.

Typically, hydrophobic crustose and foliose lichens form a ‘trimline’, or ‘lichen line’, extending from the upper portions of a substrate down to the upper limit of antecedent water levels. For substrates and systems with fluctuating water levels, and where both crustose and foliose forms are present, two or more lichen lines may exist, with the line of the former form typically positioned higher in elevation than the latter. In pond-cypress (*Taxodium ascendens*) and mixed-forested wetlands in central Florida, lichen lines are usually stratified on tree boles in this manner, with a distinct crustose lichen line located above a more diffuse foliose lichen line.

Although identified in the scientific literature as indicators of hydrology in wetlands (Hale 1984, Hull et al. 1989, Carr et al. 2006), only limited research has been conducted on lichen lines. Even fewer studies have investigated the vertical distribution of species-specific lichen lines and their relationship with recurring high water in wetlands. Two recurring water elevations of particular interest, of which lichens are indicative, are the seasonal high water level (seasonal high) and the normal pool water level (normal pool). Although there is some disagreement in the definitions of these two terms among different government agencies and authors, a generalized definition of the seasonal high can be given as the maximum elevation to which water may be expected to rise in the wet season (SFWMD 2010, FDEP 2004). The seasonal high is typically related to storm events that occur during the rainy season, which cause water levels to rise for a short time, but then quickly recede within a few days (Figure Nos. 1, 2). The generally accepted definition of normal pool is the multi-year mean, sustained, wet-season water elevation (SFWMD 2010, SWFWMD, 1999) (Figure Nos. 1, 2). Elevations for different types of water control structures are set according to these recurring water levels (Hull et al. 1989, SFWMD 2010) and a number of ways have been developed to determine them.

Seasonal High Water Level

The seasonal high is best described by the SFWMD (2010) as the elevation to which water may rise during the rainy season as a result of storms. Indicators for the seasonal high include drift lines or rafted debris, water marks, and distinct lichen lines. The latter is generally interpreted to be indicated by crustose lichens and is often noted on the trunks of trees in most forested wetlands. Although the indicators for this elevation can be readily observed, recurring annual flood elevations are not static, which can reset the seasonal high ever higher every year. This dynamic diminishes the relevance of the seasonal high in determining a mean multi-year maximum water elevation in wetlands. The indicators merely provide a record of the most recent significant storm, associated rainfall, and subsequent high water elevation. Because replicates of each indicator can form and persist through one or more rainy seasons, these indicators do not provide a method for determining any meaningful average of high water levels. If a mean maximum water elevation must be determined, as is required in many regulatory scenarios, antecedent rainfall must be evaluated for normality, and consideration must be given to the fact that a crustose lichen line caused by one particular storm may take decades to become obscured by new lichen colonies (Clewell et al. 2009).

Normal Pool

Several biological indicators, including morphological plant adaptations, have been demonstrated by Carr et al. (2006) and Hull et al. (1989) as reliable indicators of normal pool in wetlands. These include the elevation of root crown bases of fetterbush

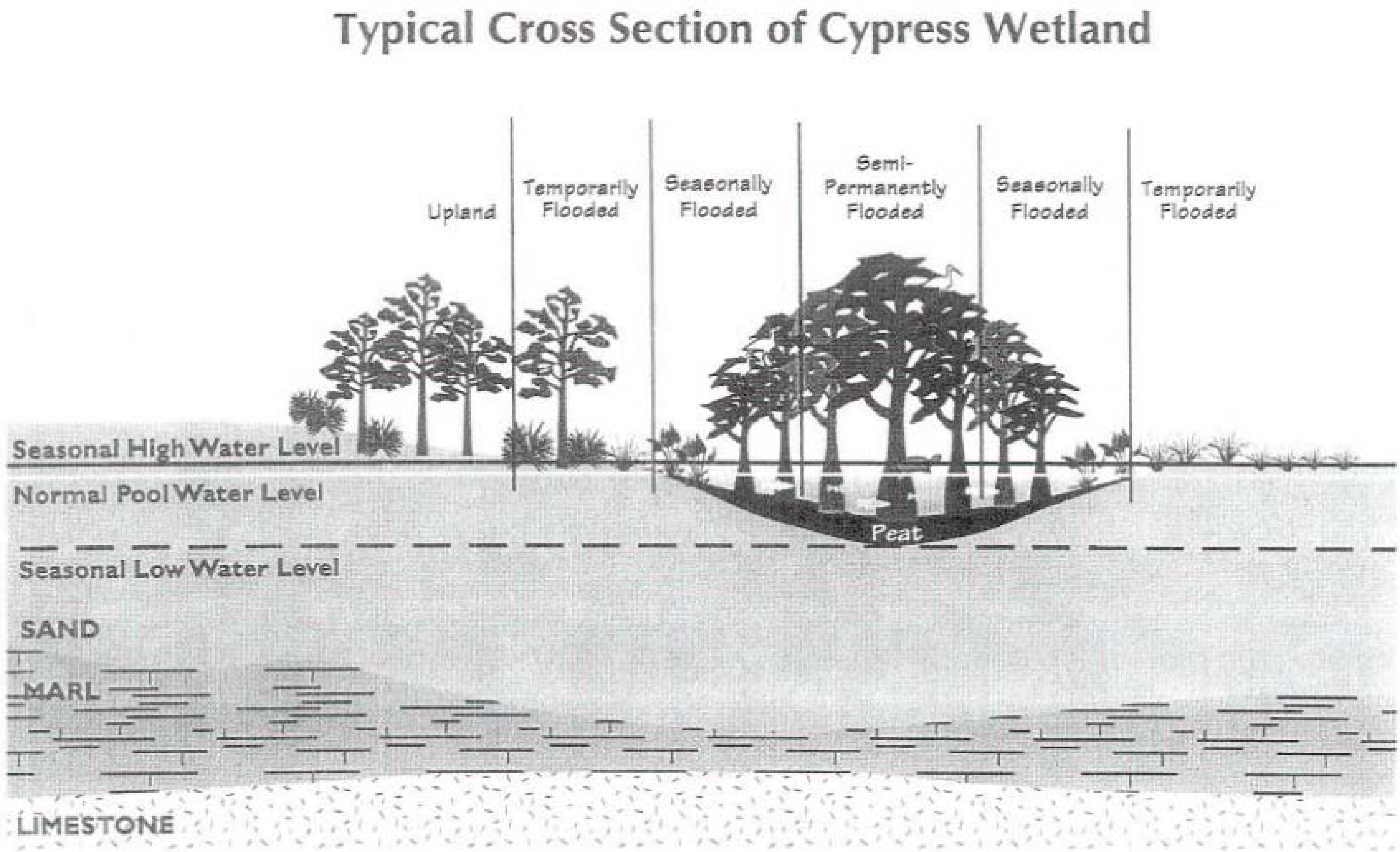

Figure 1. Seasonal High and Normal Pool Elevations in a Wetland Cross-Section (figure from SFWMD, 2010)

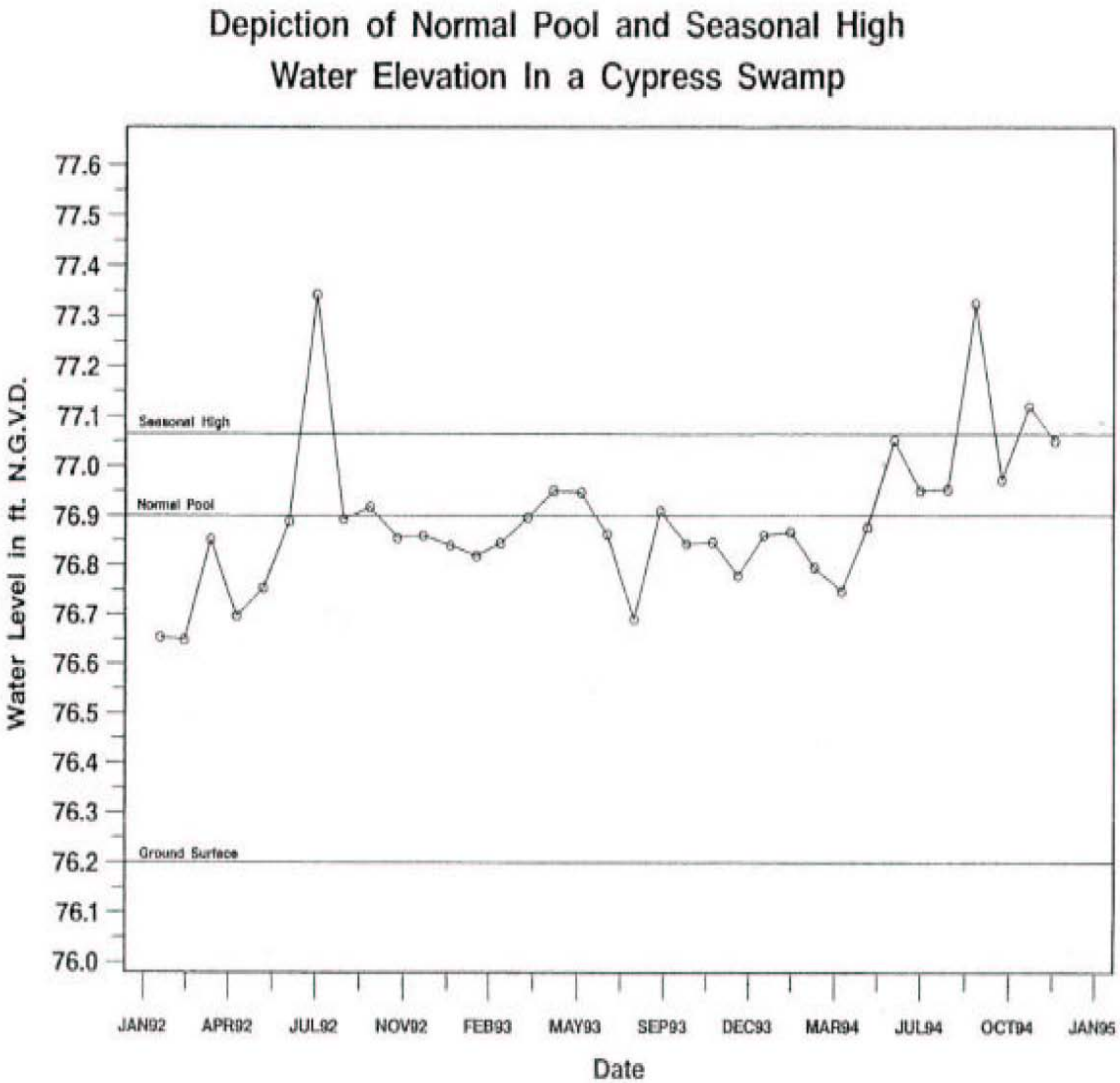

Figure 2. Seasonal High and Normal Pool Elevations
Correlated to Hydrograph (figure from SFWMD, 2010)

