SPRING LAKE AQUATIC VEGETATION SURVEY

PREPARED FOR:

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EXECUTIVE SUMMARY

Upon award from the Edwards Aquifer Authority, the BIO-WEST project team worked throughout March and completed both the aerial orthoimagery capture via Unmanned Aerial System (Baylor) and the field mapping of aquatic vegetation (BIO-WEST) for the Spring Lake Aquatic Vegetation Survey. This report highlights the results of the survey and some comparisons and notable changes between the 2009/2010 survey completed by Texas River Systems Institute, now the Meadows Center for Water and the Environment. In overview, aquatic vegetation in Spring Lake remains dominant with both native and non-native aquatic plant species present. Since 2009, the aquatic vegetation community has experienced a moderate change in its composition. The non-native *Myriophyllum spicatum* has undergone an expansion through a large majority of the lake while several native species have seen a decline in their distribution and density. Other non-native species (*Hydrilla verticillata*, *Colocasia esculenta*) have been all but eradicated due to restoration efforts and one native species, *Zizania texana*, has seen a dramatic increase in coverage also as a result of restoration. This mapping effort should help inform and guide future restoration efforts of the Edwards Aquifer Habitat Conservation Plan (EAHCP) in Spring Lake.

Introduction

Spring Lake is an artificial impoundment of the San Marcos springs created in 1849 to power a saw mill and covers approximately 22 surface acres (9 hectares). It is the collective headwaters for the San Marcos River which begins once waters flow out of Spring Lake. The San Marcos springs issue from the karstic Edwards Aquifer which underlies a large portion of Central Texas. These springs are considered the second largest spring system in Texas. The Edwards Aquifer, Spring Lake and San Marcos River are all home to a variety of federally threatened or endangered species. Spring Lake proper is considered critical habitat for the fountain darter (*Etheostoma fonticola*), San Marcos salamander (*Eurycea nana*), Texas blind salamander (*Eurycea rathbuni*) and Texas wild-rice (*Zizania texana*).

In March 2020, the project team completed collection of aerial orthoimagery of Spring Lake via an Unmanned Aerial System (quadcopter drone). This was followed by an intensive field mapping effort to delineate and quantify the submerged and floating aquatic vegetation of the lake, including bryophytes and algae, in order to update the previous mapping survey which occurred in 2009. One objective of this data collection event was to provide guidance for ongoing restoration projects occurring within Spring Lake to improve habitat for Texas wild-rice.

Spring Lake can be divided into three main sections as shown in Figure 1, with two arms flowing south and joining into a common embayment. The Spring Arm, also referenced as the headwaters and located along the western shoreline, is the location of most of the major spring openings. Here, the water quality and temperature is typically consistent. Visibility is excellent and water is consistently flowing as this section is fed entirely by artesian spring water. The deepest part of the lake is found within Spring Arm at Deep Hole springs where depths reach 28 feet (8.5 meters). The included springs, historical river bed, submerged timber and exposed limestone boulders make this area highly diverse. Substrate in this section is mostly comprised of exposed limestone bedrock or cobble with accreted silt deposits. Areas around the spring openings may be dominated by sandy substrate.

The eastern shoreline of Spring Lake is comprised of the Slough Arm and Sink Creek. This section is much more typical of surface water conditions with variable water quality. Generally, the Slough Arm is lotic with flow depending mostly on rain and surface water runoff from Sink Creek as no significant springs are found in this section. The depth of the Slough Arm can reach to 10 feet (3 meters) with a silt bottom found along the entire length of the arm.

The Lower Lake area is below the confluence of the two arm reaches. The area adjacent to the Spring Lake dam is shallow, with a few pockets of deep water that range from 8 to 10 feet (2.4 to 3 meters). During base flow, the water quality here is typically characterized as spring water dominated, but during storm events visibility and water quality can be impacted by strong inflows from Sink Creek. Water quality can quickly improve once base flows dominate. Because of the reduced water velocities and input from Sink Creek this area is very silty. Matthews (2005) reported thoroughly on the geomorphology of each of these Spring Lake zones.

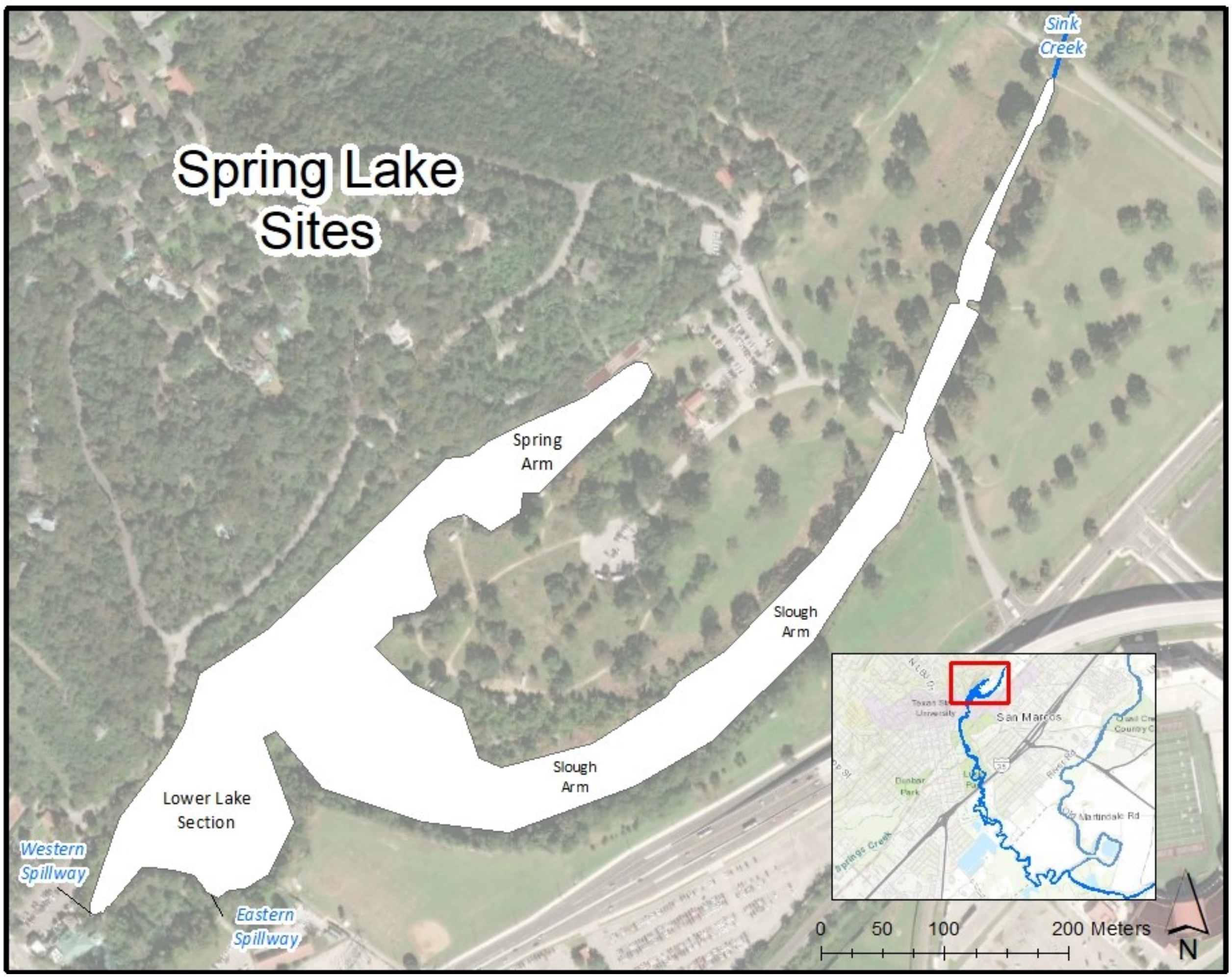

Figure 1. The layout of Spring Lake.

