Monitoring of the Lac des Allemands Swamp (BA-34-2)
Hydrologic Restoration

2021 ANNUAL REPORT

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INTRODUCTION

The Hydrologic Restoration and Vegetative Planting in the 970 ha Lac des Allemands Swamp (BA-34-2) project provided for pre-construction forested and herbaceous vegetation station establishment and data collection in project and reference area swamps beginning in fall of 2016. Monitoring the entire 2017 year provided data for computation of swamp production prior to project construction. Monitoring during 2018 - 2021 enabled us to begin measuring the response of the swamp to project completion. Interestingly, measurable project benefits manifested nearly instantaneously.

Specifically, our responsibilities include only the forested swamp vegetation and herbaceous vegetation variables of the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) Task Force approved BA-34-2 monitoring plan dated July 2016. The Coastal Protection and Restoration Authority of Louisiana (CPRA) Operations Division has developed a standard operating procedures (SOP) manual entitled "A Standard Operating Procedures Manual for the Coastwide Reference Monitoring SystemWetlands: Methods for Site Establishment, Data Collection, and Quality Assurance/Quality Control" (Folse et al. 2020). Those data collection variables will be monitored through subsequent contracts (years 0–19), such that collection procedures established during our initial pre-construction phase continue to maintain data consistency.

MATERIALS AND METHODS

Project Description

The BA-34-2 project involved increasing the hydrologic exchange between the swamp and Bayou Chevreuil by creating eight gaps in the spoil bank. To capture restoration benefits, sixteen project-specific 625 m^2 (25 m x 25 m) forested swamp stations that were established in 2016 containing 1,049 trees which were also sampled in the project (Sites 2-8) and reference (Site 1) areas during 2017 - 2021 (Figure 1).

Planning and Layout of Vegetation Survey

Within each of the sixteen stations, four 2 m x 2 m plots for sampling herbaceous cover and canopy closure were sampled for a total of 64 herbaceous plots and microdensiometer measurements, respectively. Each herbaceous plot was located roughly 5 m from each station corner pole and situated such that no trees were located in any herbaceous plots.

Forested Swamp Vegetation

Sixteen 625 m^2 (25 m x 25 m) forested swamp stations in the BA-34-2 project and reference areas were sampled. The directional corners (NE, NW, SE, & SW) of these stations were marked with 3 m sections of PVC pipe and UTM NAD 83 coordinates were established at the southeast corner of each station with a differential GPS (DGPS) with sub-meter accuracy. The pipe at each of these is painted with three stripes and all 1,049 tree tags are pointed at the three-striped pipe of each station. A tag was fastened to each tree with a 3" deck screw so that the screw could be backed out as the tree gained diameter over the 20-year monitoring effort.

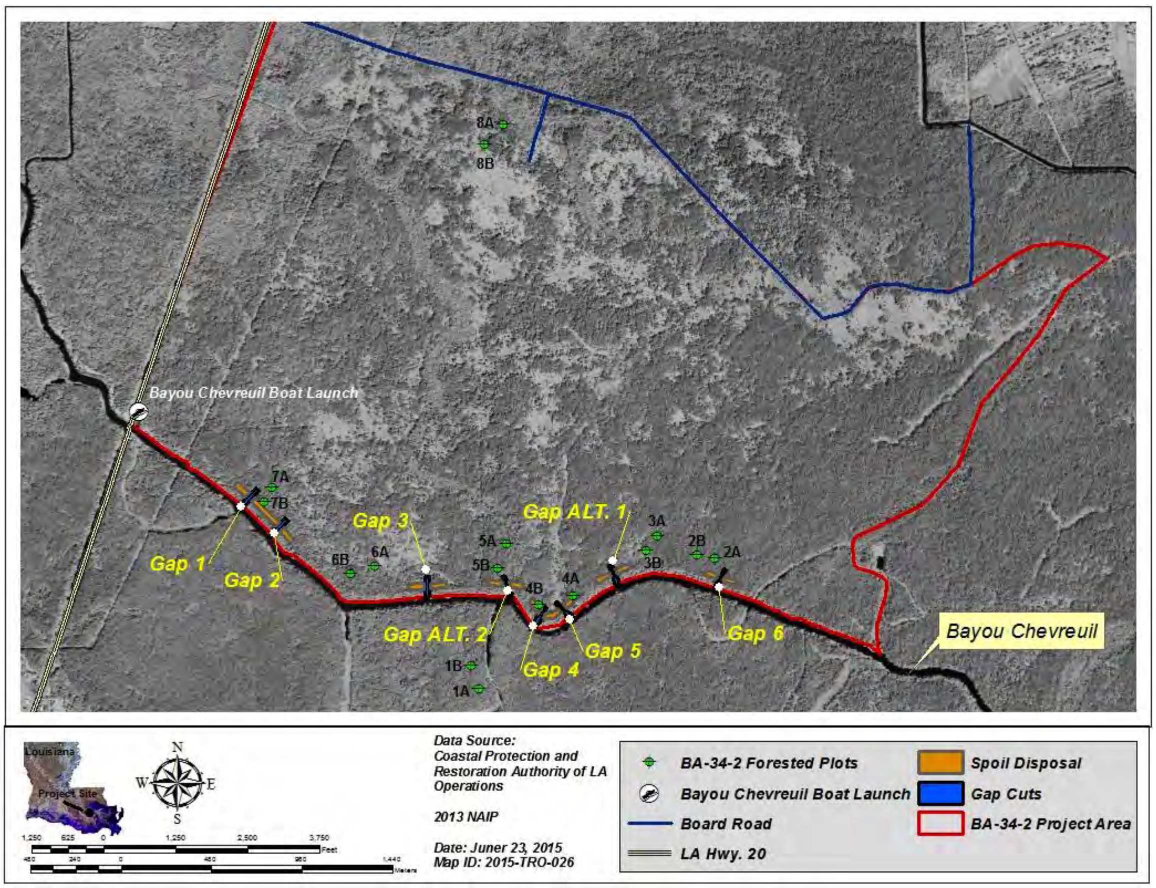

Figure 1. Aerial map showing the location of the sixteen 625 m^2 stations (eight sites) established at the BA-34-2 Lac des Allemands swamp restoration project. Locations of the eight gaps are also shown.

In addition, a second screw was placed at the base level of each tag 90 degrees on the backside of each tree to increase accuracy of subsequent annual diameter measurements (Shaffer et al. 2009, 2016). Each tree also is tagged with one strand of bright survey tape; every other year a second strand of survey tape is fitted or removed from each tree to increase the efficiency of locating and measuring all trees. Trees were identified to species, canopy cover was estimated at each of the four 2 m x 2 m herbaceous vegetation plots, diameter at breast height (DBH – actually at 2 m to avoid buttress swell; Shaffer et al. 2009, 2016) was measured for canopy and midstory trees (≥ 4 cm diameter). Herbaceous cover, by species, was estimated within the forested stations at each of the four 2 m x 2 m plots located roughly 5 m from station diagonals. Forested swamp stations were sampled during late fall (October through early December) of 2016 - 2021. In addition, four 0.25 m^2 litterfall traps were randomly deployed at each station once the 2016 canopy leaves had completely fallen from all trees. These traps are swept about every 2 months and roughly monthly during periods of high litterfall until all leaves have fallen (generally mid- to late-March of the following year). The leaves are sorted to the two canopy species *Nyssa aquatica* and *Taxodium distichum*, and Midstory (almost exclusively Acer *rubrum* var. *drummondii*), dried and weighed. Canopy closure was estimated with a microdensiometer at each of the 64 herbaceous plots in the fall of 2016 and annually through 2021.

