Sustainable Rivers Program

Vegetation Resilience and Ecological Modeling Summary Report 2021

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Above: Emergent vegetation including arrowhead at Mile 210 in Pool 26 (USACE photo)

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1 Introduction

Environmental Pool Management (EPM) for Mississippi River Pools 24-26, where the pool is held below full pool during the summer growing season, has shown that ecological conditions can be significantly enhanced for annual emergent aquatic plants production (moist-soil plants). River shoreline and island fringe areas, which are exposed by the lower pool, are consistently revegetated with species such as: arrowhead (*Sagittaria* spp.), smartweed (*Polygonum* spp.), millet (*Echinochloa* spp.), sedges (*Carex* spp.), Amazon sprangletop (*Leptochloa panicoides*), flatsedge (*Cyperus* spp.), etc. Seed production of these plants are valuable for resident and migratory waterbirds and also provide, bank stabilization, nutrient processing, sediment consolidation, invertebrate habitat, egg-laying structure for fish and amphibians, food for aquatic reptiles, cover and nursery habitat for juvenile fish, etc. Furthermore, nominal commercial and recreational issues have been reported as a result of the pool water level changes. EPM is done through gates manipulation and flow management at the 3 Corps Locks and Dams in the St. Louis District. Past implementation indicates EPM is a beneficial practice to balance the needs of navigation and the needs of the ecosystem. EPM is an ecosystem restoration tool that has resulted in measured improvements in ecosystem function and health.

The vegetation resilience and ecological monitoring project consisted of four primary activities during FY21. These included several measures of arrowhead populations and corm dynamics, development of ecological parameters for several abundant species, development of a non-EPM water surface elevation dataset, and verification a refinement of model outputs. A summary description of each activity is provided in the following paragraphs and results provided in the following report sections.

Field study of arrowhead resilience. Arrowhead grow from rhizomes, seed and from corms (often referred to as tubers) developed during past growing seasons (Marburger, 1993; Sutton, 1995). Corms can remain viable for years and dynamics are not wholly understood, though corm densities, positions, and energy content are an important component in arrowhead resilience. We investigated arrowhead resilience as it relates to implementation of EPM. In 2020, known locations of arrowhead were surveyed and a protocol for assessing tuber bioenergetics and abundancies was developed. During the summer of 2021, we utilized three methods to evaluate arrowhead populations and monitor growth and development in future years.

Ecological modeling. An existing ecological model that simulates arrowhead recruitment, vegetative growth, and mortality was expanded to also include millet, smartweed, and waterfowl. Ecological information for millet and smartweed recruitment, growth, biomass including seed production, and mortality was developed in cooperation with SRP and incorporated in the model. Known tuber dynamics were modeled for arrowhead. Ecological information for waterfowl was developed and incorporated in the model for mallards, geese, and swan migration (season, species, and counts) and forage preferences.

Simulated water surface scenario. Existing H&H data used in the ecological model consists of a terrain and simulated water surface elevations for the 2016 growing season, 01Mar-30Nov (with EPM). A second scenario was added during FY21 to simulate a without EPM scenario for the same time period. Having two scenarios, with and without EPM, will allow comparisons of simulated ecosystem responses that may be useful for communicating the benefits of EPM to the public.

Model verification. Finally, we worked with SRP to verify model outputs for vegetation and made refinements to ecological information and parameters used in the model. Verification used existing field observations for 2016. Spatial distributions of moist-soil plants as well as plant condition/productivity was considered.

2 Arrowhead corm sampling

2.1 Method

Arrowhead (*Sagittaria latifolia*) were sampled randomly along transects in an area where it was known to occur previously. A total of 29 samples were gathered over three survey periods. The number of samples gathered per trip was limited by space to process samples. Spring sampling was used to gather data on Arrowhead biomass near the beginning of the growing season. Additional samples were gathered in August and October of 2021 to gather data on corm condition near the end of the growing season. August sampling dates were originally thought to be late enough in the season to measure corm production, but no corms were collected or observed. The final sampling period occurred prior to the first frost of the season.

Individuals were destructively sampled by excavating individual arrowhead plant root systems within a (0.5m X 0.5m X 0.5m) 0.125 m3 of sediment with long-bladed drain spades. During all three sampling periods, sampling locations were flooded with several inches of water which made root and corm sample collection more challenging to extract. A 0.5 m circle was first cut with a drain spade to approximately 0.5 m deep. Next multiple spades were used to help lift the sediment from the sample plot. Sediment samples with roots were transferred to labelled collection containers and brought back to a field office for further processing.

At the field office, roots of samples were washed with running water to remove sediment from plant tissues. Roots of other species such as smartweeds, millets, and others were separated from arrowhead roots. Care was taken to extract as many of the fine arrowhead roots and tender rhizomes as possible. Entwined root systems were challenging to separate without damage. After sediment was completely removed from an arrowhead sample, plant parts were transferred back to a clean collection container, air dried with a fan for 48 hours, and dried using a food dehydrator for 72 hours. After drying, samples were measured and weighed.

2.2 Results

Stem, root, and corm weights were recorded as available (Table 1).

Table 1: 2021 Arrowhead root, stem, corm sample data. Stem/root lengths measured only from dry intact stems and roots. Corm samples limited by plant production and sampling.