Survey Methods

The project team completed two tasks in order to provide updated information and data regarding the aquatic plant diversity and coverage in Spring Lake. The first task was to collect aerial imagery via an Unmanned Aerial System drone (UAS). A request to fly the drone over Spring Lake was submitted and approved by the Texas State University's Department of Environmental Health, Safety and Risk Management. The team used a DJI Phantom 4 model quadcopter equipped with a 12-megapixel camera. The UAS was flown at an altitude of 40 meters providing a resolution of 2 cm per pixel. The team selected the flightpath for the drone to encompass primarily the water surface area of the lake and flying was completed autonomously using flight tracker software.

After the flight was completed, the collected imagery was downloaded and compiled with 60% imagery overlap using AgiSoft software to create a single aerial image of Spring Lake, and this aerial image mosaic was used to plan field mapping activities. The imagery was also used as background imagery during the field mapping and editing process.

The team used a 10 foot sit in kayak with a plexiglass window for visual observations to complete the field mapping portion of the project. A Trimble GPS unit and external Tempest antenna set on the bow of the kayak was used to collect high accuracy (10 cm – 60 cm) geospatial data. A data dictionary along with pre-determined attributes was loaded into the GPS unit for data collection in the field, and a team member in the kayak recorded discrete patches and density of vegetation and substrate observed from the surface while an accompany free diver verified these observations (Figure 2).

The discreteness of an individual vegetation patch was determined by the dominant species located within the patch compared to surrounding vegetation. Once a patch of vegetation was visually delineated, the kayak was navigated around the perimeter of the vegetation patch to collect geospatial data with the GPS unit. This action creates a vegetation polygon. Attributes were assigned to the polygon in the GPS unit including species type and percent cover of each of the top four dominant species. The type of substrate (silt, sand, gravel, cobble, organic) was identified if open substrate was a dominant feature within the patch. The team mapped rooted aquatic vegetation, floating aquatic vegetation, bryophytes, algae, and *Zizania texana* (Texas wild-rice) as separate features. Only aquatic vegetation patches one meter in diameter or larger were mapped as polygons. However, all *Zizania texana* was recorded, with individual *Z. texana* plants too small to delineate as polygons mapped as points instead.

During post processing, the data were downloaded from the GPS unit and run through a secondary program to correct spatial data and create the files for the feature classes and their associated data. Spatial data was projected using the Projected Coordinate System NAD 1983 Zone 14N. Post processing was conducted to clean polygons, check for and correct errors, and calculate cover for individual discrete polygons as well as totals for all encountered aquatic plant species.

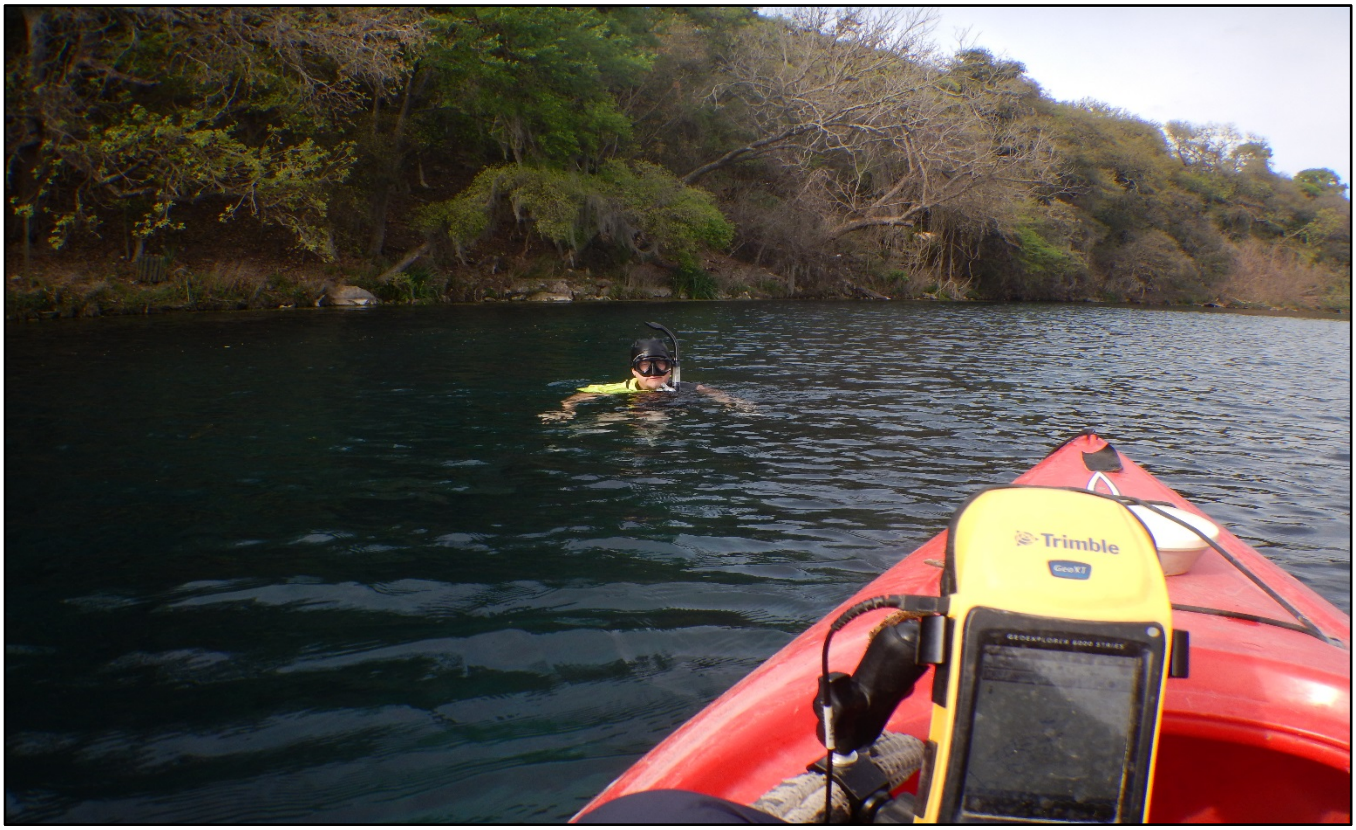

Figure 2. Vegetation mapping with a kayak and the aid of a free diver.

Results

The results of this survey show a total of 19 species mapped, with seven of the 19 species considered non-native and /or invasive, and a few other observed species not abundant enough for mapping included in the species list (Table 1).
The total coverage of rooted aquatic vegetation in Spring Lake currently exceeds 52,000 m^2. Unrooted vegetation (floating plant species like *Pistia stratiotes*) account for over 6,000 m^2. In a few instances, floating plant species, notably *Eichhornia crassipes,* were mapped as rooted vegetation because their growth habit at the time of mapping was that of stranded plants rooted in mud or silt, although normally this species is free floating on the water surface. Bryophytes cover approximately 100 m^2 and algae 1,641 m^2 (Table 2).

The present aquatic vegetation community in Spring Lake is a heterogeneous mix of 5 to 6 dominant plant species with smaller amounts of additional species occurring intermittently although species composition and density varies per each section.

The Spring Arm region is populated by a mix of *Ceratopyllum demersum*, *Myriophyllum spicatum*, *Myriophyllum heterophyllum* and *Sagittaria platyphylla*. *Cabomba caroliniana* is dominant in only the upper most end of Spring Arm, but is intermittent throughout the section in small amounts. *Myriophyllum spicatum* is common around the spring openings while *C. demersum* is dominant in the deeper areas adjacent to the springs, usually affixed to submerged structures or other plant species. Most species are intermingled along the lake bottom with alternating dominant species.

Table 1. List of observed aquatic plant species in Spring Lake during surveying timeframe.