Herbaceous Vegetation

As mentioned above, four specific 4 m^2 (2 m x 2 m) herbaceous plots within each of the sixteen 625 m^2 forested stations were sampled to estimate herbaceous vegetation cover by species in 5 % increments (Shaffer et al. 2009, 2016). Four 2 m PVC stakes permanently mark each herbaceous plot. Herbaceous plots were sampled each fall of 2016 – 2021.

Soil Strength

Soil cores were collected during fall of 2017 and spring of 2018. Four cores were taken at each of the 16 stations using a battery-powered impact driver with a sharpened aluminum pipe attached to it that was about 30 cm long with a diameter of 3.5 cm. The soil cores were drilled to a depth of 10 cm and all four cores were pooled into a labeled plastic bag. The soil samples were stored in a ventilation oven in the wetland lab at Southeastern Louisiana University where they were dried for several weeks. Once the moisture had been completely removed from the samples, they were weighed for dry weight. The dry weight and the volume of the entire soil sample were then used to calculate bulk density.

To calculate the percent organic material within the soil, the samples were burnt in a ceramic kiln at 600 °F for several hours. After burning off all organic material, the samples were returned to the ventilation oven for 24 hours and re-weighed for mineral weight. The percent organic material was then calculated by comparing the mineral weight to the total dry weight.

Chronological Summary of Work

All field trips involve the Chief Scientist (Dr. Gary Shaffer) and two to five seasoned Field Scientists. In 2016, the sites were located near and roughly halfway between the restoration gap locations to crisply capture maximum and minimum project benefits, respectively. Stations within sites were located at least 100 m apart to ensure true replication. In addition, a healthy reference site was located on LSU Island and a site also was located near the northern border (Figure 1), which was conceived unlikely to benefit from the gaps in Bayou Chevreuil (yet it too has benefited). From 2017 through 2021, litterfall traps were swept regularly and all vegetation measurements were repeated during fall of each year.

Each year, tree diameter was used to compute tree wood biomass using published regression formulas (Clark et al. 1985, Muzika et al. 1987, Scott et al. 1985). Wood production was calculated as the difference in wood biomass per year. Wood production per tree was then summed by species category per station and then converted to total wood production per square meter per year (g m^{-2} y^{-1}).

Data Processing and QA/QC Procedures

My team has been following EPA QA/QC protocols annually since 2000 (Lee Wilson & Associates 2001). Our results using these procedures are published in international journals (e.g., Shaffer et al. 2009, 2016, 2020). In addition, for the BA-34-2 monitoring project, we also are following QA/QC protocols of CPRA, which differ only in formatting templates.

Data Analysis

Forest data were analyzed with the GLM procedure of SYSTAT 13 software. For wood net primary production, because of pseudoreplication (i.e., the exact same trees are measured every year), a repeated measures analysis was performed and Hotelling-Lawley Trace F values are reported. Herbaceous data were analyzed using the non-metric multidimensional scaling procedure of Primer 7. Resemblance matrices were computed using Bray-Curtis similarity.

RESULTS AND DISCUSSION

Soil Strength

The bulk density ranged from 0.052 g/cm^3 at Station 3B to 0.142 g/m^3 at Station 5B (Table 1) and averaged 0.088 g/cm^3 ($\pm$ 0.006 g/cm^3 S.E.). The percent organic matter ranged from 30.57 % at Station 2A to 92.70 % at Station 8A and averaged 61.88 % ($\pm$ 4.60 % S.E.). These soils are extremely weak and quite similar to those of the far more degraded Maurepas swamp located in the Pontchartrain Basin (Shaffer et al. 2009, 2016).

Table 1. Soil bulk density and percent organic matter at the reference site (1) and seven sites located in the Lac des Allemands swamp.

Site	Station	Bulk Density (g/cm^3)	Percent Organic (%)
1	A	0.082	56.47
	B	0.075	62.98
2	A	0.083	30.57

	B	0.095	38.17
3	A	0.079	72.78
	B	0.052	76.83
4	A	0.094	69.22
	B	0.132	49.78
5	A	0.087	58.25
	B	0.142	37.01
6	A	0.073	79.10
	B	0.078	67.80
7	A	0.105	51.76
	B	0.113	54.84
8	A	0.058	92.70
	B	0.065	91.74

Forest Structure

All trees $\geq$ 4 cm diameter were labeled with aluminum tags fastened at roughly 2 m height to ensure measurements were made above all buttresses (Shaffer et al. 2009, 2016, 2020). In 2017 (We measure basal area and stem density on a decadal cycle.), basal area differed widely between sites ($F_{7,1032}$ = 8.64, $p < 0.0001$) and tree species ($F_{8,1032}$ = 36.45, $p < 0.0001$). In general, basal area averaged 53.78 m^2/ha and ranged between 43.14 m^2/ha and 69.41 m^2/ha (Figure 2), nearly double that of most of the Maurepas swamp (Shaffer et al. 2009, 2016). Interestingly, several stations in the project area had higher basal areas than the reference site (Figure 2). Although nine woody species were present, *Acer rubrum* var. *drummondii*, *Nyssa aquatica*, and *Taxodium distichum* accounted for 96.8% of the stems present. Basal areas of these three species differed widely ($F_{2,991}$ = 122.66, $p < 0.0001$; Figure 3) and was highly inconsistent across sites (interaction $F_{14,991}$ = 5.59, $p < 0.0001$). Basal area of the two main canopy species, *T. distichum* and *N. aquatica*, varied in dominance (Figure 3).

Stem density per station in 2017 averaged 65.5 and ranged between 33 and 104 (Figure 4) and was highest at the Reference Site. This is the same site as Conner and Day's (1976, 1992) "Natural" Site which had stem densities ranging between 880 and 990 stems per hectare. This site now has greater than 1,600 stems per hectare. *Acer rubrum* var. *drummondii* had the greatest number of stems only at Site 6, whereas *Nyssa aquatica* contained the greatest number of stems at five of the eight sites (Figure 5).