Date	#	Stem length (cm)	Root length (cm)	Whole plant (g)	Stem (g)	Root (g)	Corms (g)	Corm d1 (cm)	Corm d2 (cm)
5/30	1	35.0	-	2.5	2.3	0.1	0.1	2.2	1.4
5/30	2	37.0	20.0	3.8	3.1	0.6	0.1	3.7	2.1
5/30	3	29.0	-	2.7	1.9	0.7	0.1	2.5	2.0
5/30	4	23.0	-	1.1	0.5	0.5	0.1	2.1	0.9
5/30	5	37.0	-	3.8	2.5	1.0	0.3	3.2	2.4
5/30	6	30.0	-	2.8	2.3	0.4	0.1	2.8	1.2
5/30	7	31.0	-	5.1	3.2	1.5	0.4	3.8	2.2
5/30	8	36.0	-	5.0	2.5	2.5	-	-	-
5/30	9	46.0	-	4.2	4.1	1.0	-	-	-
5/30	10	41.0	-	7.5	6.8	0.7	-	-	-
5/30	11	15.0	-	0.1	0.1	0.1	-	-	-
5/30	12	16.0	-	0.1	0.1	0.1	-	-	-
5/30	13	21.0	-	0.5	0.4	0.1	-	-	-
5/30	14	14.0	-	0.1	0.1	0.1	-	-	-
5/30	15	21.0	-	0.6	0.5	0.1	-	-	-
5/30	16	25.0	-	1.7	1.2	0.5	-	-	-
5/30	17	31.0	-	1.3	0.9	0.4	-	-	-
5/30	18	33.0	-	1.7	1.3	0.4	-	-	-
8/18	19	-	-	18.0	14.7	3.3	-	-	-
8/18	20	-	-	21.2	16.8	3.4	-	-	-
8/18	21	-	-	15.1	11.8	3.3	-	-	-
8/18	22	-	-	13.1	10.4	2.7	-	-	-
8/18	23	-	-	12.1	11.2	0.9	-	-	-
10/25	24	61.5	31.0	4.9	2.4	2.5	-	-	-
10/25	25	70.5	32.0	7.4	2.9	4.5	3.4	3.2	2.0
10/25	26	70.5	23.0	4.0	3.1	0.9	-	-	-
10/25	27	46.0	15.0	8.8	6.2	2.6	1.0	1.3	1.0
10/25	28	66.0	21.5	15.6	12.8	2.8	0.7	1.2	1.0
10/25	29	80.0	24.0	22.2	15.7	6.5	-	-	-

2.3 Discussion

The 2021 growing season appeared to provide good conditions for arrowhead as there were a number of first year arrowhead plants that germinated and established. In addition, clonal reproduction appeared to be ongoing within patches of arrowhead that established in previous years (discussed further in Section 4).

Overall, corm production and density were relatively low across sampled plots. USDA NRCS (2002) notes that a single plant can produce up to 40 corms per year. Approximately 38% of samples had produced a corm in the spring and approximately 50% of samples produced a corm near the end of the 2021 growing season. Plants with corms only produced a single corm. Low production could be related to multiple biological and environmental factors. Dioecious (male and female flowers on separate plants) populations typical of permanent wetlands generally produce fewer corms per plant than monoecious populations (Dorken and Barrett, 2004). Van Drunen and Dorken (2012) found that there is a tradeoff between sexual reproduction and clonal reproduction. The Mile 210 area plants encountered when flowering were diecious and they may be spreading primarily through rhizomes currently. It is also possible that Arrowhead plants are still recovering from the long duration flood event of 2019 followed by the early season flooding of 2020 despite suitable conditions for the entire growing season in 2021. Overall plant weights and measurements were highly variable. Average corm weight and volume were approximately 0.34 grams $\pm$ 0.31 and 9.88 cm^3 $\pm$ 5.74. Plant part weight values were variable across samples, but a fairly strong relationship was observed for overall plant dry weight to corm weights ($r^2 = 0.73$) (Figure 2). Stem to root weights also showed a fairly strong relationship as well when considering samples with and without corms ($r^2 = 0.68$) (Figure 3). Corms sampled in the spring appeared to be may have been utilized by plants as storage reserves rather than for clonal reproduction. Several factors limited the accuracy of our root measurements. First, the flooded conditions made it difficult to sample root samples and ensure that all roots in a sample were from the same individual. Additionally, the fragile rhizomes and fibrous root systems of arrowhead also made it difficult to extract entire root systems. All samples had some degree of root severing that occurred through the extraction process. Despite these limiting factors, plants with larger aboveground biomass typically had larger belowground biomass and corm weights as would be expected. Also, one sample had severing occur from a larger vertical root that presumably terminated at a corm as other samples like this one did. Additional excavation was done for this sample but a corm was not found.