Species name	Common name	Introduced or Native (I/N)
Vascular Plants		
Alternanthera philoxeroides	alligator weed	I
Cabomba caroliniana	fanwort	N
Ceratophyllum demsersum	hornwort	N
Eichhornia crassipes	water hyacinth	I
Hydrocotyle verticillata	pennywort	N
Hygrophila polysperma	Indian swampweed	I
Juncus texanus	Texas rush	N
Lemna	duckweed	N
Ludwigia repens	water primrose	N
Myriophyllum heterophyllum	variable-leaf milfoil	N
Myriophyllum spicatum	Eurasian milfoil	I
Nuphar lutea	cow lily	N
Pistia stratiotes	water lettuce	I
Ranunculous scleroides	buttercup	I
Sagittaria platyphylla	delta duck potato	N
Typha domingensis	Southern cattail	N
Utricularia gibba	bladderwort	N
Veronica anagallis aquatica	water speedwell	I
Zizania texana	Texas wild-rice	N
Zizaniopsis milicea	rice cutgrass	N
Filamentous algae		
Oscillatoria		N
Bulbochaeta		N
Spirogyra		N
Bryophyte		
Hygroamblystegium varium		N
Riccia fluitans	crystalwort	N

The Lower Lake section is occupied by *Hygrophila polysperma*, *S. platyphylla* and *M. heterophyllum* as the most dominant species, with *M. spicatum* and *C. demersum* also common. This is the location of *Z. texana* in Spring Lake and this species is found adjacent to both the Eastern spillway and the mill race of Spring Lake dam. *Nuphar lutea*, *C. caroliniana* and *Ludwigia repens* are present but much less common in this area.

The aquatic vegetation in the Slough Arm is dominated by *N. lutea* and *C. caroliniana* in deep water, while a variety of species are found in the shallow water sections along the floating boardwalk and the Slough Arm mouth. This section has a well-formed littoral zone with littoral species such as *Typha domingensis* abundant. The Slough Arm also has numerous silt banks that may become exposed during reduced water levels. These are almost exclusively dominated by stranded water hyacinth (*Eichhornia crassipes*). *Alternanthera philoxeroides*, *Ranunculus scleroides* and *Juncus texanus* are common along the silt banks and littoral edges. The section of the Slough Arm above the low water crossing at Spring Lake Drive and continuing upstream along Sink Creek are almost entirely covered with *P. stratiotes* with some occurrences of *N. lutea*. This area is notably devoid of submerged aquatic vegetation.

Map arrangements located in Appendix 1 at the end of this report provide a detailed distribution of aquatic vegetation throughout the sections Spring Lake.

Figure 3 below highlights the makeup of the rooted aquatic vegetation community. The single most dominant plant species in Spring Lake is *C. demersum* accounting for nearly 40% of the vegetation community. This plant is not exclusive to any one section of the lake but present throughout the system. *Ceratophyllum demersum* is not a rooted plant and generally anchors itself by growing wrapped around other submerged aquatic species or by becoming partially buried in sediment. It can also grow suspended in the water column or even floating at the water surface. The variety of growth habitats allows *C. demersum* to grow virtually anywhere within Spring Lake and facilitates its abundance. The second most dominant species, at a distant 14% coverage, is *N. lutea* although its distribution is mostly limited to portions of the Slough Arm. This rooted waterlily species is heavily concentrated in the Slough Arm of Spring Lake with a few patches located in the lower section of the lake. It is uncommon in the Spring Arm. The third most dominant species mapped is *M. spicatum* which is heavily concentrated in the Spring Arm of the lake, extending to the lower lake section. *Myriophyllum spicatum* appears to be most dense in areas with moving water, especially adjacent to the spring openings. It is less common in the Slough Arm and other lentic locations. *Cabomba caroliniana* is the fourth dominant species. While small amounts of *C. caroliniana* are noted throughout Spring Lake, there are notable areas where the plant dominated, such as the uppermost end of the Spring Arm and the upper end of the Slough Arm. Less dense patches of *C. caroliniana* are common adjacent to the floating boardwalk of Spring Lake. *Sagittaria platyphylla* is present and common in the Spring Arm and Lower Lake sections, but is completely absent in the Slough Arm. *Myriophyllum heterophyllum*, a native milfoil, is generally common throughout the Spring Arm and the Lower Lake section of Spring Lake and occasionally present in the littoral areas of the Slough Arm. This species appears to be most dominant in shallower areas between 2 and 4 feet (0.6 to 1.2 meters) of depth and in areas with silty substrate. *Hygrophila polysperma* is almost exclusively limited to the Lower Lake section where it is found dominant in flowing water and silty locations, although it is also observed in a few locations along the edge of the Spring Arm.

Table 2. Species coverages in square meters.

Species	Cover (m^2)
Rooted Vegetation	
Ceratophyllum demersum	19,611.66
Nuphar lutea	7,208.00
Myriophyllum spicatum	7,070.51
Cabomba caroliniana	5,222.55
Sagittaria platyphylla	4,336.57
Myriophyllum heterophyllum	3,430.23
Hygrophila polysperma	2,075.07
Typha domenguinesis	1,475.38
Chara species	726.89
Utricularia gibba	443.08
Eichhornia crassipes	414.60
Zizania texana	236.69
Ludwigia repens	34.49
Zizaniopsis milicea	6.51
Veronica anagalis-aquatica	4.71
Ranunculus scleroides	4.26
Hydrocotyle verticillata	1.79
Floating Vegetation	
Pistia stratiotes	3,685.60
Lemna species	2,003.00
Ceratophyllum demsersum	263.24
Utricularia gibba	176.88
Eichhornia crassipes	124.53
Bryophyte (multiple species)	114.64
Algae (multiple species)	1,641.43