(*Lyonia lucida*) growing on tree tussocks; the inflection point on pond-cypress where the angle of the swollen buttress becomes more steep; the lower limit of epiphytic moss collars on pond-cypress; the ground elevation at the landward-most pond-cypress; the uppermost adventitious root of sandweed (*Hypericum fasciculatum*); and the ground elevation of the lowest roots of saw palmetto (*Serenoa repens*) at the saw palmetto line (Carr et al. 2006) (Figure No. 3). In Carr et al. (2006), the first three indicators (e.g. fetterbush, inflection points, and moss collars) had the least variability among them and, as such, can be inferred to be more reliable indicators than the others. Additionally, according to W. Michael Dennis and W. F. Grey (Wetland Scientists, Breedlove, Dennis & Associates, Inc., Winter Park, Florida; pers. comm. 2011) a rippling effect on the buttress of cypress (*Taxodium* sp.) can be used in combination with other indicators to determine normal pool.

Despite the apparent abundance of indicators that may be used to identify normal pool, only rarely are all the indicators consistently present and near enough to each other to allow for elevation comparisons in the field. For example, the outermost pond-cypress and saw palmetto line would not be expected to be near moss collars or buttress inflection points, because the inundation that causes the expression of the two latter indicators rarely, if ever, occurs at the wetland edge. Moreover, even when several indicators are present and in close enough proximity to each other, they may not be located on the same tree, the same aspect on other trees, or otherwise within line-of-sight of each other to allow for correlation between them. Due to the sometimes limited availability or inconvenient distribution of normal pool indicators, it becomes apparent that more studies about the indicators and normal pool could be useful.

Study Objective

One way to add to the body of knowledge about normal pool would be to identify new or previously ignored biological indicators. While searching for such indicators in the field, this author observed a particular foliose lichen, Ravenel's cup lichen (*Cladonia ravenelii* Tuck), to be consistently distributed on pond-cypress at only slightly higher elevations

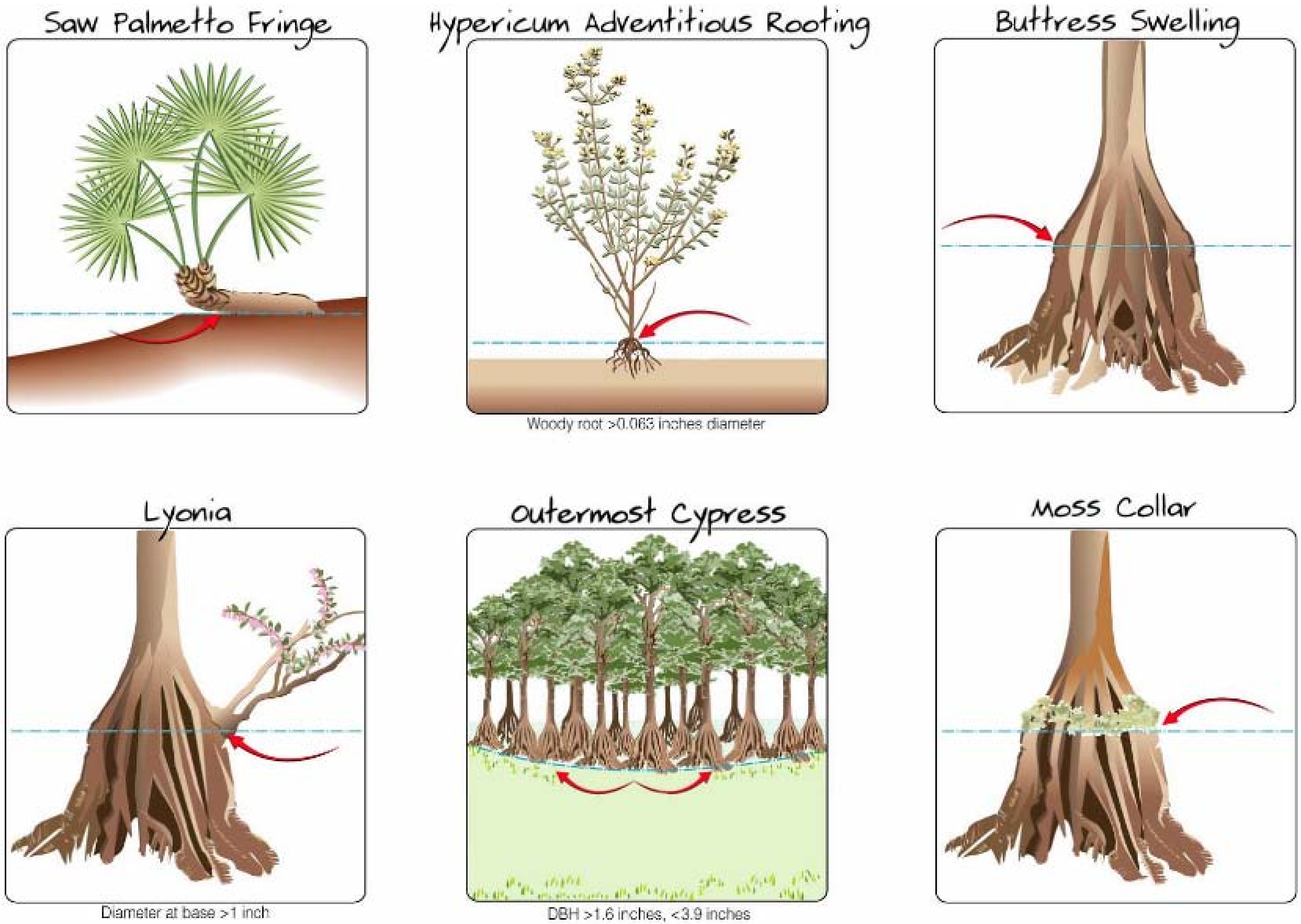

Figure 3. Biological Indicators of Normal Pool Elevation (figure from Carr et al. 2006)

than buttress inflection points and moss collars. Subsequently, this investigator began studying the potential correlation between this lichen and normal pool. This study will evaluate the relative elevations of crustose lichen lines, peak high water elevations, quantitative seasonal high and normal pool, Ravenel's cup lichen lines, and biological indicators of normal pool. This study may prove invaluable in establishing proper water control elevations in wetlands and stormwater ponds for projects without historical hydrodata and should provide an additional indicator for determining normal pool in similar wetlands in central Florida.

Methods

Study Site

This study was conducted in three mixed-forested pond-cypress and pine (*Pinus* sp.) strand wetlands in Flagler County in east central Florida (Figure Nos. 4, 5). Two of the wetlands (Wetland Nos. 1 and 2), were historically the same system, but have since been divided by local roads. The study site is located wholly within the Plantation Bay Planned Unit Development Phases II and III project site (Plantation Bay), located south of Old Dixie Highway, west of Interstate Highway 95 and east of U.S. Highway 1 (Figure 6). The wetlands in this study are part of compensatory mitigation for wetland impacts associated with the development of Plantation Bay. These wetlands have been altered from their historical condition by the excavation of several drainage ditches and canals throughout the site. Subsequently, berms were installed that facilitated longer wetland hydroperiods, but, over time, breaches occurred in these berms that ultimately led to drier conditions. As part of the enhancement portion of the mitigation plan, the berm breaches were plugged to again increase the hydroperiod in these wetlands. Wetland enhancement activities, including repairs to berm breaches, were completed in May 2007.

This site was selected because multiple water level recorders (WLRs) were installed throughout Plantation Bay (Figure 7) in May 2006 to determine whether the mitigation areas were meeting success criteria specified by the Environmental Resource Permit (ERP) issued by the St. Johns River Water Management District (SJRWMD). The hydrodata from the WLRs provide a record of antecedent water levels for this study, although it should be noted that not all WLRs have continued to function since their installation. Some of the hydrodata for some of the selected wetlands was missing from the record. Missing data was extrapolated from other nearby WLRs that had data for the period of interest by using the TREND function in Microsoft Excel.