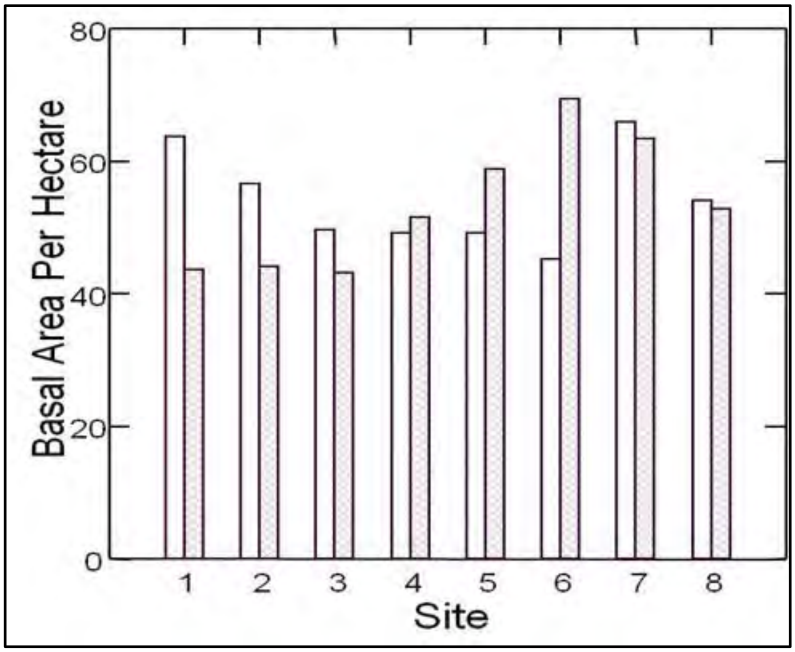

Figure 2. Overall basal area for Stations A (open) and B (hatched) at Sites 1-8 in 2017.

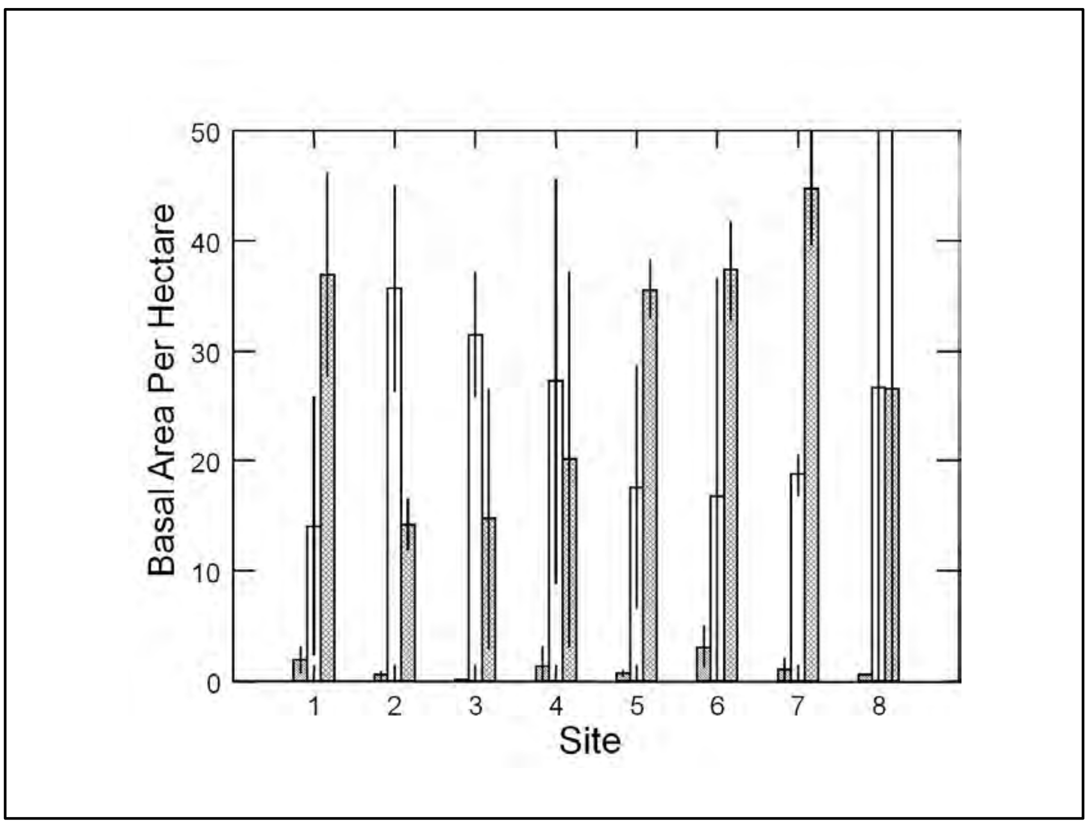

Figure 3. Basal area ($m^2/ha \pm$ s.e.) for the three dominant tree species *A. rubrum* var. *drummondii* (gray), *N. aquatica* (open) and *T. distichum* (hatched) at Sites 1-8 in 2017.

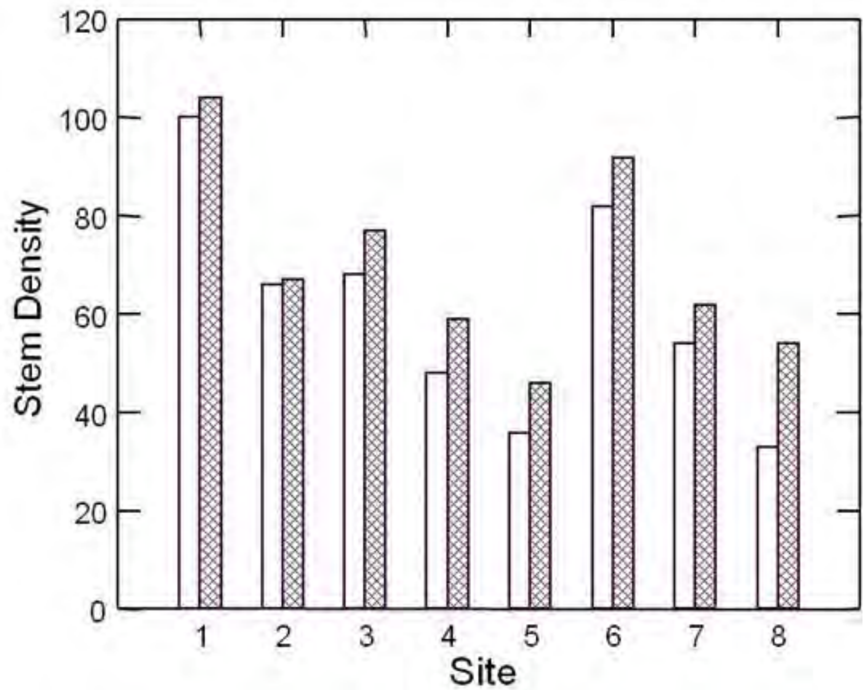

Figure 4. Overall stem density for Stations A (open) and B (hatched) at Sites 1-8 in 2017.

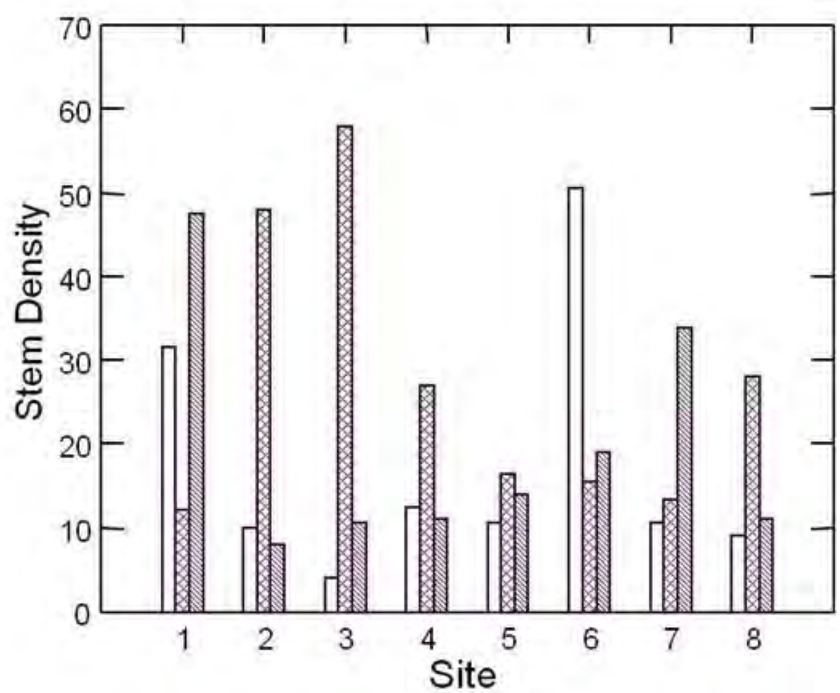

Figure 5. Stem density for the dominant midstory species *Acer rubrum* var. *drummondii* (open), and the two dominant canopy species *Nyssa aquatica* (hatched) and *Taxodium distichum* (stripped) at Sites 1-8 in 2017.