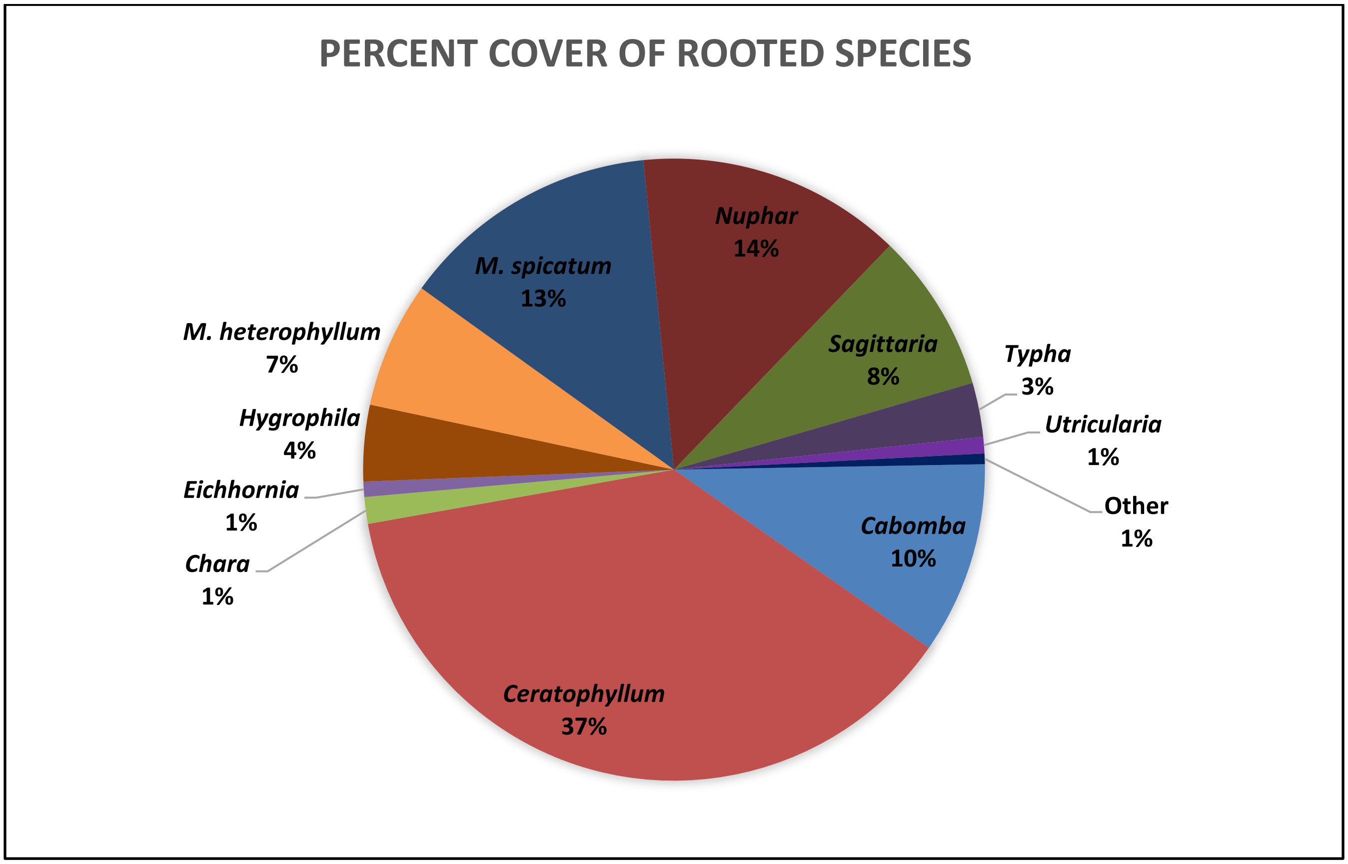

Figure 3. Percent composition of the rooted aquatic plant community.

Other species that are not widespread but instead concentrated in particular areas included *Utricularia gibba*, *Chara* species, *Eichhornia crassipes* and *Typha domingensis*. Although *Z. texana* is prominent at both the Western and Eastern spillway, it does not occupy any considerable portion of the greater vegetation community in Spring Lake. This species has increased in cover significantly due to restoration, but its overall distribution within the lake is limited.

The floating vegetation is overwhelmingly dominated by *Pistia stratiotes* and *Lemna* species occurring almost entirely in the Slough Arm section, with *P. stratiotes* concentrated above the low water crossing. Most other floating vegetation species that are present are intertwined in the canopy of rooted submerged species. Floating *C. demersum* colonies are present in limited patches in the Spring Arm.

The occurrence of dense algae beds is mostly observed along the Slough Arm with *Spirogyra* algae the most prominent, growing amongst and on top of *C. demersum*. Other algae types (listed in Table 1) were collected and observed in varying degrees of density and in multiple locations from lentic to lotic flow regimes.

A single dense patch of bryophyte occurs in the system at the extreme upper end of the Spring Arm. This patch of *Hygroamblystegium riparium* is tightly packed and clings to the cobble and rock faces around spring openings and bare surfaces as well as the concrete wall bordering the upper end of this section.

One noteworthy non-plant species is the freshwater mussel *Utterbackia imbecillis* (paper pondshell) observed alive in the Slough Arm area along the deepest channel. Selected field photographs are located in Appendix 2 at the end of this report. All pictures will be submitted in a separate file with this report.

Notable aquatic vegetation changes between 2009/2010 and 2020 surveys:

In the fall of 2009 and winter of 2010 Spring Lake was mapped by the Texas River Systems Institute in a very similar fashion to this survey. The report is located in Appendix 3 at the end of this report and contains more information regarding the historical aquatic vegetation in Spring Lake. Figures 4 and 5 below illustrate the changes in distribution and density of selected species between 2009/2010 and 2020. Based on coverages calculated between our mapping event and the earlier survey, a 75% decrease in the coverage of *C. caroliniana*, a 66% decrease in *M. heterophyllum* and a 40% decrease in *S. platyphylla* was noted. Notable increases in cover included an 82% increase in *C. demersum* and a 62% increase in *Hygrophila polysperma*. Exceptionally notable changes include *Z. texana* which between 2009 and 2020 increased significantly, from 1.34 m^2 to 236 m^2.

Regarding species diversity, several species were absent in this survey which were present, sometimes in significant quantities in the earlier mapping. The team found few colonies of *Colocasia esculenta* (elephant ear) around Spring Lake in 2020. Those observed were mixed with *Typha domingensis*. In 2009, this species covered over 700 m^2. Other species notable in 2009 but absent in 2020 include *Ceratopteris thalictroides* and *Iris pseudacorus*, both non-native species. A few native species documented in 2009 were also not observed. These include *Acmella repens* and *Schoenoplectus tabernaemontani.*

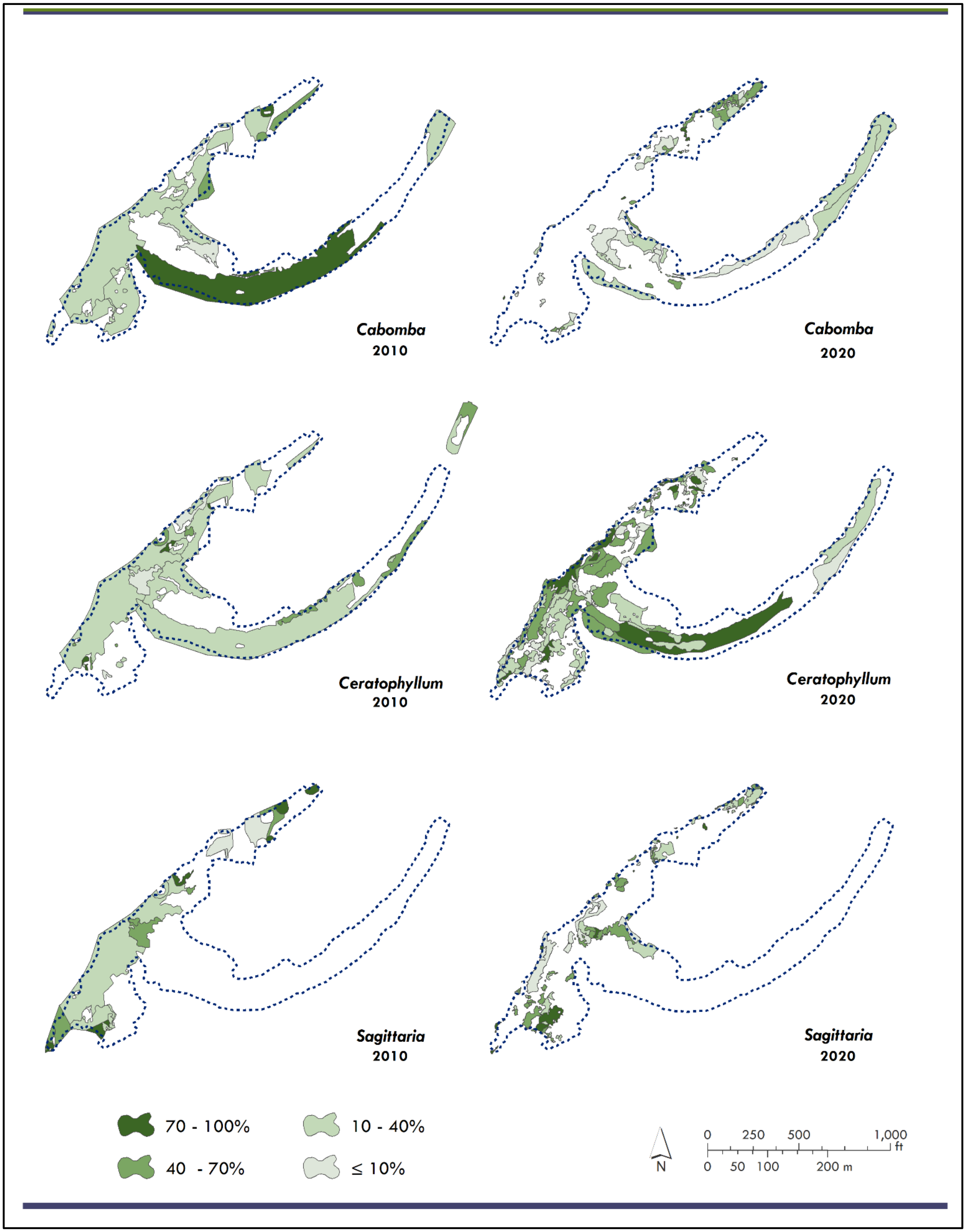

Figure 4. Changes in distribution of selected species between 2010 and 2020.