Figure 4. Select Areas of Study Site

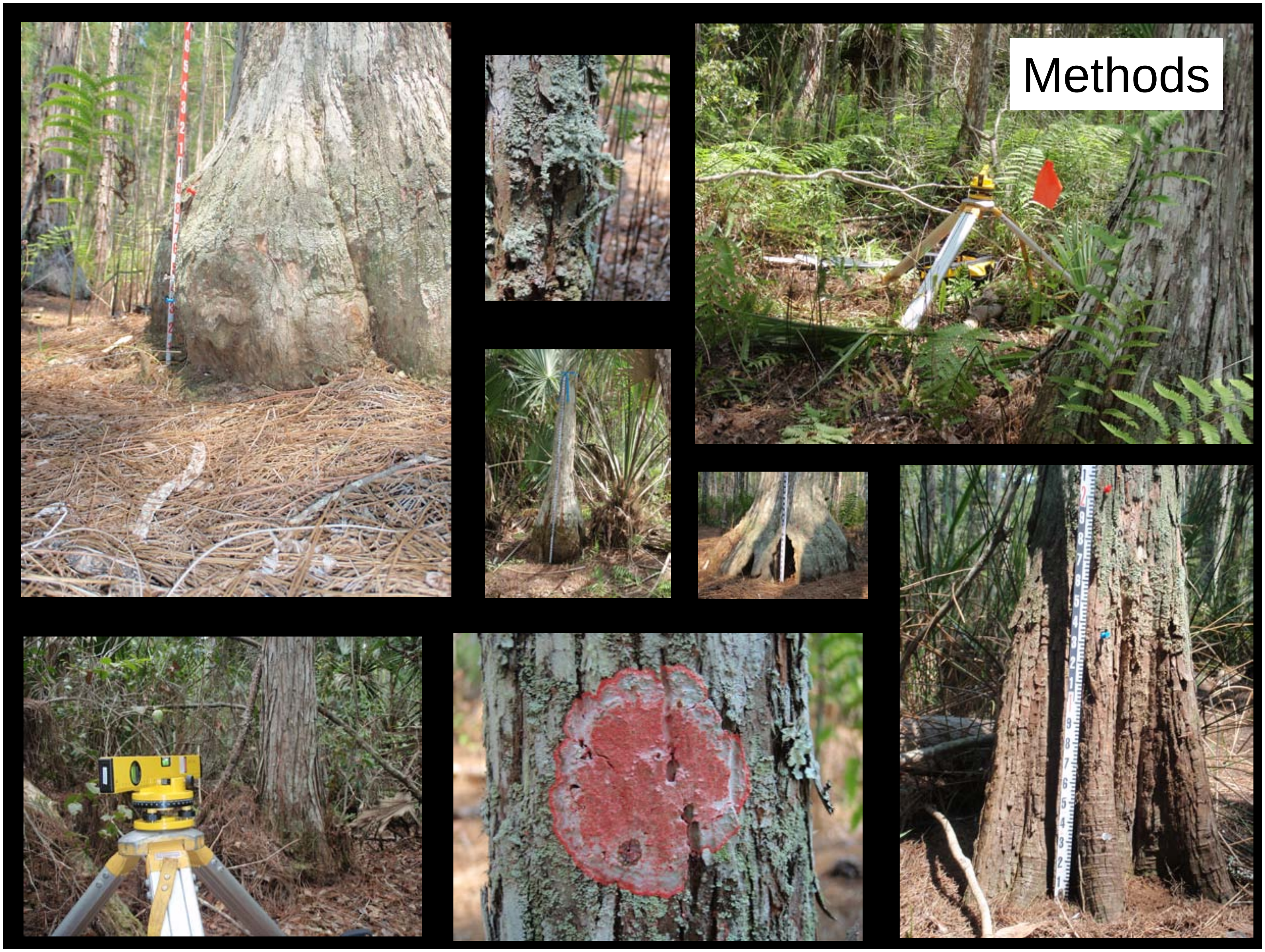

Figure 5. Pictorial Summary of Methods Used in this Study

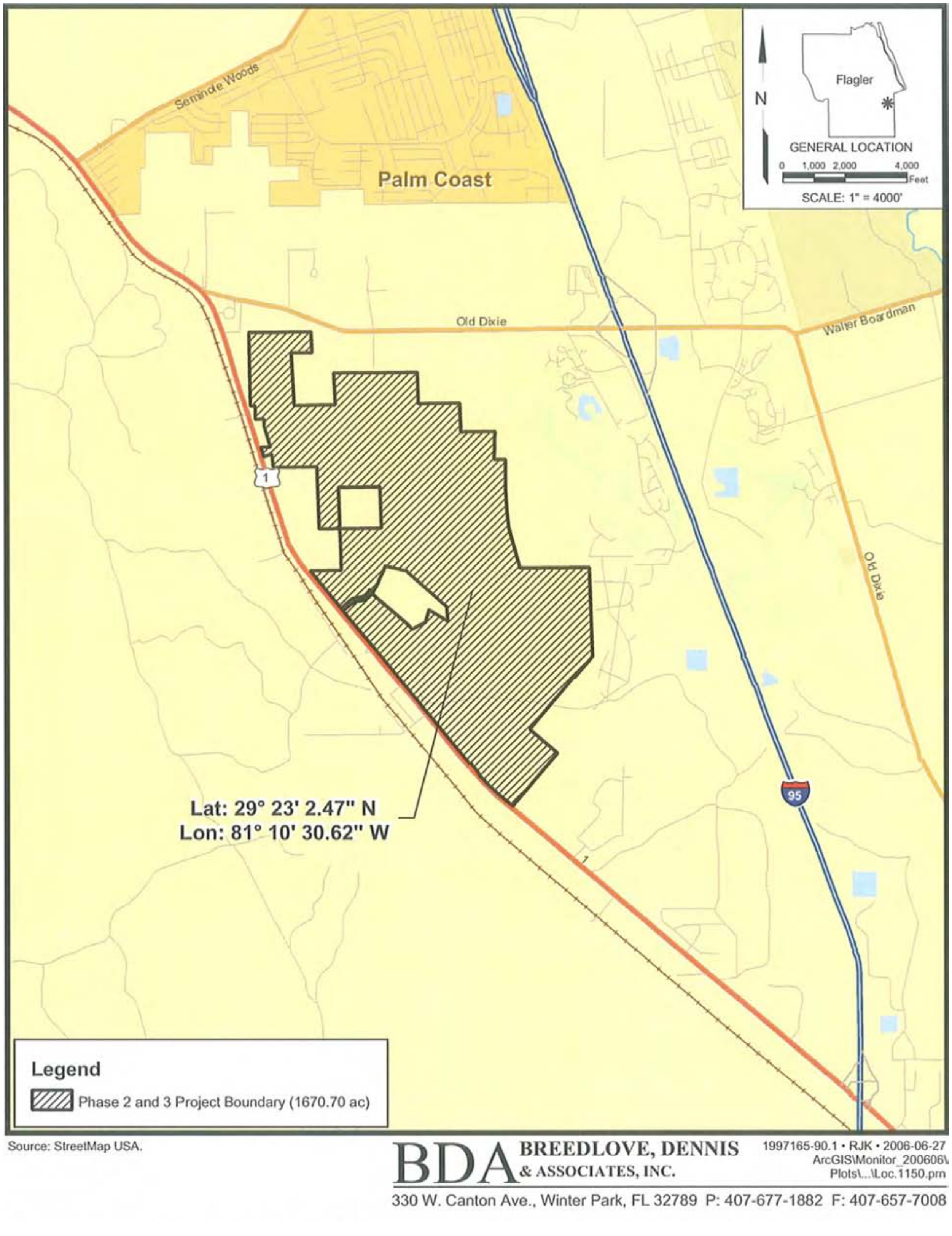

Figure 6. Location of the Plantation Bay PUD Phases II and III Project Site, Flagler County, Florida (figure provided by Breedlove, Dennis & Associates, Inc.)