Forest Function

Canopy Closure

Percent canopy closure was nearly identical for 2016 and 2017 (Figure 6). During 2018 - 2021, canopy closure increased by about 20 percent ($F_{5,336} = 52.80$, $p < 0.0001$) demonstrating that the forest responded to the hydrologic restoration nearly instantaneously (Figure 6).

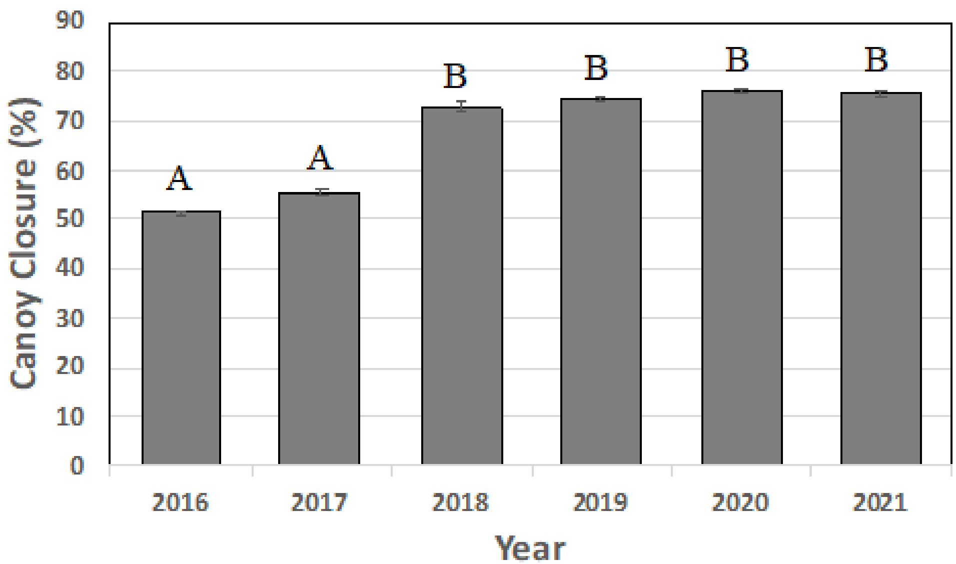

Figure 6. Percent canopy closure (mean $\pm$ s.e.) for 2016 - 2021. Bars that share letters are not statistically different according to a contrast of 2016 + 2017 vs. post-project years ($F_{1,336} = 254.48$, $p < 0.001$).

Wood Net Primary Production

Wood net primary production differed across sites ($F_{7,212} = 2.73$, $p = 0.01$; Figure 7) and species ($F_{2,212} = 147.20$, $p < 0.0001$; Figure 8). Importantly, the Reference Site had its highest wood production in 2017, whereas most of the seven sites in the Lac des Allemands swamp experienced increases from 2018 onward (Figure 7), presumably caused by the hydrologic restoration (i.e., increased sheet flow and drainage). The increase in 2019 was not as large, presumably because the sites were far more flooded than during 2018; during 2018, the swamp was completely drained for about half of the growing season. Six of seven experimental sites had their highest wood NPP in 2020. Pooled together, the 2018 - 2021 years had significantly higher diameter increases than the pre-project 2017 season (contrast $F_{1,217} = 87.38$, $p < 0.0001$).

Similarly, all three of the dominant species experienced increased wood net primary production in 2018 compared to 2017 (Figure 8). According to Bonferroni-adjusted means, baldcypress had the greatest wood NPP, followed by water tupelo, and the midstory species had the least. Interestingly, the decreased productivity during 2019 compared to 2018 was primarily attributable to baldcypress (Figure 8).

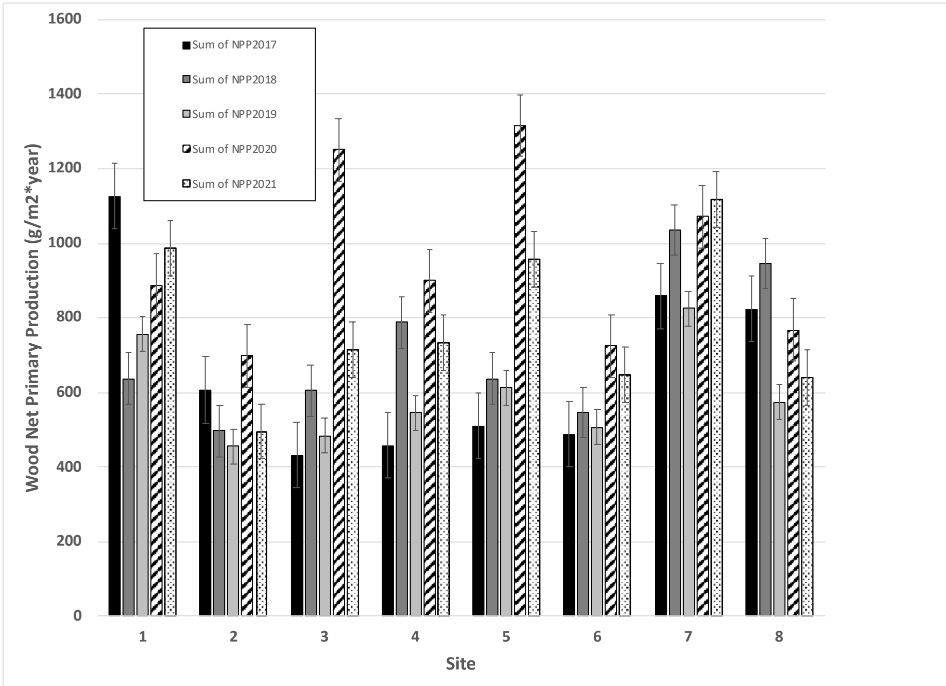

Figure 7. Net wood primary production (mean ± s.e.) for Sites 1-8 for 2017 (black), 2018 (dark gray), 2019 (light gray), 2020 (stripped) and 2021 (stippled) growing seasons.