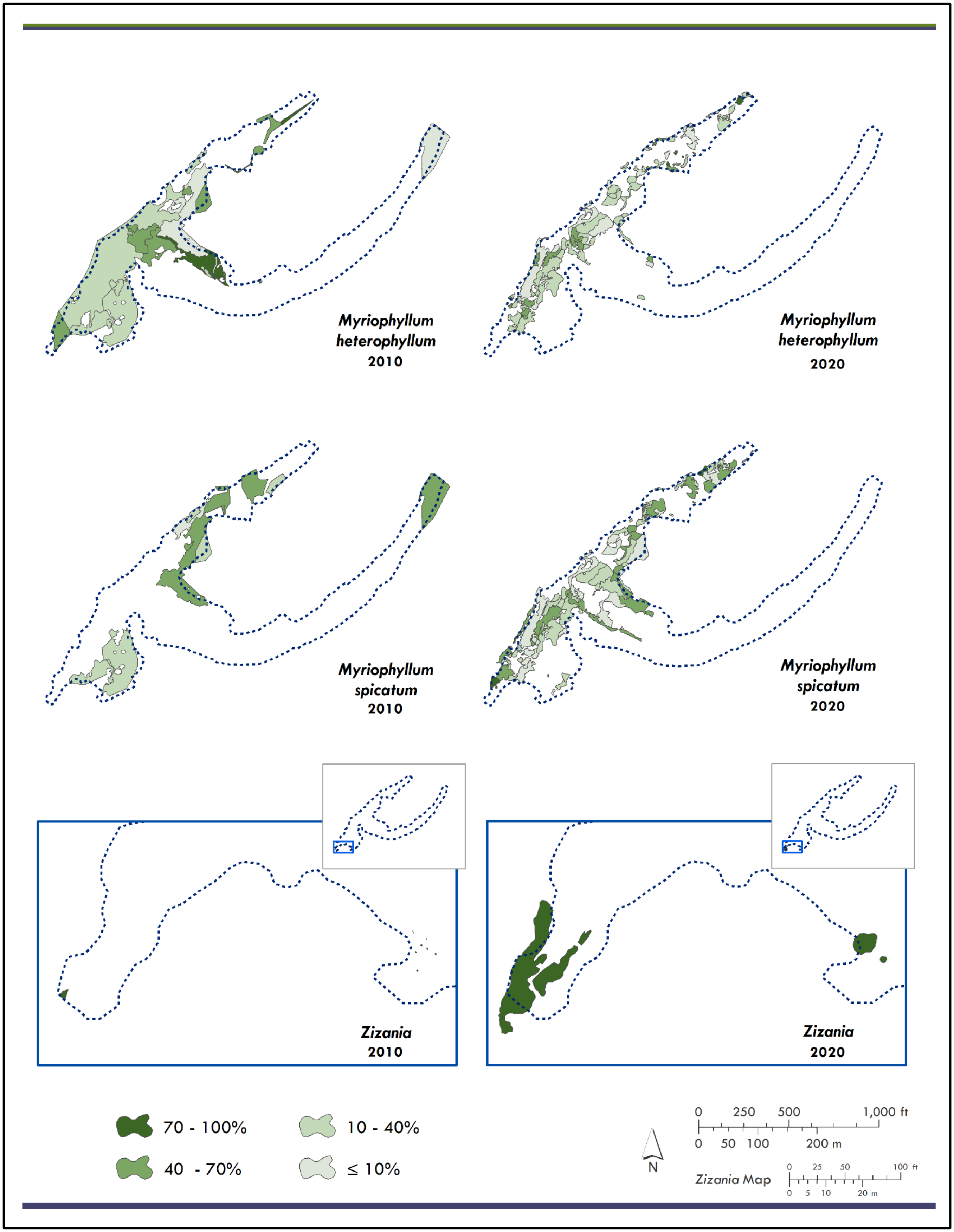

Figure 5. Changes in distribution of selected species between 2010 and 2020.

Discussion

A review of documentation of the aquatic vegetation in Spring Lake indicates long term change in the diversity of the aquatic plant community throughout the years. Reports as early as 1930 (Watkins) documented a long list of native and non-native species, some of which can still be found in the lake while others have disappeared. For example, *Hydrilla verticillata*, also mistakenly identified as *Elodea canadensis* or *Egeria densa* in past Spring Lake surveys, was reported as early as 1940 by Devall and expanded by 2001 to encompass up to 70-80% of the lake (Owens et al., 2001). By 2009, however, *H. verticillata* was not observed in Spring Lake and it was not detected during this 2020 survey. Changes in diversity can be attributed to a combination of species persistence, seed bank or propagule longevity, plant health, interspecific competition and human intervention. Multiple non-native species were undoubtedly introduced to Spring Lake for ornamental purposes when the waterbody was used as a public attraction. Over time some species have waned, likely as a result of the combined factors listed above. Others have become more prominent in the vegetation community, and all species noted during this survey have been observed or mapped in previous studies.

The cover and distribution for some aquatic plant species is partially a result of seasonal growth patterns. Our past professional experience has shown that *C. caroliniana* growth is greatly reduced during the winter and spring, but reaches a peak biomass period in late summer. This may be the reason for seemingly absent or sparse coverage of this species in the Slough Arm as the survey was carried out during the minimal biomass period for *C. caroliniana*. In contrast the Spring Arm area, which experiences more minimal temperature fluctuations, has relatively consistent *C. caroliniana* growth throughout the year.

Interspecific competition may also be driving coverage changes between species, as losses of one species become coverage gains for another. This could be a reason for the reduced coverage of *C. caroliniana* in the Spring Arm while *M. spicatum* has expanded in this same region since 2009/2010. The negative impacts *M. spicatum* have on native aquatic plant communities are well documented by Boylen et al. (1999) and other literature. The Spring Lake vegetation community may also be shaped by physical effects including harvesting and removing overgrown vegetation both by a mechanical harvesting boat as well as SCUBA divers. Consistent and persistent mechanical or hand harvesting may drive plant community changes as some species react by gradually declining as a result of harvesting while others, native and non-native, may increase biomass (i.e. side shoot) production or adapt their growth habits to this artificial occurrence (Hussner et al., 2016). *Hydrilla verticillata* was successfully eradicated with the help of volunteer SCUBA divers carefully removing patches of the plant by hand over the past 20 years. Human intervention via restoration planting and conservation techniques can significantly increase the presence of native species. Harvesting operations may be modified to encourage growth of desired species.

Restorative actions have led to the dramatic increase in *Z. texana* since 2009. In 1930, *Z. texana* was prominent in the Lower Lake section of Spring Lake based on maps from Watkins. By 1967 only one plant was located in Spring Lake (Emory, 1967). Replanting trials were undertaken in the 1990's (Rose and Power, 1993) continuing intermittently as trial experiments and studies. Larger scale restoration activities were implemented as part of the Edwards Aquifer Habitat Conservation Plan and continue. Promoting the growth and expansion of other native species such as *Ludwigia repens, Cabomba caroliniana* or *Myriophyllum heterophyllum* in Spring Lake by direct planting or passive management improve the habitat for target aquatic species including the fountain darter.