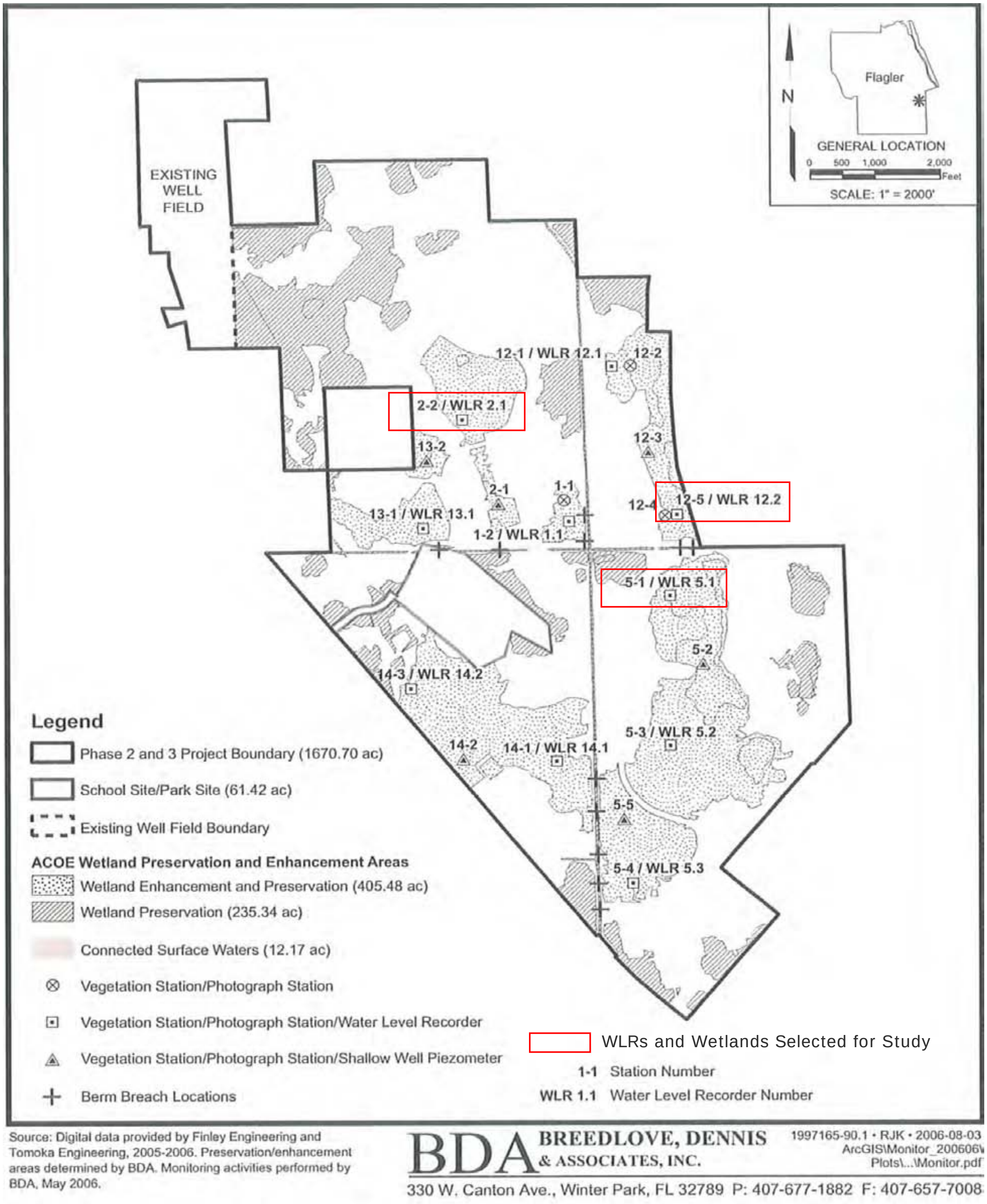

Figure 7. Location of Water Level Recorders and Wetland Areas Selected for Study on the Plantation Bay PUD Phases II and III Project Site, Flagler County, Florida (figure provided by Breedlove, Dennis & Associates, Inc.)

Three factors were significant in selecting the three study areas, namely, whether a properly functioning WLR was available, and the relative abundance of Ravenel's cup lichen and normal pool indicators. The areas that best met these factors included the wetland areas in the vicinity of WLR Nos. 2.1, 5.1, and 12-2 (Figure 7). These areas are referenced as Wetland Nos. 1, 2, and 3, respectively. The WLRs are programmed to record water levels once every 24 hours within 72.0 inches of the top of the instrument (head) to the bottom. The head of the WLR is installed approximately three feet above ground to allow for ease of use during calibration, download, and maintenance activities. A calibration line on the WLR casing facilitates normalization of the hydrodata to the ground elevation.

For this study, a 16-inch Centech rotating laser level (Model No. 90980) was positioned on a tripod near each WLR to project a beam onto the calibration line on the WLR casing. Once properly leveled and projected on the calibration line, the laser level was rotated to project the beam on surrounding trees that had occurrences of indicators of interest. Four trees in the vicinity of each WLR were selected for study. The distance from the position of the laser beam projected onto the tree, to occurrences of the indicators of interest, including; biological normal pool indicators; the mean lower limit of prevalent Ravenel's cup lichen colonies; and the mean lower limit of prevalent crustose lichen colonies, were recorded in decimal feet using a Kesson Pocket-Rod (Model No. PR-610). This provided a means to correlate actual antecedent water levels with normal pool indicators and lichen lines and compare these among multiple trees within each wetland. See Figure 6 for a pictorial summary of the methods used in this study.

Other data recorded from each tree selected for study included the tree species, approximate height, and trunk diameter at four feet in height (DBH); the aspect of the side of the tree selected for study (e.g., north side, south side); the degree of shading of the tree (e.g., full sun, partial shade); occurrences of lichens other than Ravenel's cup lichen within seven feet of the ground elevation at the tree; and apparent soil moisture. Nomenclature of lichen species follows Esslinger (2011). The coordinates of the WLRs, laser level, and trees selected for study were recorded with a handheld Garmin

GPSmap 60Cx Global Positioning System (GPS) receiver. The distance and heading from the WLRs to each tree studied was measured with a Stanley PowerWinder 300 feet tape (Model No. 34-762) and recorded in decimal feet. The trees were also marked with blue flagging tape should it become necessary to collect additional data at a later date. A reference specimen of each lichen species observed was collected and sent to Dana Griffin, III for identification. Photographic documentation was collected of each indicator on each tree selected for study. These photographs were used by three other experienced wetland scientists to provide a quality assurance and quality control analysis of this author's determinations of the elevations of interest in this study. Select photographs representative of typical trees selected for study with depictions of elevations of parameters of interest are included as Exhibit 1. Photographs were also taken of the laser level setup and representative areas of the vegetative community (Figure Nos. 6 and 7).

Statistics calculated for this project include the mean normal pool elevation for each wetland. The normal pool elevations for the four trees selected at each WLR were averaged in Microsoft Excel to determine this mean elevation. In a similar manner, the overall mean lower limit of prevalent Ravenel's cup lichen colonies was calculated by averaging the data collected at the four trees at each WLR. The overall mean lower limit of prevalent crustose lichen colonies was calculated in the same way.

The water level data from the WLRs was used to provide a 'desk assessment' of the elevation of the seasonal high, normal pool, and peak high water elevations of sufficient duration to kill lichen thalli. Water elevations recorded as above ground (including projected data) for each WLR for the period from June 2007 to August 2011 were averaged to provide an approximate quantitative normal pool elevation. Those water elevations from this same period greater than the normal pool elevation were averaged to provide an estimate of the seasonal high. This method of calculating the seasonal high and normal pool from hydrodata was taken from SFWMD (2010).

Results

All of the elevations provided in this section were normalized to the ground elevation at the WLRs. A summary table of the normalized individual and mean elevations of the biological indicators of normal pool, Ravenel's cup lichen lines, crustose lichen lines, and quantitative seasonal high and normal pool, for each tree and wetland, is provided in the Discussion section as Table No. 1.

Wetland No. 1

Tree No. 1

All of the trees selected in this study were pond-cypress. Tree No. 1 was located 69.80 feet east-southeast of WLR 2.1. The approximate height and DBH of Tree No. 1 was 35.00 feet and 0.63 foot, respectively, and the tree was moderately shaded. The lichens selected for study were on the west side of the tree. The soil was dry at Tree No. 1. The normal pool elevation at this tree was estimated at 1.45 feet and the indicators were the absence of lichen colonies and buttress inflection point. The Ravenel's cup lichen line was at 1.80 feet. The crustose lichen line was at 2.30 feet. Other lichens noted on this tree include *Parmotrema praesorediosum* (Nyl.) Hale, *Pseudoparmelia uleana* (Müll. Arg.) Elix, and an unidentified crustose lichen.

Tree No. 2

Tree No. 2 was located 76.10 feet east-southeast of WLR 2.1. The approximate height and DBH of Tree No. 2 was 30.00 feet and 0.34 foot, respectively, and the tree was moderately shaded. The lichens selected for study were on the west side of the tree. The soil was dry at Tree No. 2. The normal pool elevation at this tree was estimated at 1.59 feet and the indicators were the absence of lichen colonies, buttress inflection point, and rippled bark. The Ravenel's cup lichen line was at 1.70 feet. The crustose lichen line was at 2.80 feet. Other lichens noted on this tree include *Pseudoparmelia uleana* (Müll. Arg.) Elix, *Usnea mutabilis* Stirton, and an unidentified crustose lichen.

Tree No. 3

Tree No. 3 was located 50.00 feet southeast of WLR 2.1. The approximate height and DBH of Tree No. 3 was 40.00 feet and 0.54 foot, respectively, and the tree was moderately shaded. The lichens selected for study were on the north side of the tree. The soil was dry at Tree No. 3. The normal pool elevation at this tree was estimated at 1.56 feet and the indicators were the absence of lichen colonies, buttress inflection point, and rippled bark. The Ravenel's cup lichen line was at 1.60 feet. The crustose lichen line was at 2.50 feet. Other lichens noted on this tree include *Parmotrema praesorediosum* (Nyl.) Hale, and an unidentified crustose lichen.

Tree No. 4

Tree No. 4 was located 62.00 feet southeast of WLR 2.1. The approximate height and DBH of Tree No. 4 was 30.00 feet and 0.75 foot, respectively, and the tree was moderately shaded. The lichens selected for study were on the west side of the tree. The soil was dry at Tree No. 4. The normal pool elevation at this tree was estimated at 1.40 feet and the indicators were the absence of lichen colonies and buttress inflection point. The Ravenel's cup lichen line was at 1.60 feet. The crustose lichen line was at 2.50 feet. Other lichens noted on this tree include an unidentified crustose lichen.

Wetland No. 2

Tree No. 1

Tree No. 1 was located 48.50 feet east of WLR 5.1. The approximate height and DBH of Tree No. 1 was 45.00 feet and 0.52 foot, respectively, and the tree was significantly shaded. The lichens selected for study were on the west side of the tree. The soil was moist at Tree No. 1. The normal pool elevation at this tree was estimated at 0.16 foot and the indicators were the absence of lichen colonies, buttress inflection point, moss collar, and rippled bark. The Ravenel's cup lichen line was at 0.90 foot. The crustose lichen line was at 1.60 feet. Other lichens noted on this tree include *Cryptothecia rubrocincta* (Ehrenb.: Fr.) G. Thor, *Usnea mutabilis* Stirton, *Parmotrema perforatum* (Jacq.) A. Massal., and an unidentified crustose lichen.

Tree No. 2

Tree No. 2 was located 53.50 feet east of WLR 5.1. The approximate height and DBH of Tree No. 2 was 45.00 feet and 0.56 foot, respectively, and the tree was significantly shaded. The lichens selected for study were on the west side of the tree. The soil was moist at Tree No. 2. The normal pool elevation at this tree was estimated at 0.03 foot and the indicators were the absence of lichen colonies and rippled bark. The Ravenel's cup lichen line was at 0.9 foot. The crustose lichen line was at 1.6 feet. Other lichens noted on this tree include *Cryptothecia rubrocincta* (Ehrenb.: Fr.) G. Thor, *Usnea mutabilis* Stirton, *Parmotrema perforatum* (Jacq.) A. Massal., *Parmotrema praesorediosum* (Nyl.) Hale, and an unidentified crustose lichen.