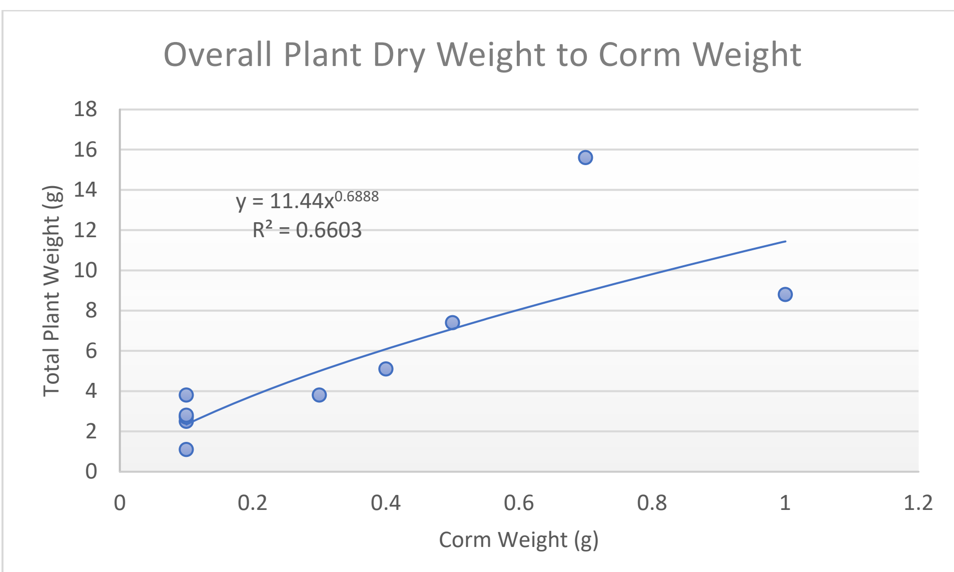

Figure 2: Plant dry weight to corm weight relationship.

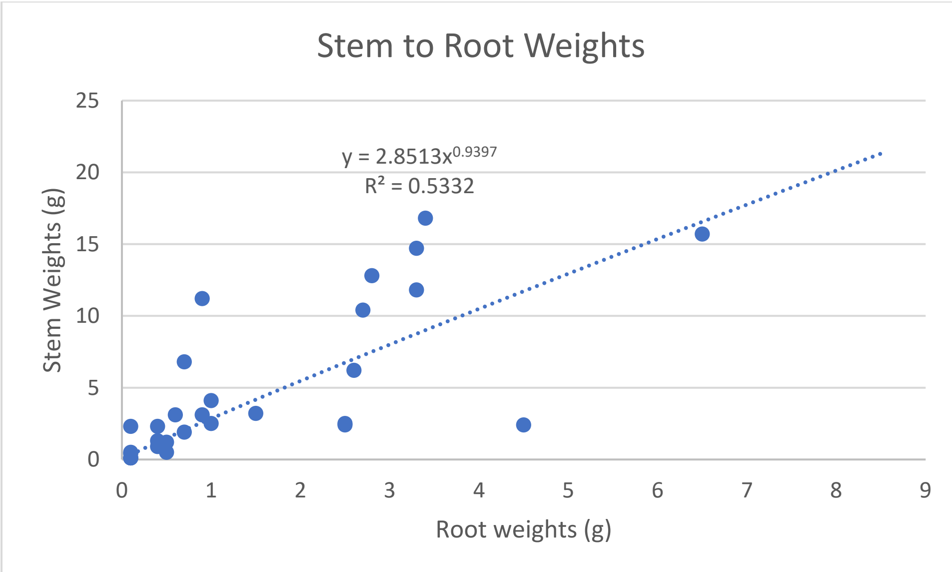

Figure 3: Stem dry weight to root weight relationship.

Extensive rhizome growth was observed on most of the individual plants sampled. Lateral rhizomes provide an additional mode of clonal production for arrowhead. This may be the primary contributor to arrowhead expansion at Mile 210 area based on the distribution of adult plants in the numerous patches of arrowhead found within the area. Due to the low corm production rates and the above observations, nondestructive sampling methods of assessment were also utilized as described in sections 3.1 and 4.1 to assess arrowhead population status and track growth and spread in upcoming years.

3 Transect Vegetation Surveys

3.1 Methods

The Illinois Natural History Survey Critical Trends Assessment Protocol for Wetland sites (INHS 2002) was modified to evaluate the plant community in an emergent wetland on Mile 210 area that previously supported extensive beds of arrowhead. Potential areas were screened by elevation and removed if not exposed during typical environmental pool drawdown targets (i.e., stages between 417-419). Random points were generated for ten transect locations within this zone (Figure 4). Each transect was placed along a north bearing. When lying the transect, the tape measure is pulled taut, and laid upon the ground at all points along its length. Herbaceous vegetation is sampled in ¼ m^2 quadrats at an interval of every 2m along the transect, starting 2m from the baseline (Figure 5). A total of 10 quadrats are sampled per transect. Quadrats are placed 1m from the transect on alternate sides, starting on the right at the 2m point (e.g., the first quadrat covers the area from 2-2.5m along the transect, at a distance covering 1-1.5m right of the transect). Average species percent cover by site, frequency of occurrence, species richness, Shannon's Diversity Index, Shannon's equitability Index, and Hill Numbers were calculated.