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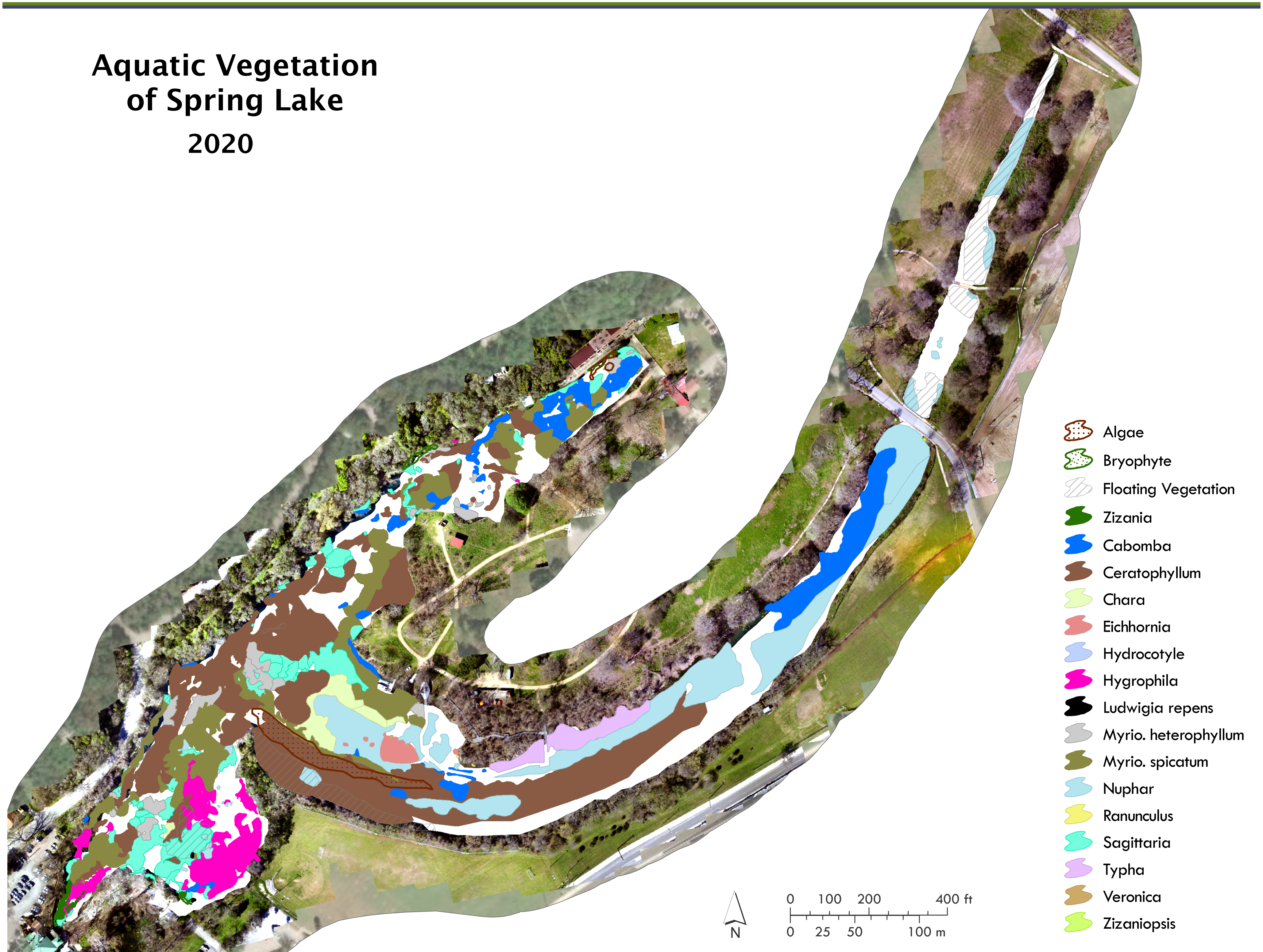
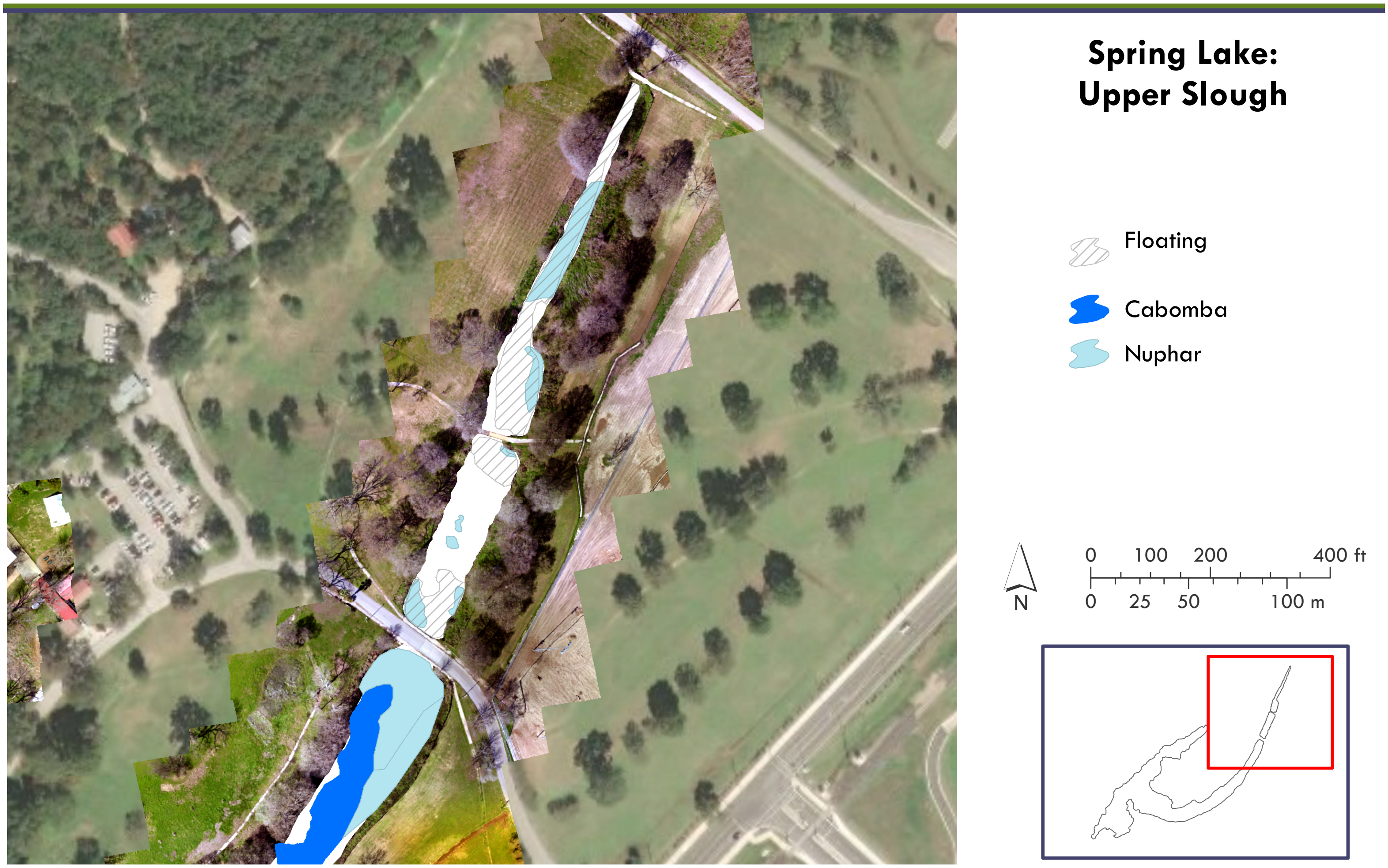
Appendix 1 Map Sections