Tree No. 3

Tree No. 3 was located 74.00 feet east of WLR 5.1. The approximate height and DBH of Tree No. 3 was 50.00 feet and 0.67 foot, respectively, and the tree was moderately shaded. The lichens selected for study were on the west side of the tree. The soil was moist at Tree No. 3. The normal pool elevation at this tree was estimated at below ground (relative to the ground at the WLR) at -0.34 foot and the indicators were the absence of lichen colonies, buttress inflection point, and rippled bark. The Ravenel's cup lichen line was at 0.4 foot. The crustose lichen line was at 1.1 feet. Other lichens noted on this tree include *Cryptothecia rubrocincta* (Ehrenb.: Fr.) G. Thor, *Usnea mutabilis* Stirton, *Parmotrema perforatum* (Jacq.) A. Massal., *Parmotrema praesorediosum* (Nyl.) Hale, and an unidentified crustose lichen.

Tree No. 4

Tree No. 4 was located 39.50 feet east-southeast of WLR 5.1. The approximate height and DBH of Tree No. 4 was 50.00 feet and 0.67 foot, respectively, and the tree was moderately shaded. The lichens selected for study were on the north side of the tree. The soil was moist at Tree No. 4. The normal pool elevation at this tree was estimated at 0.39 foot and the indicators were the absence of lichen colonies and rippled bark. The Ravenel's cup lichen line was at 0.9 foot. The crustose lichen line was at 1.3 feet. Other lichens noted on this tree included *Cryptothecia rubrocincta* (Ehrenb.: Fr.) G.

Thor, *Usnea mutabilis* Stirton, *Parmotrema perforatum* (Jacq.) A. Massal., *Parmotrema praesorediosum* (Nyl.) Hale, and an unidentified crustose lichen.

Wetland No. 3

Tree No. 1

Tree No. 1 was located 22.00 feet east of WLR 12.2. The approximate height and DBH of Tree No. 1 was 15.00 feet and 0.10 foot, respectively, and the tree was significantly shaded. The lichens selected for study were on the south side of the tree. The soil was moist at Tree No. 1. The normal pool elevation at this tree was estimated at 0.90 foot and the indicators were the absence of lichen colonies and a subtle moss collar. The Ravenel's cup lichen line was at 1.05 feet. The crustose lichen line was at 1.65 feet. Other lichens noted on this tree include *Cryptothecia rubrocincta* (Ehrenb.: Fr.) G. Thor, *Parmotrema perforatum* (Jacq.) A. Massal., *Parmotrema praesorediosum* (Nyl.) Hale, and two unidentified crustose lichens.

Tree No. 2

Tree No. 2 was located 34.00 feet east of the WLR. The approximate height and DBH of Tree No. 2 was 50.00 feet and 0.82 foot, respectively, and the tree was moderately shaded. The lichens selected for study were on the north side of the tree. The soil was moist at Tree No. 2. The normal pool elevation at this tree was estimated at 0.68 foot and the indicators were the absence of lichen colonies and buttress inflection point. The Ravenel's cup lichen line was at 1.00 foot. The crustose lichen line was at 1.50 feet. Other lichens noted on this tree include *Cryptothecia rubrocincta* (Ehrenb.: Fr.) G. Thor, *Pseudoparmelia uleana* (Müll. Arg.) Elix, *Parmotrema perforatum* (Jacq.) A. Massal., *Parmotrema praesorediosum* (Nyl.) Hale, *Usnea mutabilis* Stirton, and an unidentified crustose lichen.

Tree No. 3

Tree No. 3 was located 33.50 feet east-southeast of WLR 12.2. The approximate height and DBH of Tree No. 3 was 50.00 feet and 0.71 foot, respectively, and the tree was significantly shaded. The lichens selected for study were on the north side of the tree.

The soil was moist at Tree No. 3. The normal pool elevation at this tree was estimated at 0.89 foot and the indicators were the absence of lichen colonies, buttress inflection point, and subtle moss collar. The Ravenel's cup lichen line was at 1.18 feet. The crustose lichen line was at 1.34 feet. Other lichens noted on this tree include *Cryptothecia rubrocincta* (Ehrenb.: Fr.) G. Thor, *Pseudoparmelia uleana* (Müll. Arg.) Elix, *Parmotrema praesorediosum* (Nyl.) Hale, *Usnea mutabilis* Stirton, and an unidentified crustose lichen.

Tree No. 4

Tree No. 4 was located 70.50 feet southeast of the WLR. The approximate height and DBH of Tree No. 3 was 50.00 feet and 0.67 foot, respectively, and the tree was significantly shaded. The lichens selected for study were on the west side of the tree. The soil was moist at Tree No. 4. The normal pool elevation at this tree was estimated at 0.65 foot and the indicators were the absence of lichen colonies, buttress inflection point, and subtle moss collar. The Ravenel's cup lichen line was at 1.25 feet. The crustose lichen line was at 1.45 feet. Other lichens noted on this tree include *Cryptothecia rubrocincta* (Ehrenb.: Fr.) G. Thor, *Parmotrema praesorediosum* (Nyl.) Hale, and an unidentified crustose lichen.

Discussion

This section will provide a comparison between the relative elevations of crustose lichen lines, peak high water elevations, quantitative seasonal high and normal pool, Ravenel's cup lichen lines, and biological indicators of normal pool. The hydrodata recorded by the WLRs will be used to provide a quantitative estimate of the seasonal high and normal pool elevations to evaluate consistency, if any, with the biological indicators, although with some caution. There is only limited literature regarding best methods for calculating and interpreting the normal pool and seasonal high from hydrodata, or for comparing these calculated levels with field indicators. For the purposes of this paper, the normal pool elevation was calculated as the mean annual above-ground water elevation from June 2007, when the berm breaches were repaired, to August 2011. The seasonal high was calculated as the mean annual water elevation occurring above normal pool for the same time period. These two quantitative water levels are provided in Table 1, as are the elevations of biological indicator levels observed for each parameter of interest for each tree and the mean elevation for each parameter for each wetland. Figure Nos. 8 through 10 are provided as a graphical depiction of all parameters of interest for each wetland, including hydrodata for the period from May 2006 through August 2011. Rainfall data for the period from August 2007 to August 2011 was retrieved from the Ormond Beach Municipal Airport, Weather Station No. KFLORMON17, located nine miles southeast of the study site (Weather Underground, Inc. 2011). Figure 11 is a graphical depiction of the mean elevations of the parameters of interest in this study and is provided for comparative purposes across and within wetlands.

Crustose Lichen Lines

Upon assessment of the data depicted in the following figures, the elevations of several parameters of interest are comparable to expected conditions, while others appear inconsistent. In Wetland No. 1, the mean elevation of crustose lichen lines is 2.52 feet while the peak of high water of sufficient duration to kill lichens is only 1.60 feet. This suggests that an earlier, unrecorded high water event could have formed this lichen line.

Wetland No.	WLR No.	Tree No.	Normal Pool (Quantitative) Elevation (ft)	Seasonal High (Quantitative) Elevation (ft)	Normal Pool (Biological Indicators) Elevation (ft)	Mean Normal Pool (Biological Indicators) Elevation (ft)	Ravenel's Cup Lichen Line Elevation (ft)	Mean Ravenel's Cup Lichen Line Elevation (ft)	Crustose Lichen Line Elevation (ft)	Mean Crustose Lichen Line Elevation (ft)
1	2.1	1	0.91	1.21	1.45	1.50	1.79	1.69	2.32	2.52
		2			1.59		1.71		2.83	
		3			1.56		1.64		2.49	
		4			1.40		1.64		2.45	
2	5.1	1	0.71	1.21	0.16	0.06	0.90	0.77	1.60	1.40
		2			0.03		0.88		1.57	
		3			-0.34		0.39		1.09	
		4			0.39		0.91		1.33	
3	12.2	1	0.80	1.18	0.90	0.78	1.05	1.11	1.65	1.48
		2			0.68		0.96		1.48	
		3			0.89		1.18		1.34	
		4			0.65		1.25		1.45	

Table 1. Normalized Mean Elevations of Recorded Water Levels and Hydrologic Indicators