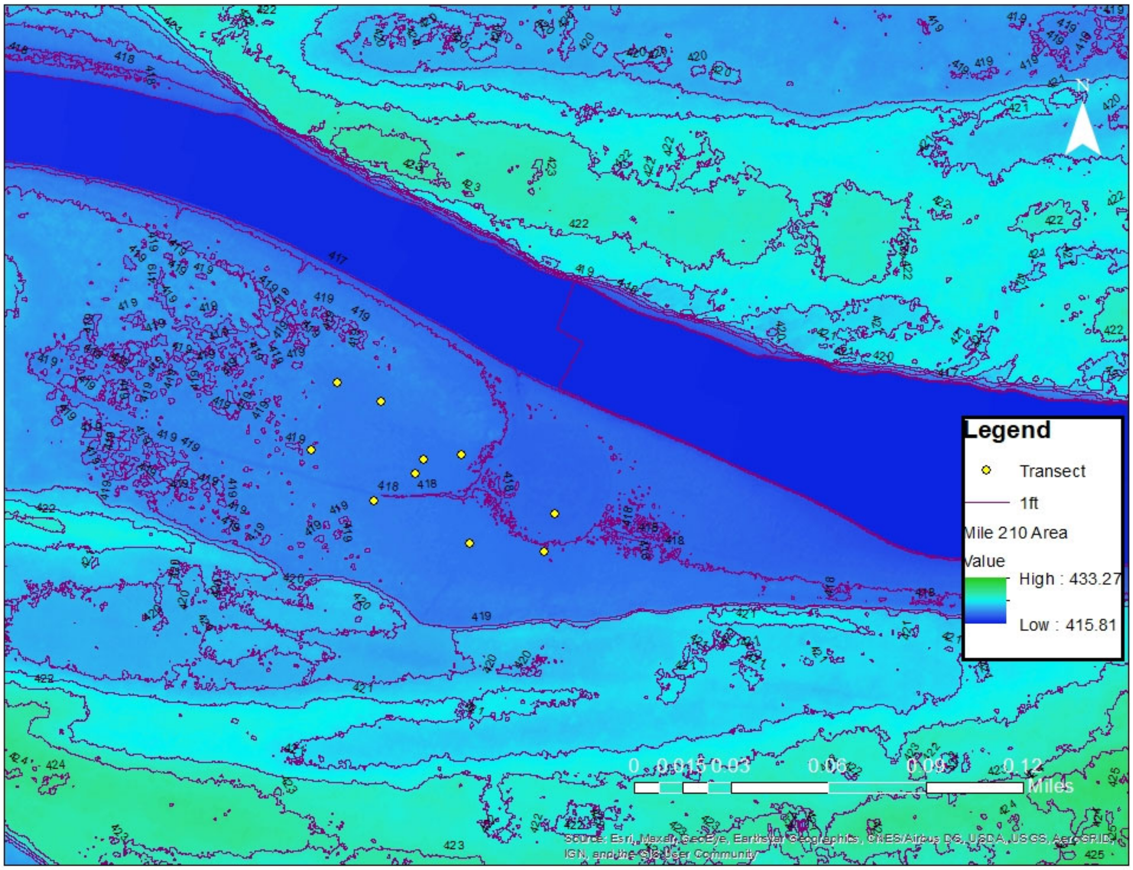

Figure 4: Random transect start locations within Mile 210 area.

Figure 5: Quadrat layout along transect.

Diversity Measures

Hill Numbers are calculated from other diversity indices such as Shannon's Entropy or Simpson's Index and describe the equivalent number of equally common species needed to give the same value of a diversity measure. When these values are plotted as in Figure 9, a comparison of diversity and evenness can be made. When q=0 the value equals overall species richness. When the value of q increases to 1 the effective number equals the inverse of Shannon Entropy and is a balance between richness and species evenness. The value at q=1 gives the approximate number of 'typical' species in the plant community for a given site. When the value of q increases to 2 the effective number equals the inverse of Simpson diversity), and there is greater weight given to more abundant species in the plant community. A value at q = 2 gives the approximate number of 'very abundant' species in a community

(Hill 1973). A value at q= ∞ is equal to the reciprocal of the Berger-Parker Dominance value, which is a measure of the numerical importance of the most abundant species. As the reciprocal of the Berger-Parker Dominance Value (proportional abundance of the commonest species) increases there is an increase in diversity and a reduction in dominance within the community. Taken together the Hill Numbers below can be used to evaluate species richness and evenness. Units with a shallower slope as q increases from 0 to ∞ reflect greater community evenness, and larger values mean greater overall diversity within the community. Average percent cover, frequency of occurrence, and diversity metrics are plotted in Figures 6-8, respectively.