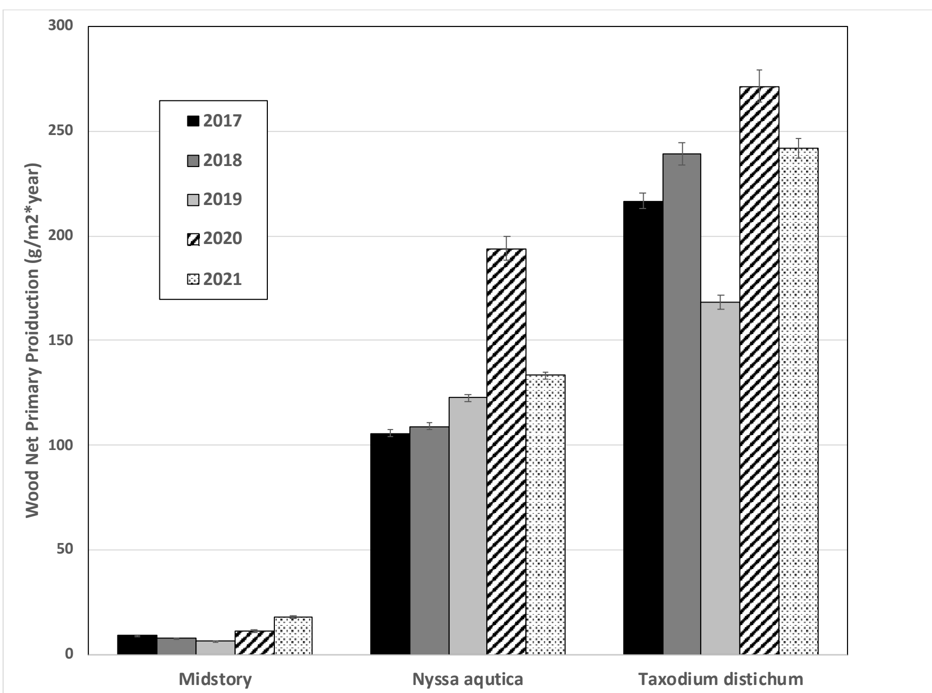

Figure 8. Net wood primary production (mean ± s.e.) for midstory species, *Nyssa aquatica*, and *Taxodium distichum* for 2017 (black), 2018 (dark gray), 2019 (light gray), 2020 (stripped) and 2021 (stippled) growing seasons. Midstory species were nearly all *Acer rubrum* var. *drummondii*.

Leaf Net Primary Production

Leaf net primary production varied significantly across sites ($F_{7,204} = 5.06$, $p < 0.0001$) and varied greatly over years ($F_{4,204} = 23.85$, $p < 0.0001$) (Figure 9). We believe that Hurricane Zeta removed substantial leaf litter in 2020 as our traps had oak litter from trees located over 200 m away; also 2020 in general had the highest wood NPP and these two forms of primary production tend to track one another (Shaffer et al. 2009, 2016). Interestingly, by far the greatest leaf litter production occurred in 2021, in part attributable to Hurricane Ida. Although very few interior forest trees experienced windthrow, up to 50% of the branches were thrown and nearly all of the leaves were lost. As a result, in the early fall *T. distichum* (interaction $F_{2,437} = 23.41$, $p < 0.0001$) had a second flush of leaves resulting in nearly twice the leaf litter production than any other year (Figure 10). In general, litterfall is the noisiest dependent variable because of the (baldcypress) leafroller and the (water tupelo) forest tent caterpillar; during two of our litter collections each year, most of the tissue in the traps is reduced to the midribs of leaves.

In general, *Taxodium distichum* produced far more leaf litter than *Nyssa aquatica* and both produced far more litter than midstory species ($F_{2,204} = 395.84$, $p < 0.0001$; Figure 10).

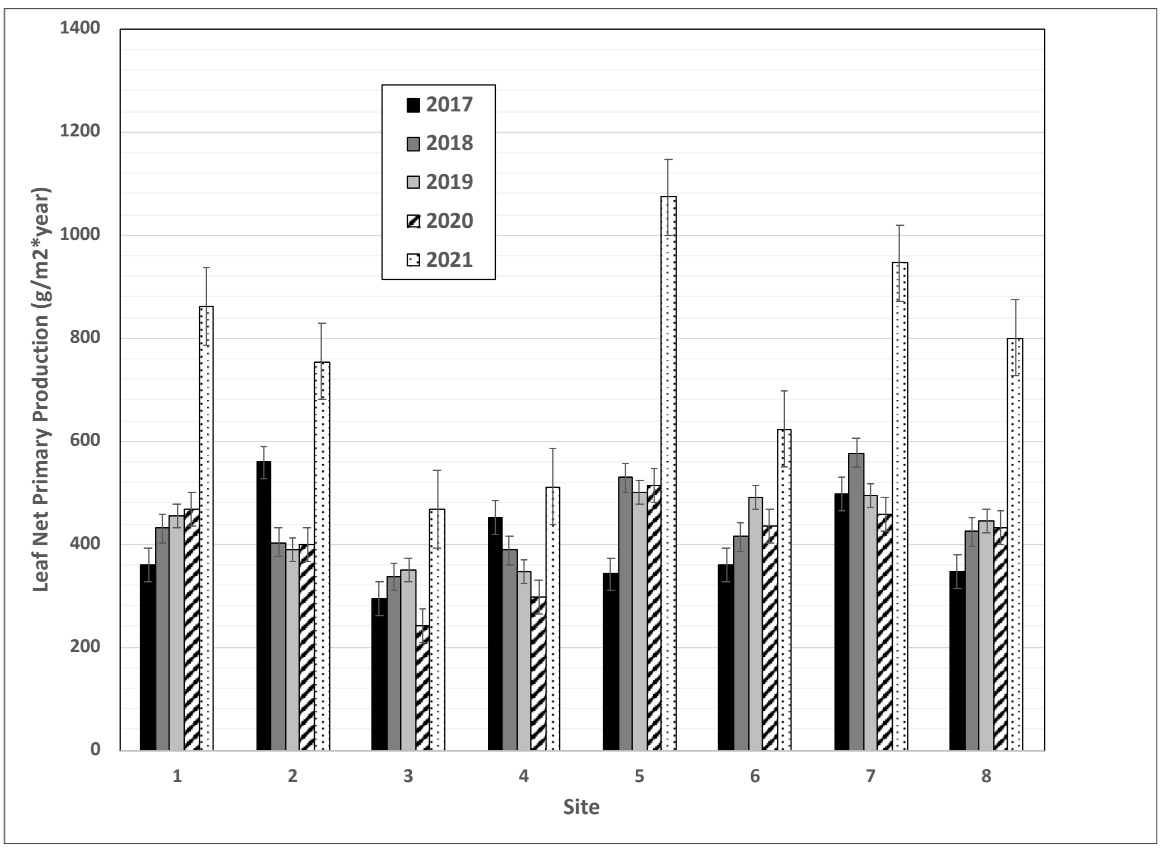

Figure 9. Leaf litter production (mean + s.e.) for each site in the Lac des Allemands swamp during 2017 (black), 2018 (dark gray), 2019 (light gray), 2020 (stripped) and 2021 (stippled) as well as the reference site (Site 1).