Wetland No. 1 - Water Levels and Indicators

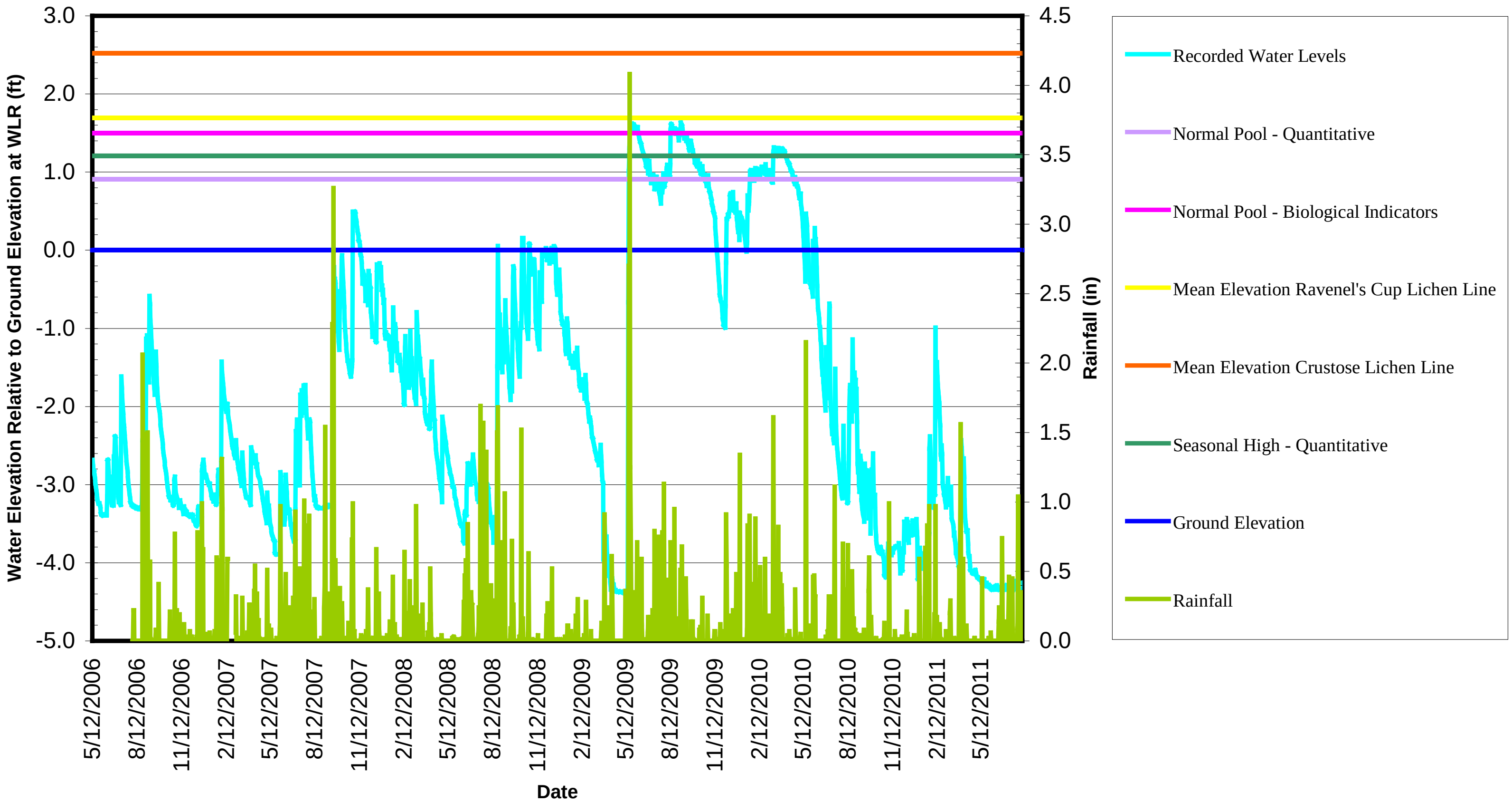

Figure 8. Recorded Water Levels, Rainfall, and Hydrologic Indicators for Wetland No. 1
(Rainfall data from Weather Underground, Inc. Recorded water level data provided by BDA, Inc.)

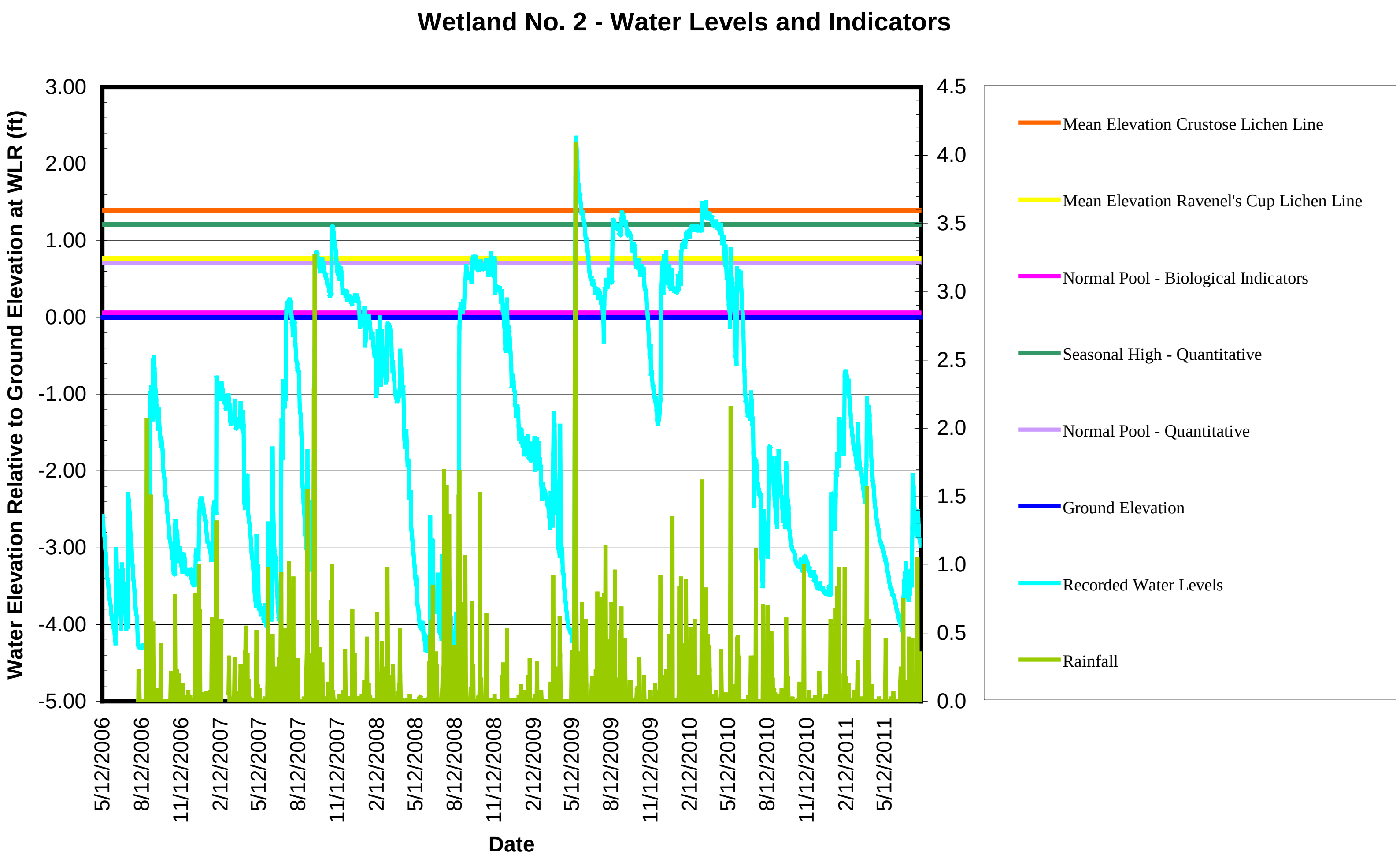

Figure 9. Recorded Water Levels, Rainfall, and Hydrologic Indicators for Wetland No. 2
(Rainfall data from Weather Underground, Inc. Recorded water level data provided by BDA, Inc.)

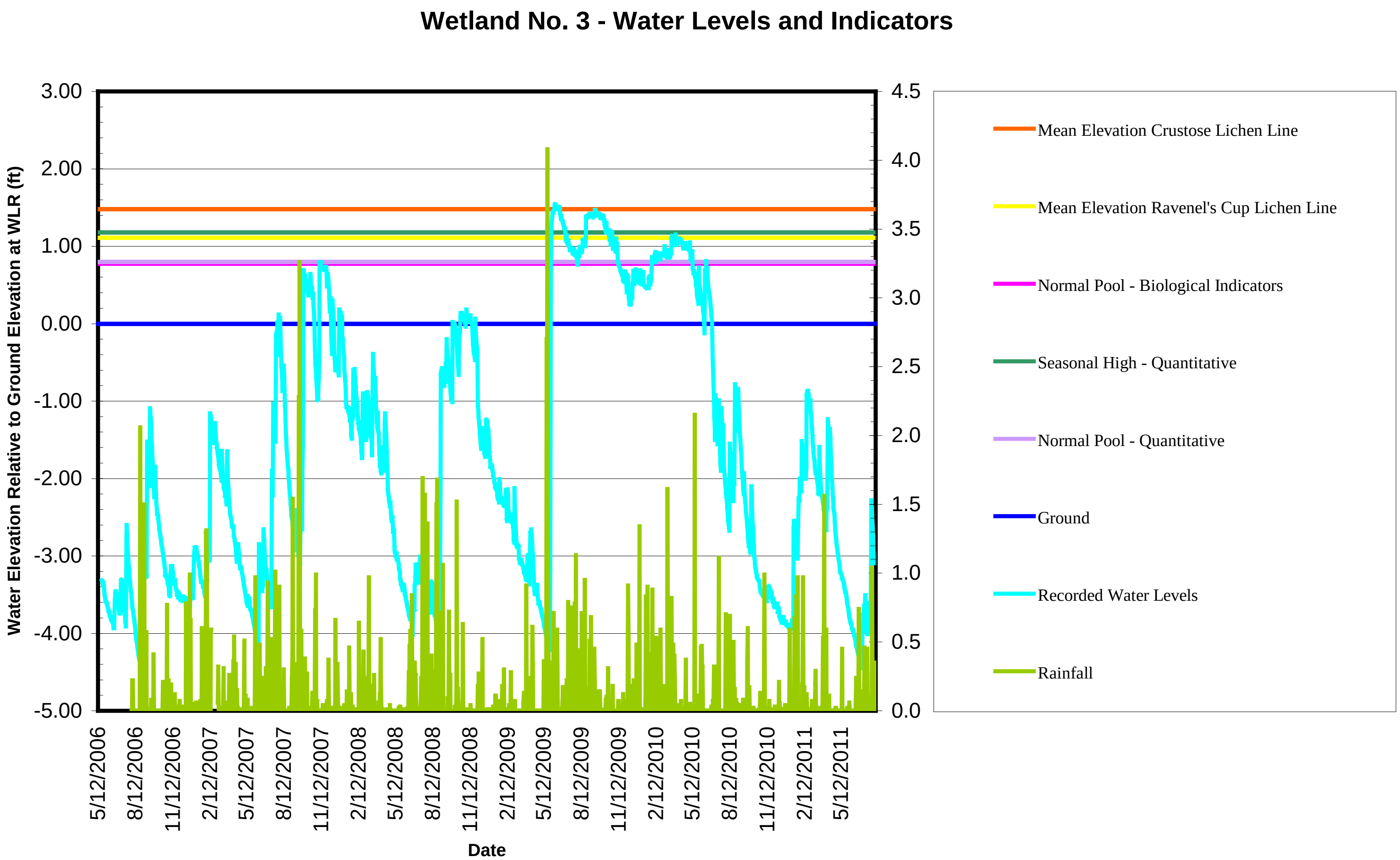

Figure 10. Recorded Water Levels, Rainfall, and Hydrologic Indicators for Wetland No. 3
(Rainfall data from Weather Underground, Inc. Recorded water level data provided by BDA, Inc.)