3.2 Results

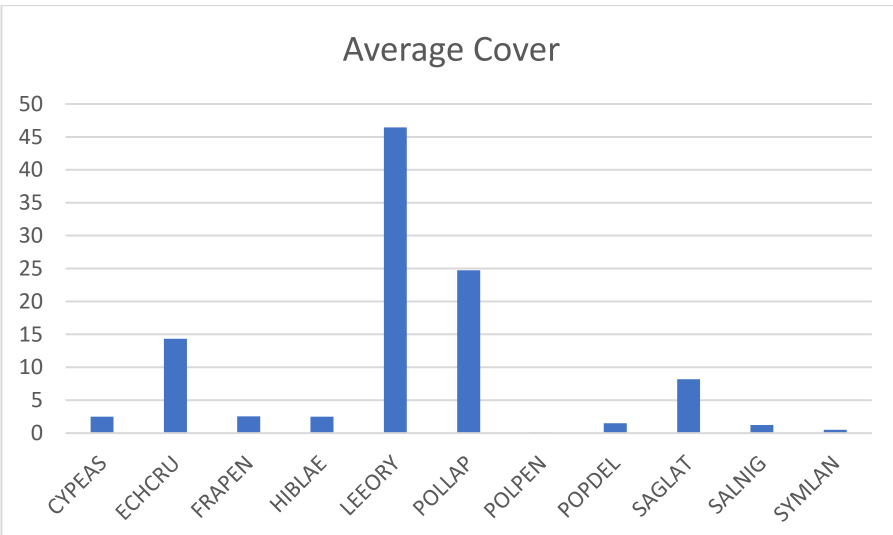

Figure 6: Average percent plant cover at Mile 210 area transects.

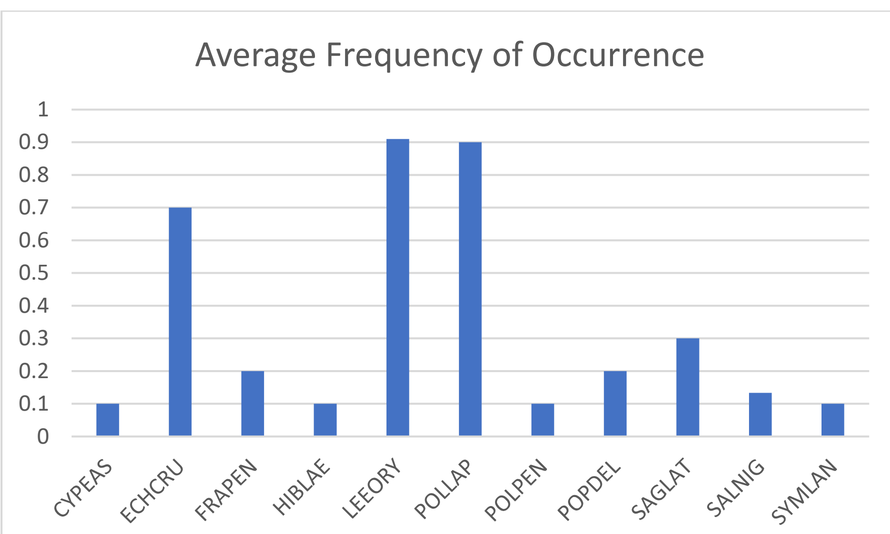

Figure 7: Plant species frequency of occurrence at Mile 210 area transects.

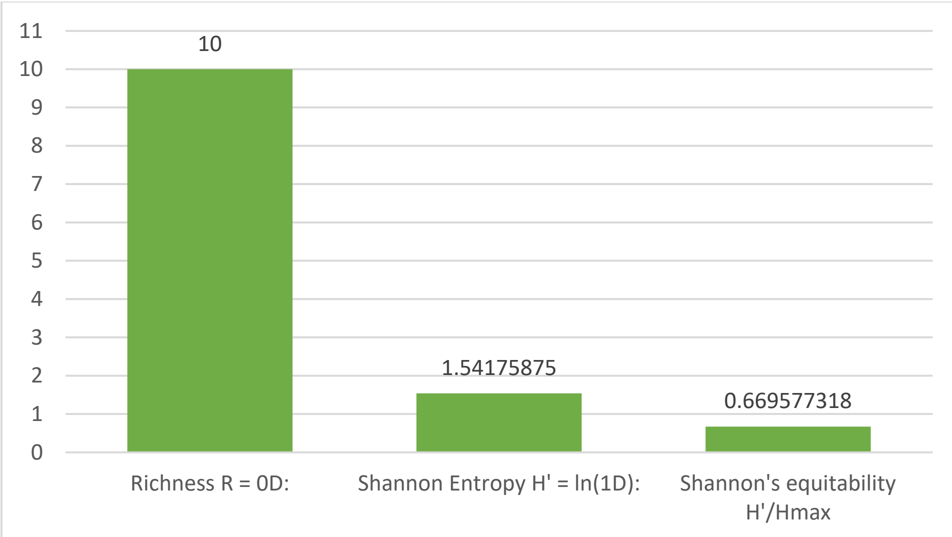

Figure 8: Plant diversity metrics at Mile 210 area transects.