Aquatic Vegetation of Spring Lake

2020





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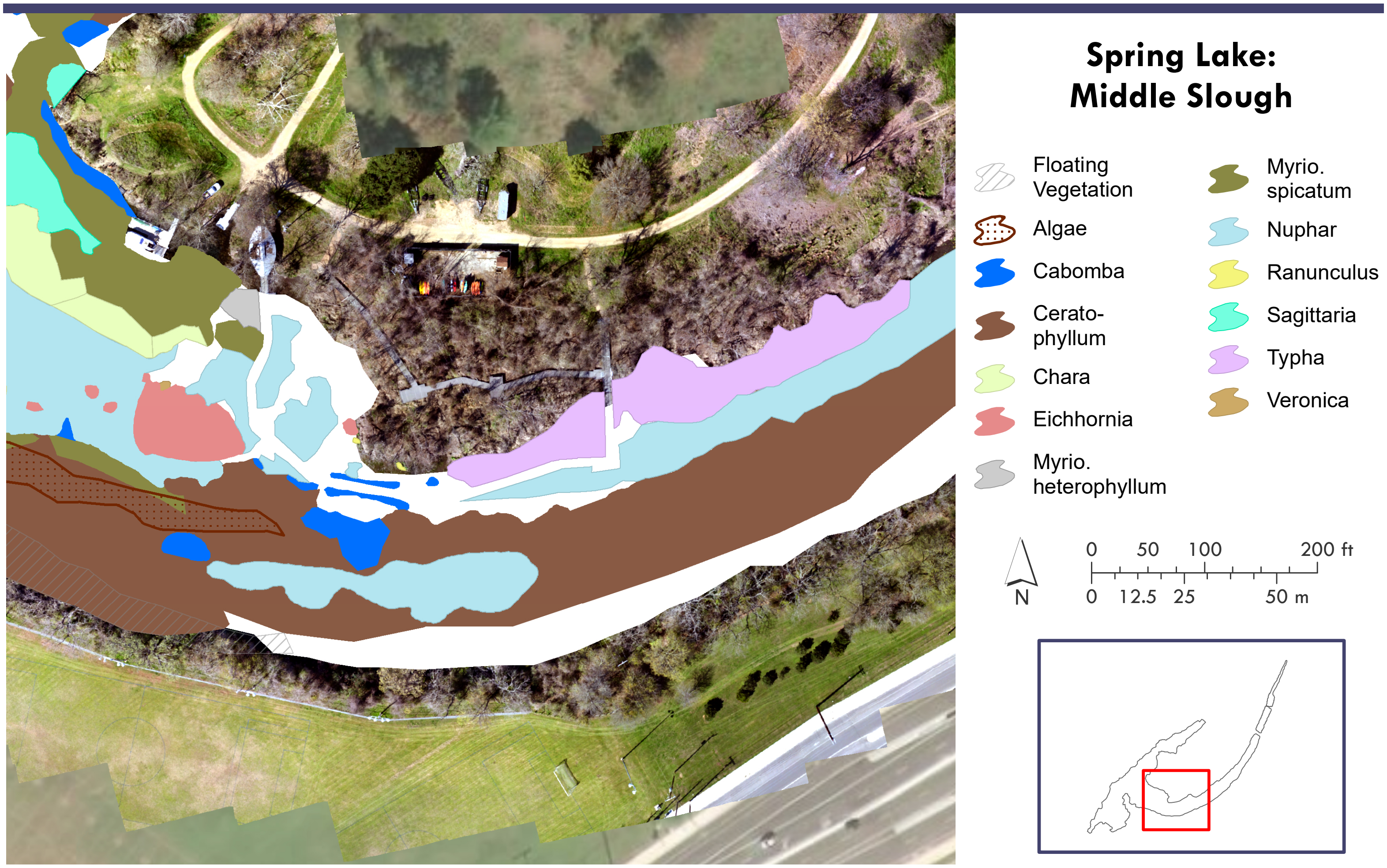

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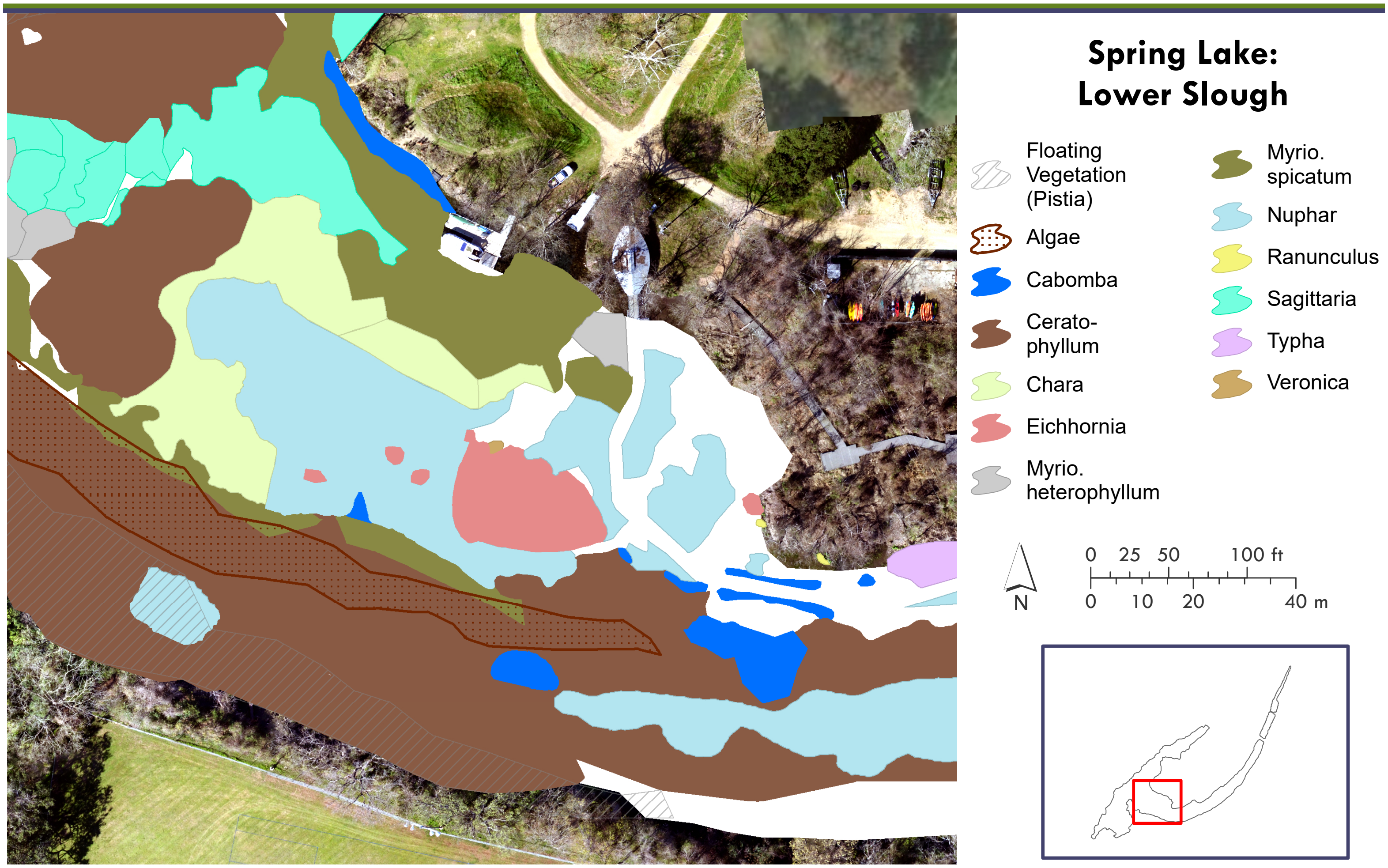