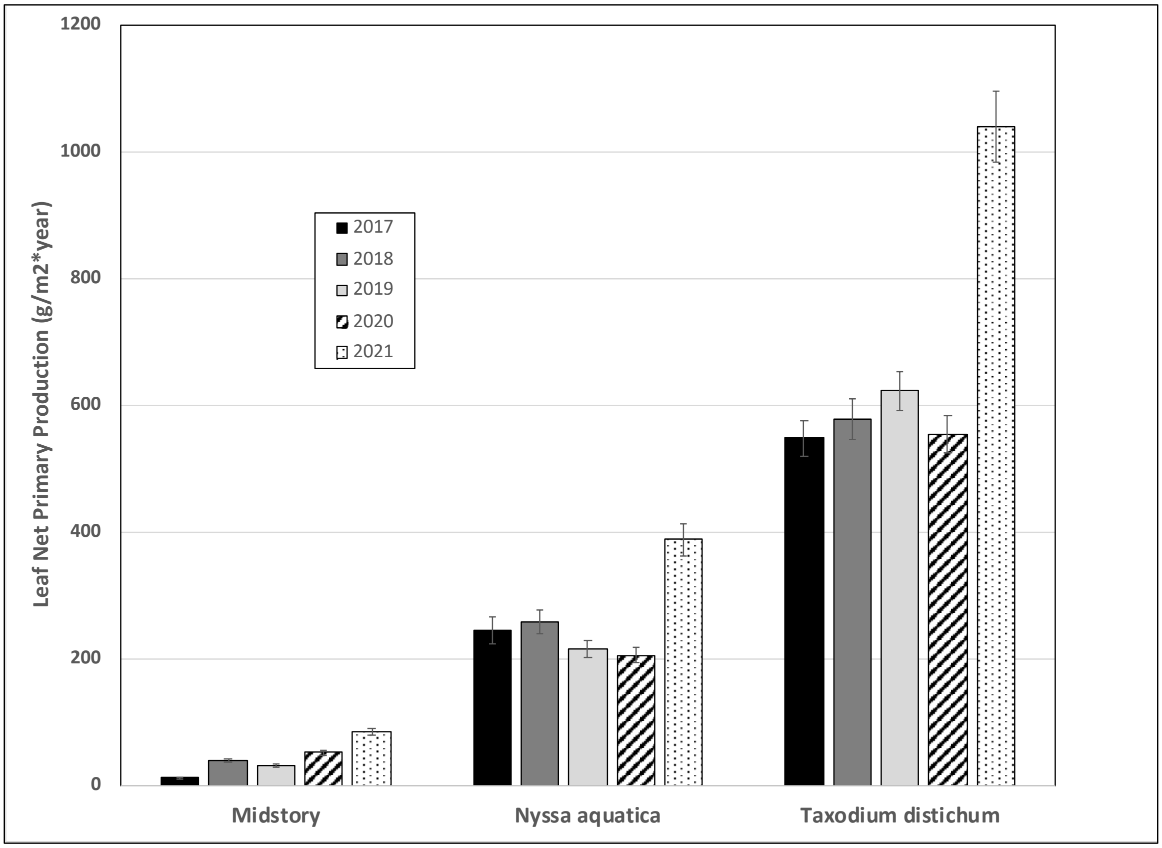

Figure 10. Leaf litter production ($g/m^2y \pm$ S.E.) during 2017 (black), 2018 (dark gray), 2019 (light gray), 2020 (stripped) and 2021 (stippled) in the reference and Lac des Allemands swamp for the two canopy species (*Taxodium distichum* and *Nyssa aquatica*) and midstory species (nearly all of which are *Acer rubrum* var. *drummondii*).

Total Aboveground Primary Production

Total net primary production was obtained by summing wood and leaf production. Six of the seven experimental sites experienced increased production for the post-project construction years compared to 2017 ($F_{4,437} = 13.60$, $p < 0.0001$) (Figure 11). Post-project aboveground production was as high to considerably higher than that measured in the Lac des Allemands swamp in the mid-1970s (Conner and Day 1976, Conner et al. 1981) and much greater than that measured in the 1980s (Conner and Day 1992). The highest aboveground production in the Lac des Allemands swamp is considerably higher than that of the healthiest sites in the Maurepas swamp and vastly greater than that of 87% of that swamp (Shaffer et al. 2009, 2016). The distribution between leaf and wood production was remarkably similar within species across years, with leaf production consistently exceeding wood production ($F_{1,437} = 29.45$, $p < 0.0001$) (Figure 12). Year 2021 total net primary production exceeded that of all other years; as described above ($F_{1,437} = 47.87$, $p < 0.001$) and this increase was exclusively due to *T. distichum*.

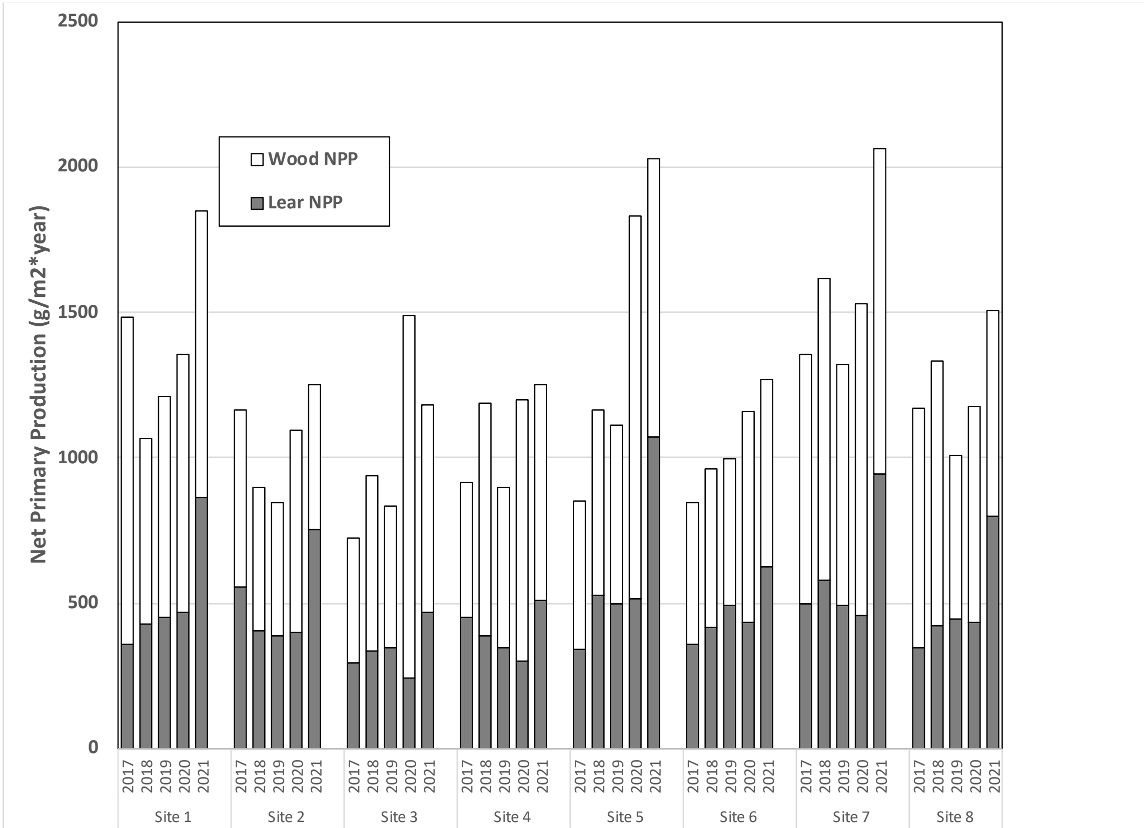

Figure 11. Total aboveground production across sites and year from 2017 – 2021.