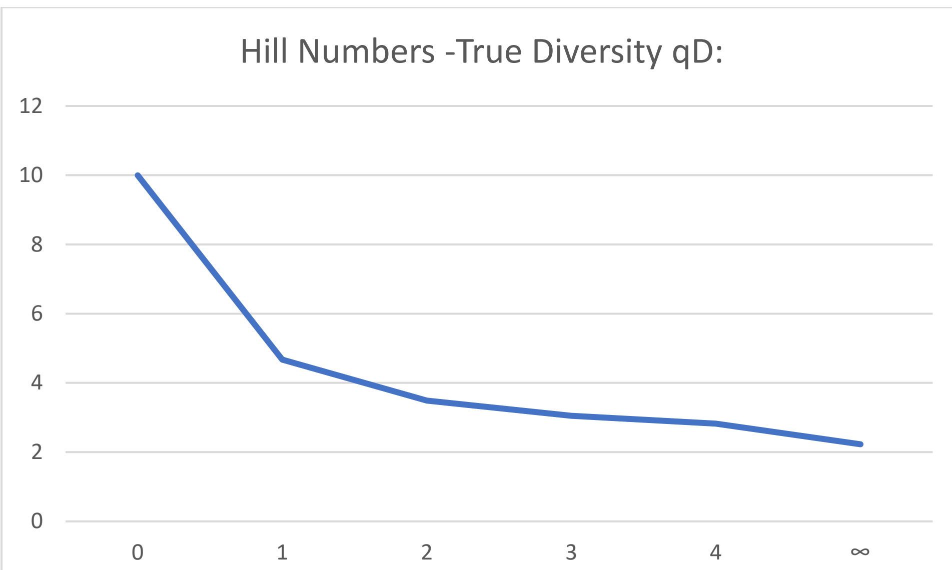

Figure 9: Hill Number diversity measures at Mile 210 area transects.

3.3 Discussion

Average percent cover along transects was greatest for rice cutgrass (*Leersia oryzoides*) followed by nodding smartweed (*Polygonum lapathifolium*), wild millet (*Echinochloa crus-galli*), and arrowhead (*Sagittaria latifolia*) (Figure 6). Arrowhead also had the fourth greatest frequency of occurrence for species encountered during transect sampling (Figure 7). Overall species richness at Mile 210 area was 10 species (Figure 8) and approximately four species were abundant within sampled areas (Figure 9).

Rice cutgrass is a perennial, rhizomatous wetland grass that frequently forms large patches under moist to wet conditions on muddy and silty substrates primarily. Rice cutgrass is dependent on bare sediment to establish and it germinates in the spring. Transect data from EPM pool vegetation sampling in 2020 and 2021 showed a large increase in rice cutgrass this growing season which may be attributed to suitable germination conditions throughout much of the Mile 210 emergent wetland area. Dense colonies may reduce establishment by other species, but colony vigor is reduced without a suitable disturbance regime (appropriate flood frequency and timing).

Nodding smartweed is frequently encountered at EPM sites and germinates under a fairly large range of temperatures and moisture conditions (Dessent, Lawler, and Nielsen, 2019). LTRM-style vegetation sampling in EPM areas has shown that it was the most abundant and frequently encountered species in Pool 26 in 2021. It has made up a significant component of EPM-related vegetation in all years evaluated for Pools 24-26. In addition, nodding smartweed is able to establish at low elevations and persist throughout the growing season better than other emergent species encountered in Pool 26.

Arrowhead was distributed throughout the central portion of the emergent wetland area exposed by environmental pool management. Elevations correspond with LiDAR elevations of approximately 417.8-418.5 (NAVD88). Many of the arrowhead plants encountered during sampling consisted of individuals that persisted from previous year(s) and were beginning to produce colonies. These colonies are assumed to be comprised of aboveground stems that expanded out from the parent plant and have the appearance of a separate individual. Arrowhead survived well through the temporary mid-season increase in water elevation and flower production appeared to be widespread. Most flowering plants observed during site visits were male based on flower morphology which provide support for vegetative spread as a potentially significant element of arrowhead spread in the Mile 210 area. A more intentional evaluation of female to male plants in the Mile 210 area could provide additional information as to the importance of various modes of spread. In the absence of a prolonged growing season flood, arrowhead would be expected to continue to expand in patch size and potentially recruit from the seed bank.

Green ash (*Fraxinus pennsylvanica*) and willow (*Salix* sp.) were recorded at 1/5 and 1/10 of sampled plots although percent cover was low when present. Much of the area on the western side of the emergent wetland area that was adjacent to transect locations (418.5 and 419 NAVD88) had expanding stands of these two species with a diameter at breast height of several inches and heights ranging from 6ft-15ft. The relatively high frequency of occurrence relative to percent cover in the sampled area suggests that areas slightly lower in elevation than 418.5 (NAVD88) are in the early stages of transition to shrubland. Succession is likely to continue in the absence of prolonged growing season disturbance.

4 Arrowhead Patch Mapping

4.1 Method

This method was utilized due to the low density of corm production by existing arrowhead plants within the Mile 210 area. Surveys used nondestructive sampling to gather baseline data on patch boundary size, composition, and reproduction in the present year. Sites can be revisited in successive years to evaluate changes in patch growth, composition, and reproduction.

Patch characteristics were recorded at 17 locations within the Mile 210 area over three sampling dates (Figure 10). Random points within the Mile 210 emergent wetland area were generated in ArcMap 10.7 and transferred over to an ArcGIS Field Map application map. Transect samples were collocated at ten of the sample locations (Samples 8-17). A field collection form was developed within the Field Map application to gather patch-specific information on the number of individual plants per patch; number of reproductive, non-reproductive, and immature individuals; patch length (long-axis); width at ¼ length; width at ½ length; and width at ¾ length. A GPS receiver with 1-m accuracy was utilized to navigate to random points. Once at a point, the area was searched for the nearest patch of Arrowhead and measurements were taken at that location.