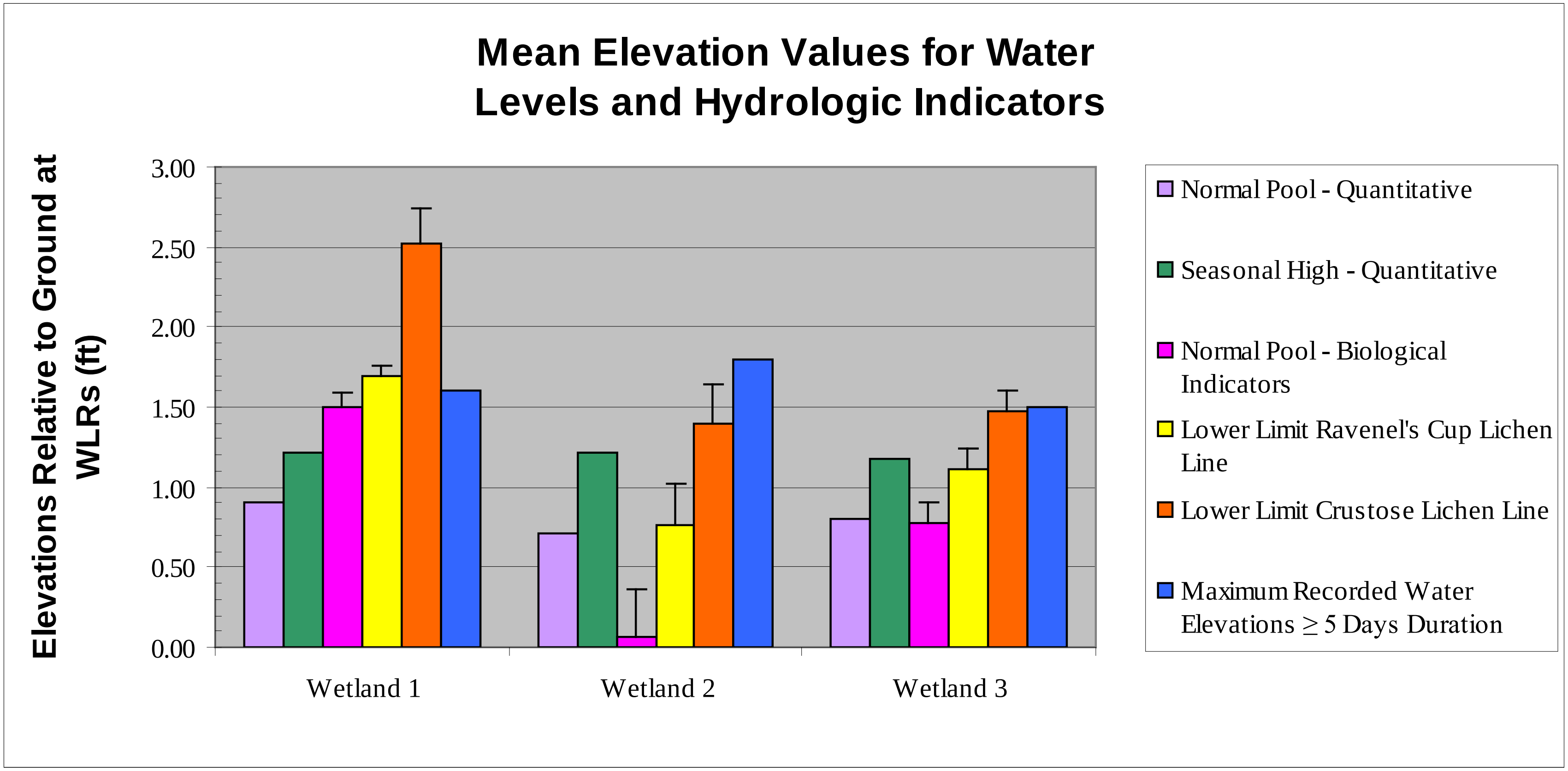

Figure 11. Mean Values for Water Levels and Indicators for Wetlands in Vicinity of Each WLR
(Recorded water level data provided by BDA, Inc.)

The recorded hydrodata only dates back to May 2006 and a significantly high number of tropical storms and hurricanes occurred throughout Florida in 2004, most notably hurricanes Charley (Aug. 13), Frances (Sept. 5), Ivan (Sept. 16) and Jeanne (Sept. 26) (FEMA 2009). Since lichens have slow rates of recolonization and growth, the elevations of the crustose lichen lines in this wetland may be explained by these antecedent storms (Hale 1984, Clewell et al 2009). However, the crustose lichen lines at Wetland Nos. 2 and 3 were not similarly positioned. If high water events that occurred earlier than the recorded hydrodata set the crustose lichen lines in Wetland No. 1, a similar effect should have been observed in Wetland Nos. 2 and 3. The cause of this discrepancy is unknown at this time, but this may be just an effect of variability in the data compounded by a small sample size.

There were additional findings regarding crustose lichen lines that were inconsistent with the literature and among wetlands. The mean elevation of crustose lichen lines in Wetland No. 2 were nearly 0.50 foot lower than recorded peak high water elevations. Rain events occurred in early May 2009 that increased the water level in this wetland to 1.80 feet. The water remained at that level for seven days. According to the hydrodata and the literature, this flood was of sufficient duration to kill lichens below that level. However, the mean elevation of crustose lichen lines in this wetland was only 1.40 feet. This lichen line elevation was likely caused by rain events later in May and early in June 2009. Water elevations during this time period remained at 1.40 feet for 18 consecutive days. This indicates that lichens can survive inundation longer than 5-7 days and that other factors may have caused the lichen deterioration in the findings of Hale (1984) and Clewell et al. (2009). Hale’s observations were of lichens on a single tree along the banks of the Peace River. The flood event that formed the lichen line in that study would have increased the water volume and elevation of the river, which in turn would have increased the rate of flow. This likely resulted in a scouring effect on the lichens on the tree Hale studied, which could have contributed to a decreased amount of time necessary to kill the lichen. No scouring would have occurred in the wetlands in this study as these were lentic systems.

In Clewel et al. (2009), Griffin removed lichens from the study site and conducted his inundation experiment at an off-site laboratory. He found that lichens can not tolerate flooding longer than five days. However, as lichens do not adapt well to being moved (Dana Griffin, III, Gainesville, Florida; pers. comm. 2010), his estimate may be too short. That the crustose lichens in this paper survived the shorter flood in early May 2009 but were killed during the longer flood a few weeks later seems to indicate a greater tolerance to inundation than previously suggested. More research is needed to determine if the findings of this study have merit, particularly because there are so few replicates and so much variability in the data.

Quantitative Seasonal High and Normal Pool

The spatial relationship between the quantitative seasonal high and normal pool elevations showed consistency with each other across wetlands but not with the other parameters of interest in this study. These two elevations were lower than the biological indicators of normal pool, Ravenel's cup lichen lines, and crustose lichen lines in Wetland No. 1, but higher than these parameters in Wetland Nos. 2 and 3. The reasons for this inconsistency are likely the variability in the data discussed at length below. Additionally, as discussed at the beginning of the discussion section, due to the limited availability of literature regarding the best methods for calculating these levels from hydrodata, these two elevations may not have any real relationship to the parameters of interest as they occur in field conditions. The intent for their inclusion in this study was merely to provide a casual assessment of their potential relationship with the real-world hydrologic indicators.

Biological Indicators of Normal Pool and Ravenel's Cup Lichen Lines

The mean elevations of the biological indicators of normal pool were approximately consistent in their spatial relationship with the other parameters of interest in Wetland Nos. 1 and 3, but showed some inconsistency in Wetland No. 2. In Wetland Nos. 1 and 3, the Ravenel's cup lichen line is approximate to the elevation of the biological indicators of normal pool, but these are dramatically different in Wetland No. 2 (Figure

11). One possible explanation of this is the variability of the data, which may be related to extreme fluctuations and changes in water levels on this site.

Oscillating patterns of drier and wetter conditions caused by alterations to hydrology on the site confound any attempts to determine many of the parameters of interest in this study. Specifically, the biological indicators of normal pool on this site are diffuse and often contradict one another. This is due to differences between the capacity of some indicators to persist through hydrological changes, and in differences in the time necessary to form the indicators. A buttress inflection point that formed under one hydrological regime will persist through subsequent periods of altered hydrology. If wetter conditions return with another site alteration, as is the case on this site, other indicators that form more quickly, such as moss collars, will indicate a different hydrological pattern than the buttress inflection points. This is one reason why this type of study would be best conducted on unaltered sites, as the indicators would be undisturbed and likely to better coincide with one another.