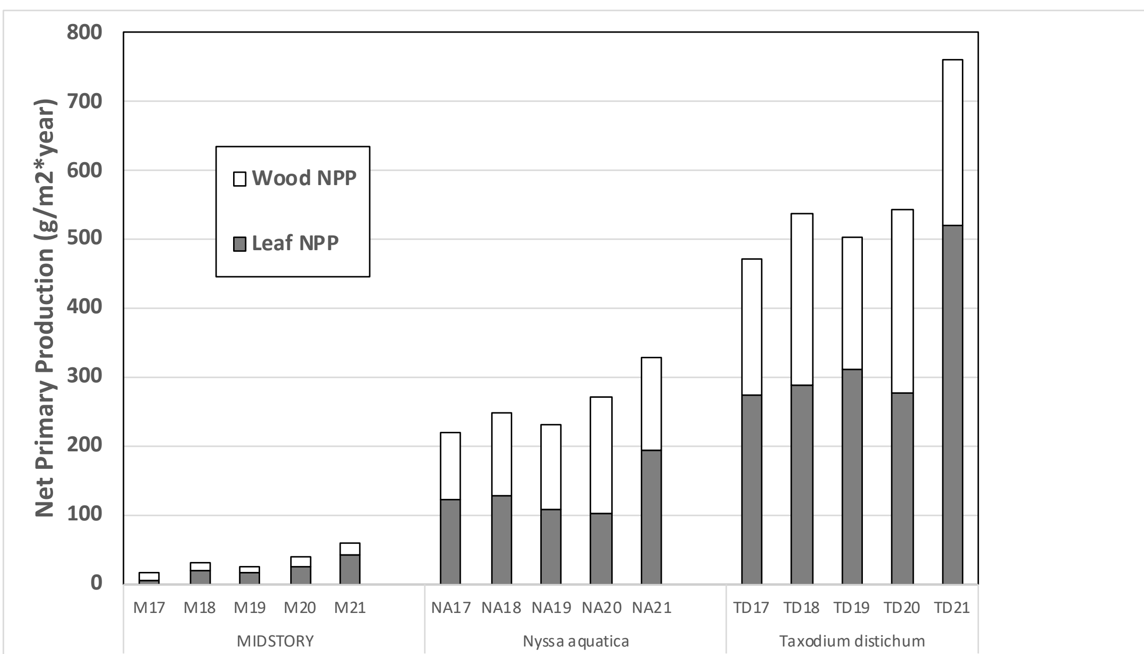

Figure 12. Total aboveground production across years for each species type from 2017 – 2021.

Herbaceous Cover

The Chief Scientist and one Field Scientist estimated herbaceous cover, by species, at all 64 herbaceous plots during fall of 2016 through 2021. The main pattern to date is that herbaceous cover tends to decrease over time, probably caused by increased shading. Years 2017 and 2018 were identical along the X-axis whereas 2019 and 2020 resembled one another on both axes (Figure 13b). The reference stations (Sites 1A and 1B) were originally dominated by *Panicum gymnocarpon*, but that species is no longer abundant (This species is known for its dependence upon sheet flow conditions). In general, the Lac des Allemands project sites are dominated by *Polygonum punctatum* (Figure 14b) and *Alternanthera phyloxeroides*. Overall, eleven herbaceous species dominate (Figure 14b). The trajectory of herbaceous cover is clearly shown when the data are averaged for each year (Figure 13b). Note that pre-restoration year 2016 and post-restoration year 2021 were nearly equally flooded with very high water (X axis), but the water was stagnant during 2016 and experienced high throughput during 2021 (Y axis). By far the driest year was 2018 where Sites 2-8 had no standing water for about half of the growing season (Figure 15) and 2017 was also relatively dry.

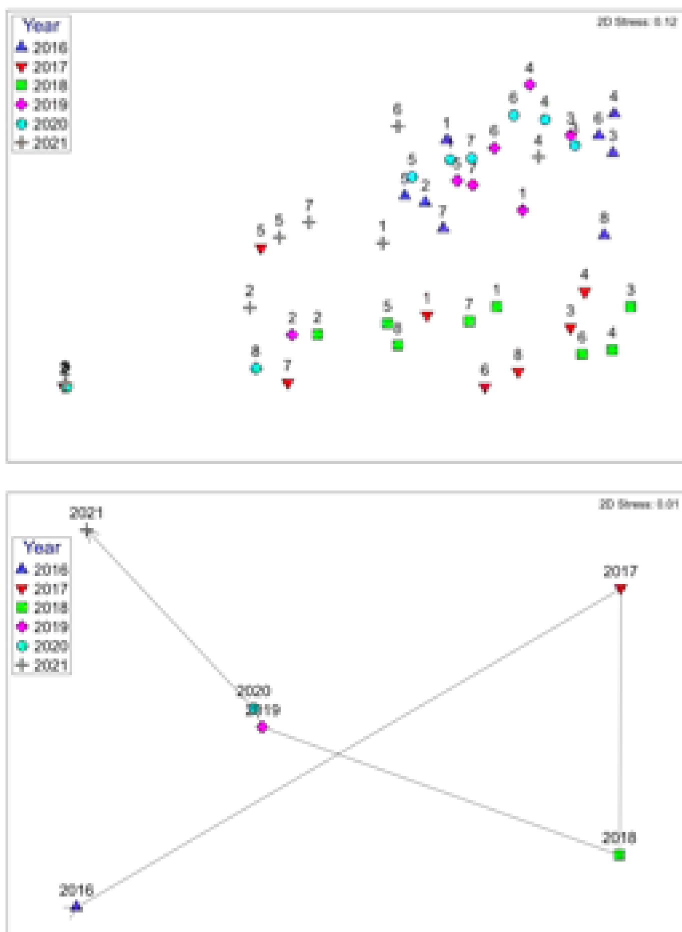

Figure 13. (A) Original ordination across all sites and years and (B) average percent cover of all herbaceous species demonstrating low-water events in 2017 and 2018 and very high flooding during 2021.