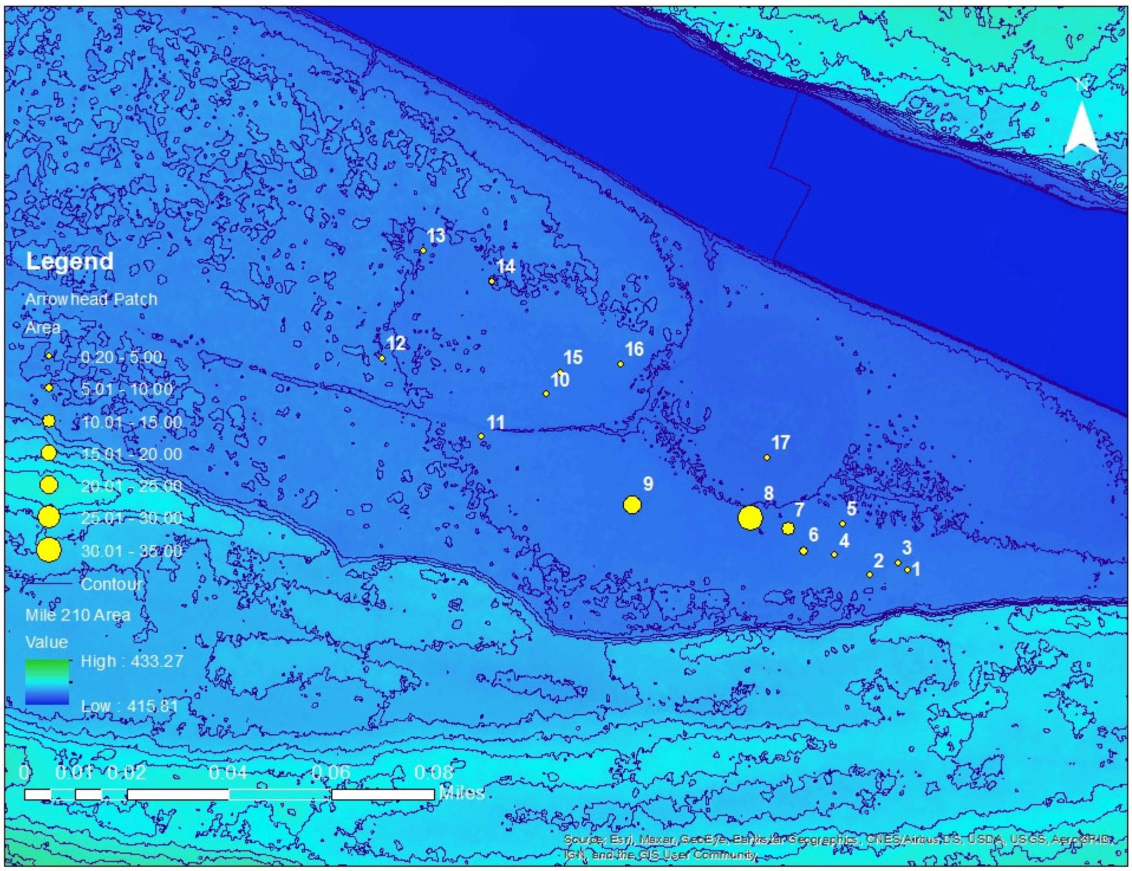

Figure 10: Patch size distribution within Mile 210 emergent wetland area. Elevation contours at 0.5 ft intervals.

4.2 Results (Table 2)

Table 2: Arrowhead patch size and characteristics.

Date	Sample	# Individuals	Patch length (m)	Width 1 (m)	Width 1/4 (m)	Width 3/4 (m)	Area (m2)	# Reproductive	# Nonreproductive	# Immature
9/1/2021	1	3	1.0	0.3	0.3	0.3	0.2	0	3	0
9/1/2021	2	14	8.0	0.5	0.5	0.5	4.4	2	7	5
9/10/2021	3	3	1.0	0.5	0.5	0.5	0.3	0	3	0
9/10/2021	4	18	5.0	0.3	0.3	1.2	1.4	5	8	5
9/10/2021	5	7	2.1	0.4	0.4	0.4	0.7	3	4	0
9/10/2021	6	30	6.7	2.7	1.0	1.0	7.0	10	15	5
9/10/2021	7	31	5.2	1.0	2.7	5.0	11.8	21	6	4
9/10/2021	8	111	14.0	0.5	6.1	2.4	31.7	94	0	17
9/15/2021	9	-	6.5	5.9	4.4	3.8	21.0	-	-	-
9/15/2021	10	6	1.6	1.4	1.4	1.4	1.8	3	3	0
9/15/2021	11	1	1.9	1.2	1.2	1.2	1.8	1	0	0
9/15/2021	12	1	0.4	0.2	0.2	0.2	0.6	1	0	0
9/15/2021	13	2	0.9	0.4	0.4	0.4	0.3	0	0	2
9/15/2021	14	4	2.0	0.9	0.9	0.9	1.4	0	4	0
9/15/2021	15	17	0.8	2.4	2.4	2.4	1.5	8	9	0
9/15/2021	16	14	3.2	2.0	1.5	1.5	3.8	5	9	0
9/15/2021	17	3	1.3	0.7	0.7	0.7	0.7	2	1	0

4.3 Discussion

We gathered patch metric data on 17 patches of varying size in the Mile 210 area. Patch size varied from 0.23-31.7m^2 with an average patch size of 5.31 m^2. 63% of plants encountered in the sampling were adult and flowering, 22% appeared to be adult but nonreproductive (i.e., >2 ft) and 15% were immature plants (i.e., <2 ft tall). A note of caution with the above proportions of life stage is that we cannot be certain how many of the "individual plants" are clonal growth from a parent plant via rhizomes and corms, and how many are genetically distinct plants. In addition, there is potential for both immature and adult nonreproductive plants to be miscategorized. The clumped distribution may be due to clonal growth or due to establishment by numerous individuals in suitable microclimates. However, the linear spread of "individuals" from and adult plant suggests that vegetative reproduction could be significant within patches.