The mean elevations of Ravenel's cup lichen lines also showed some inconsistencies among wetlands and with the literature. In Wetland No. 1, this lichen line was at the approximate elevation of the peak high water levels, which might be assumed to be the expected condition. However, this was not the case in Wetland Nos. 2 and 3. In these wetlands this lichen line was well below the level of several peak high water events of sufficient duration to kill lichens. This indicates that Ravenel's cup lichen may indeed be more tolerant of inundation than other lichens, as predicted by casual observation at the beginning of this study.

As suspected, Ravenel's cup lichen lines were consistently distributed at higher elevations than the biological indicators of normal pool, which indicates there is likely a spatial relationship between these hydrologic indicators. The mean difference between the mean elevations of Ravenel's cup lichen lines and the mean elevations of the biological indicators of normal pool was 0.41 foot. This indicates that Ravenel's cup lichen lines may be consistently located 0.41 foot above normal pool, but this study needs to be duplicated at additional sites to draw such conclusions. To further the work conducted in this study, and to provide a more comprehensive analysis, a significantly greater number of replicates from additional wetlands throughout central Florida are needed. Additional replicates at unaltered sites would eliminate many of the questions posed in this study, particularly whether the inconsistent spatial relationships among parameters across wetlands are related to environmental differences or to a small sample size. With more work, more meaningful conclusions could be made regarding the true spatial relationship between the parameters of interest in this study and wetland hydropattern.

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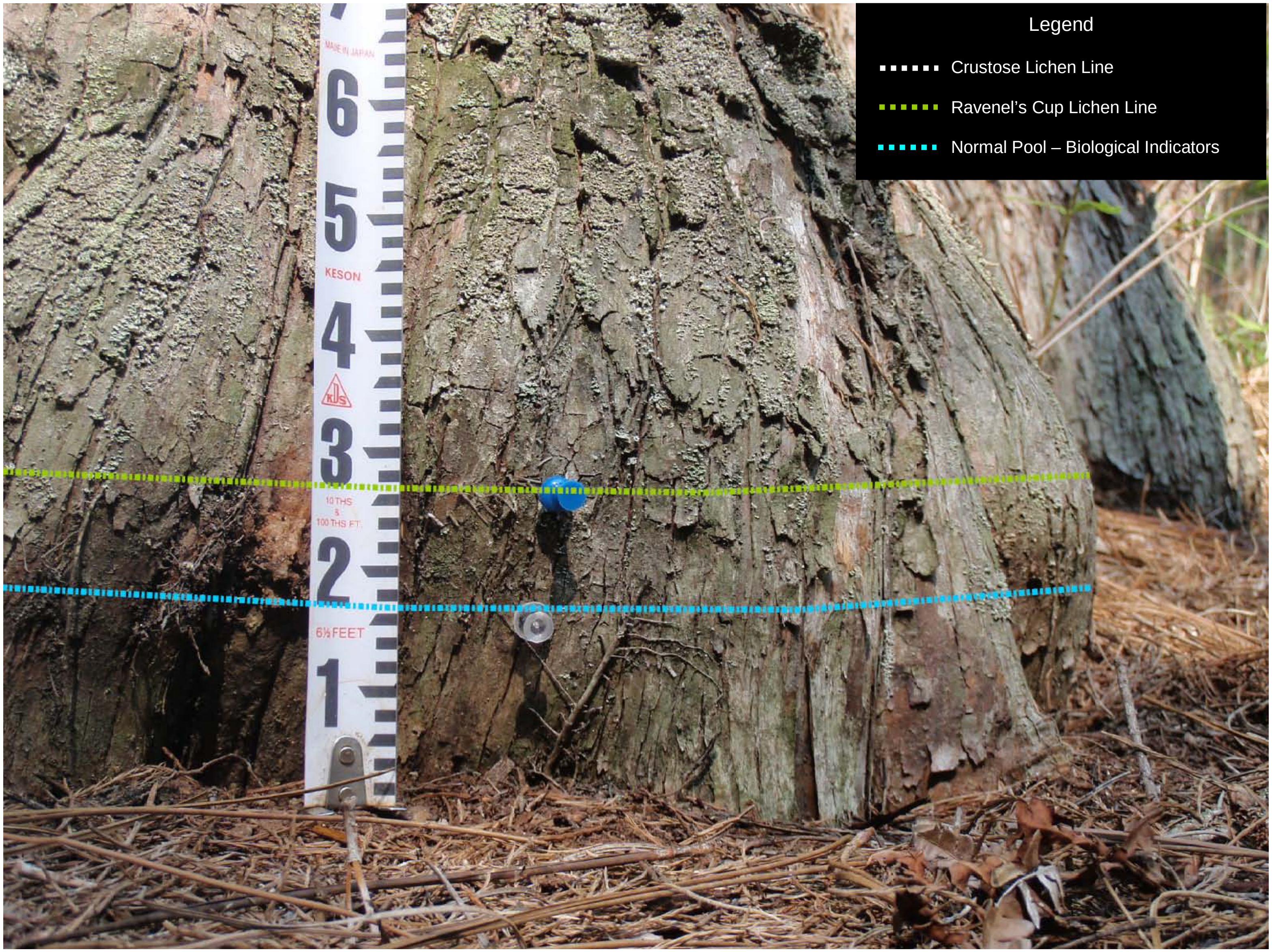
Exhibit No. 1

Select Photographs of Representative Trees

And Hydrologic Indicators Selected for Study

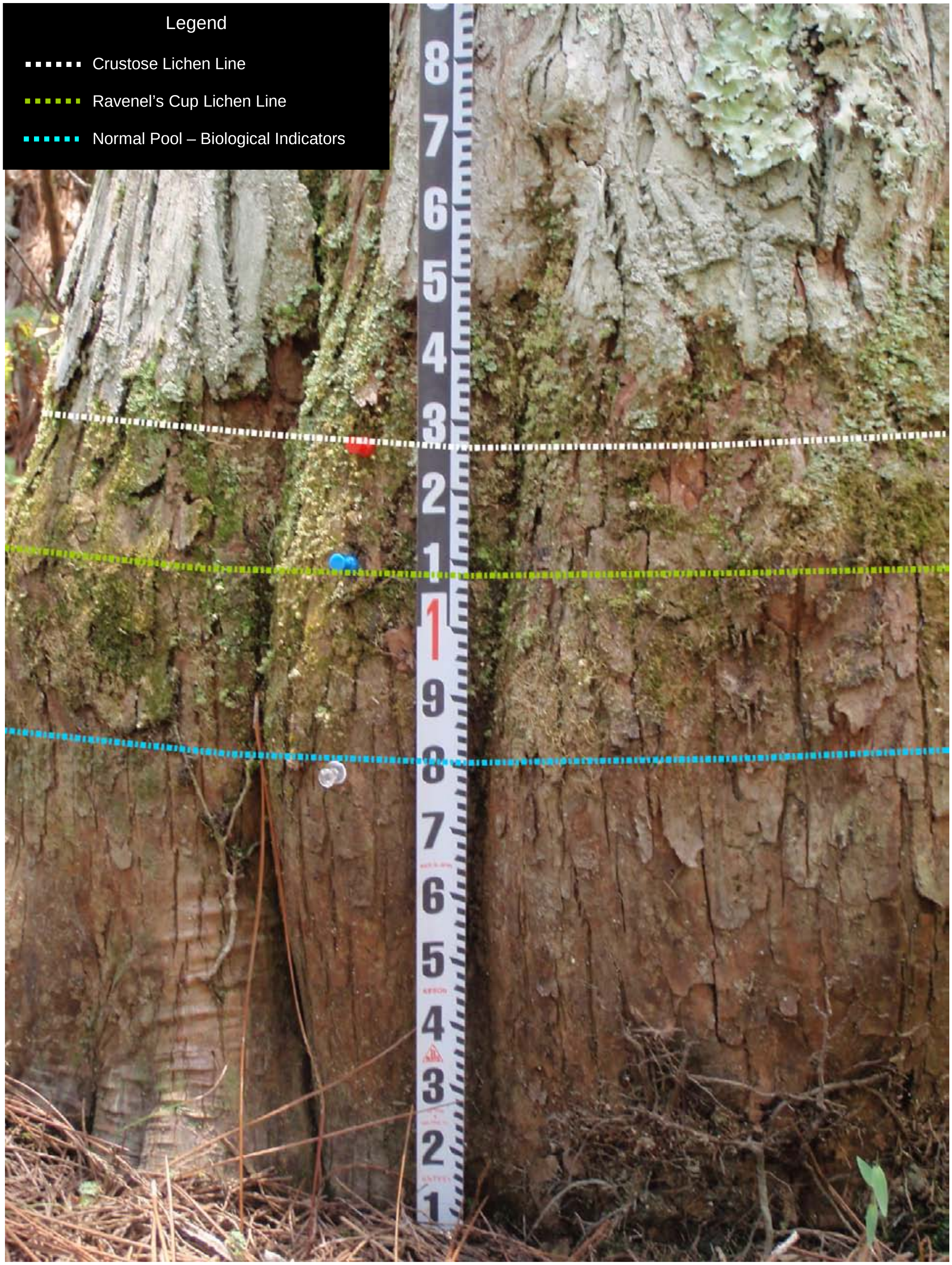
Wetland 1. Tree 2. Photo 1 of 2.



Wetland 1. Tree 2. Photo 2 of 2.

Wetland 2. Tree 2. Photo 1 of 1.

Wetland 3. Tree 3. Photo 1 of 2.



Wetland 3. Tree 3. Photo 2 of 2.