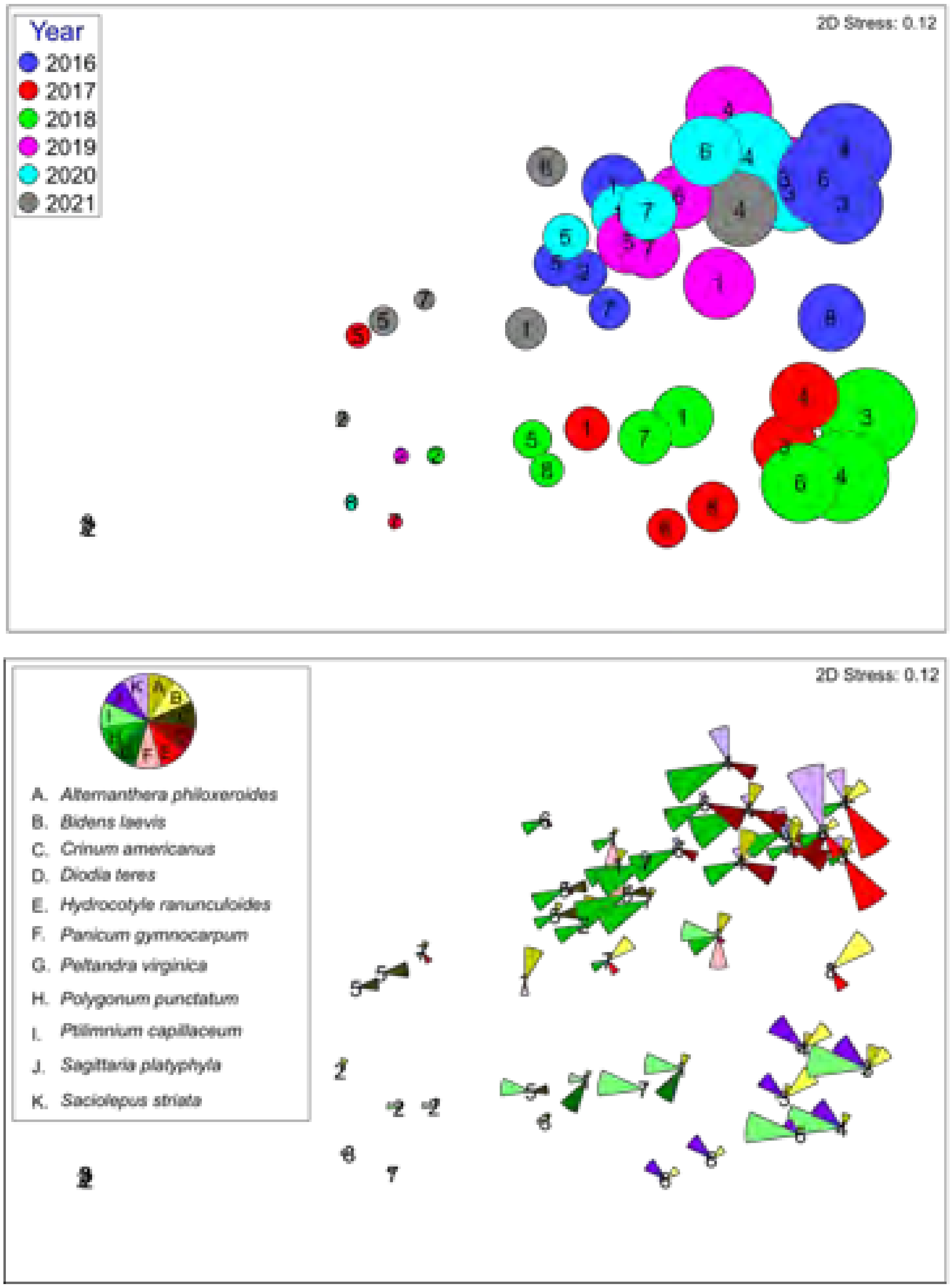

Figure 14. Percent cover of (A) all species and all years (bubble size represents relative total cover) and (B) the same ordination showing only the eleven dominant herbaceous species (*Alternanthera philoxeroides, Bidens laevis, Crinum americanus, Diodia teres, Hydrocotyle ranunculoides, Panicum gymnocarpon, Peltandra virginica, Polygonum punctatum*, *Ptilimnium capillaceum*, *Sagittaria phatyphylla* and *Sacciolepis striata*). Pie slices reflect relative percent cover of the individual species.

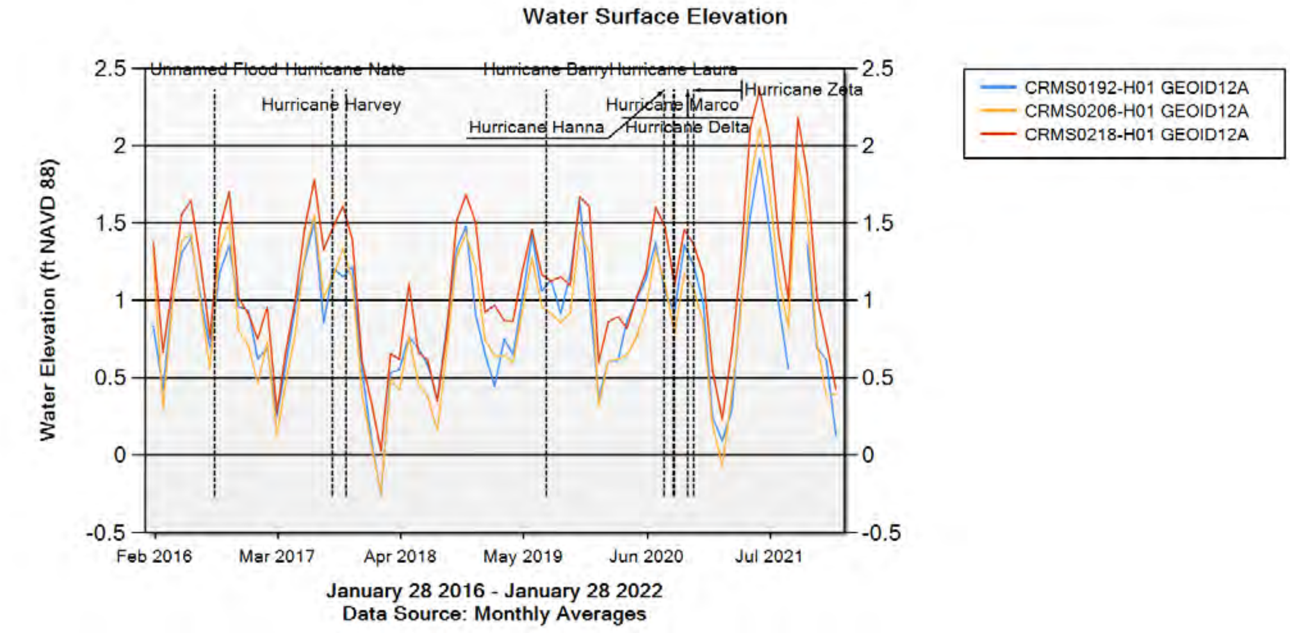

Figure 15. Stage gage records for three CRMS sites near Lac des Allemands swamp showing high water during 2016, 2017, 2019, 2020 and 2021 and very low water during 2018. Note that water levels during 2021 were notably higher than all other years. These stages were similar to the water height in Lac des Allemands swamp prior to gapping.

DELIVERABLES

Pre- and Post-Construction Monitoring Reports

This 2021 Annual Report, along with Excel files of all data collected to date, was provided to CPRA, EPA, and The Water Institute of the Gulf (TWIG). Specifically, this report was provided to the following representatives:

Glen Curole (CPRA)
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Patricia A. Taylor (EPA – Region 6 Water Division)
1445 Ross Avenue, Dallas, TX 75202
TEL: (214) 665-6403

Tim Carruthers (The Water Institute of the Gulf)

301 N. Main Street, Suite 2000, Baton Rouge LA 70825
TEL: (225) 228-2112

Upon receipt of revisions from CPRA, EPA, and The Water Institute, on the report, we will prepare a final copy of the deliverables described above to CPRA, EPA, and TWIG.

This Monitoring Report was prepared in Microsoft Word format. Data were provided in Excel files as well as the CRMS format.

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