All locations with arrowhead except one (sample 17- 417.8) occurred between the elevations of 418 and 418.5 (NAVD 88) (Figure 10). The largest patches of arrowhead were primarily located in the center of the emergent wetland at Mile 210 area. Larger patches consisted of many dense aboveground stems. Areas to the east and northwest consisted of smaller patches comprised of 14 or fewer aboveground arrowhead stems mixed with a variety of other emergent species (e.g., rice cutgrass, nodding smartweed, wild millet, etc.). During the last corm sampling event on 25 Oct 21, we noticed extensive invasive carp herbivory and disturbance in areas below 418. These areas consisted of open water while undisturbed areas consisted of many standing stems. This persistent disturbance may promote millets, smartweeds, and other annuals while limiting establishment of arrowhead below 418.

Rosenbaum et al. (1989) noted that arrowhead does not tolerate high levels of sedimentation and that high turbidity reduces plant population size. While the EPM area at Mile 210 appears to be persistent and relatively stable over the past three decades, high levels of turbidity related to fish activity and sedimentation are apparent during site visits and likely limit arrowhead and other aquatic vegetation extent. Another limiting factor could be the water fluctuations that occur during the growing season which may reflood establishing arrowhead at sensitive life stages (i.e., seedling stage). This may limit establishment from seed to years when water levels are low but stable for some critical length of time. While arrowhead is tolerant of flooding once established, it typically germinates after the sediments begin to dry out at the surface and water surface elevations are just below the sediment surface (Keddy and Constabel, 1985). With lower turbidity and physical disturbance lower elevations may be able to support arrowhead populations. Clark and Clay (1985) found arrowhead persisted to depths of nearly 2 feet in the northern reaches of the Upper Mississippi River.

5 Conclusion

Arrowhead corm sampling resulted in fewer corms than expected but this is known to vary with a number of environmental and biological factors. Arrowhead at Mile 210 area may still be recovering from the long duration flood of 2019 followed by the early season flood of 2020. Arrowhead numbers did appear to be increase from fall 2020 observations anecdotally. There was an opportunity to gather additional data on arrowhead populations that could track arrowhead population growth and resilience utilizing nondestructive sampling methods. As a result, we gathered additional transect data on plant populations at Mile 210 to evaluate plant community composition, cover, and frequency of occurrence. We also utilized methods from plant population mapping to gather patch metrics, including areal extent, life stage composition, and number of "individuals". These patches can be revisited in subsequent years to evaluate changes in area extent and composition of patches in response to environmental changes. Cumulatively the three methods can provide complementary information on arrowhead dynamics in lower Pool 26 which may be missed by any individual method of assessment. For instance, it is possible for arrowhead to establish by rhizomes or seed but produce limited numbers of corms. In 2020, there was limited corm production, and establishment via seed or via rhizomes appeared to be more important. However, corms may be important for reestablishment or spread in certain years or after certain disturbance events. Production of corms may increase as individual plants mature at the site.

6 Ecological Modeling

USACE St. Louis District worked with the SRP program to refine ecological parameters for arrowhead (*S. latifolia*) and define comparable ecological parameters for nodding smartweed (*P. lapathifolium*) and Walter's millet (*Echinochloa walterii*). Nodding smartweed was selected due to its abundance in Pools 24, 25, and 26; its relatively early germination period; and its importance as a waterfowl food. Walter's millet was selected due to its periodic abundance, its mid-season germination, and importance as a waterfowl food. For each species information was compiled on germination requirements, biomass production, seed production, size class, growth rates, and senescence.

Waterfowl were added to the model in 2021 and included three waterfowl taxa with different potential foraging depths. Mallard was selected to represent dabbling ducks due to their abundance in the region, and because the species is often used in other studies as being representative for this group of ducks. Canada Goose was selected as a species with slightly deeper potential foraging depths and also due to its abundance in the region. Finally, Trumpeter Swan was selected to represent a waterfowl species with the maximum average foraging potential in the area and due to its local nonbreeding season abundance in the region. Local IWMM (Integrated Waterbird Monitoring and Management) data from EPM areas were used to develop a bird per acre estimate by calendar date for each species.

7 Simulated Water Surface Elevation Scenario

USACE St. Louis developed a simulated water surface elevation scenario to mimic a typical 01 Mar- 30 Nov period without EPM. This was done to allow a comparison of benefits between years with EPM and years without EPM as well as evaluate model outputs based on ecological parameters.

8 Model Verification

Model development and verification is ongoing and will be documented in future reports.

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