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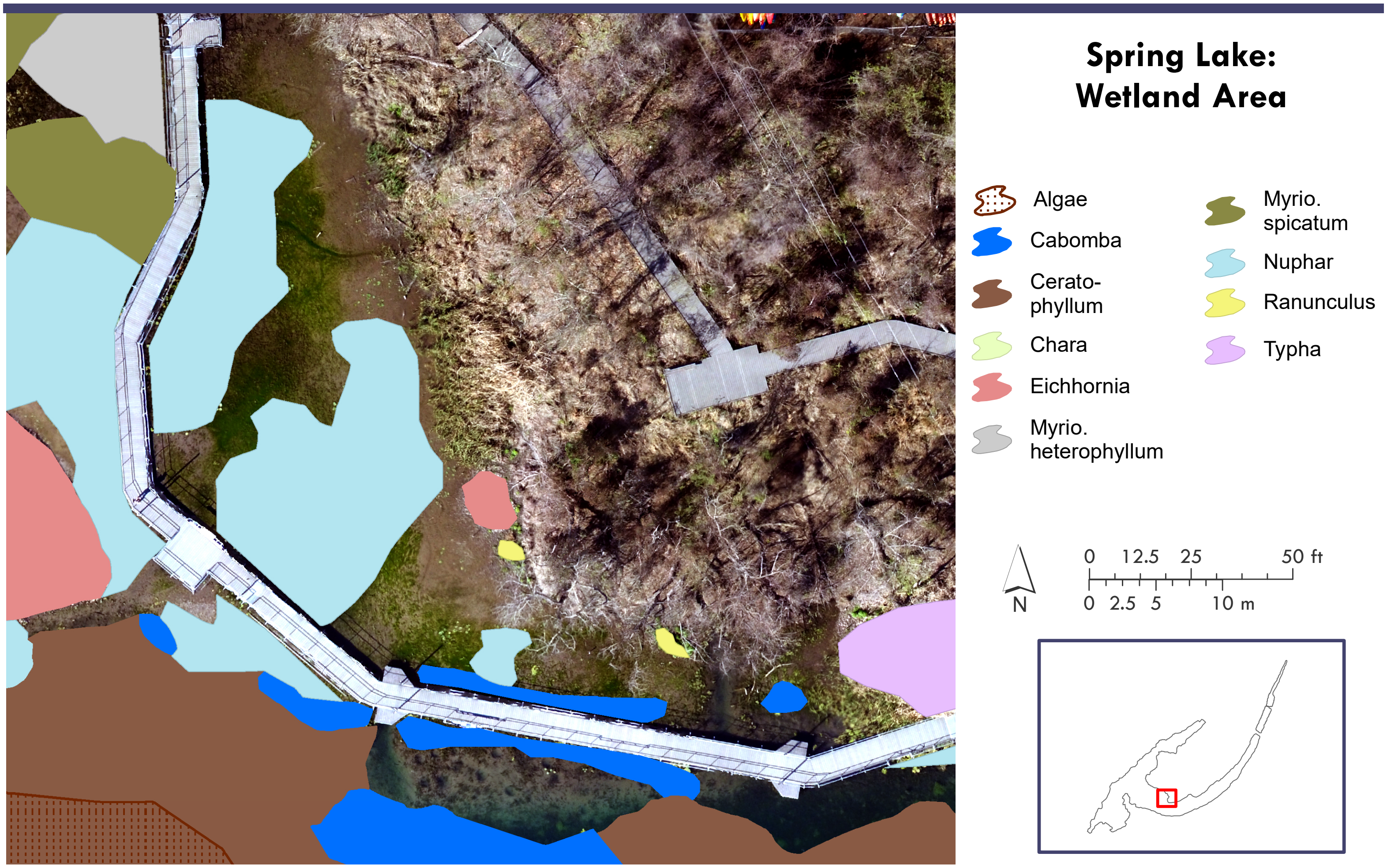

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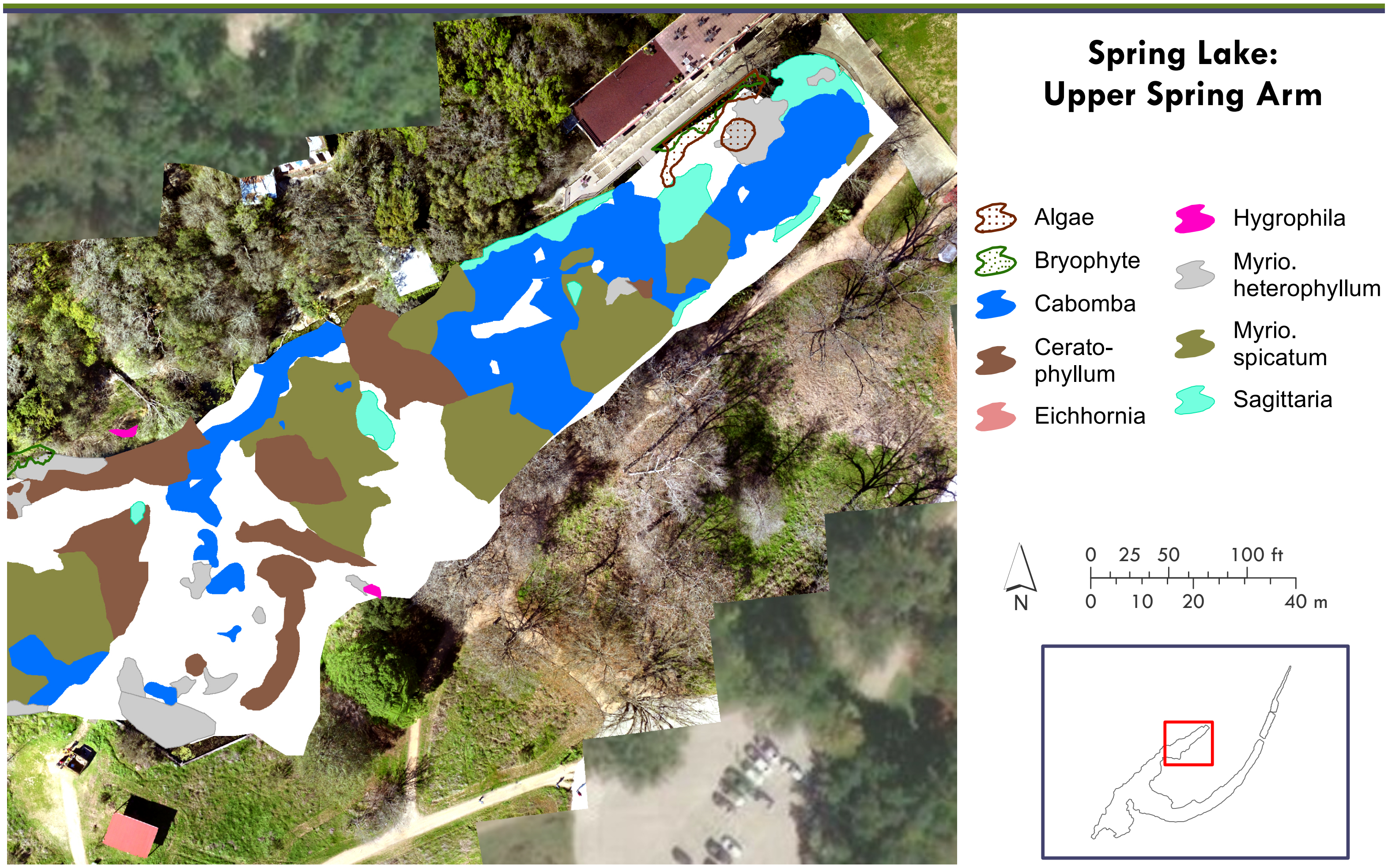

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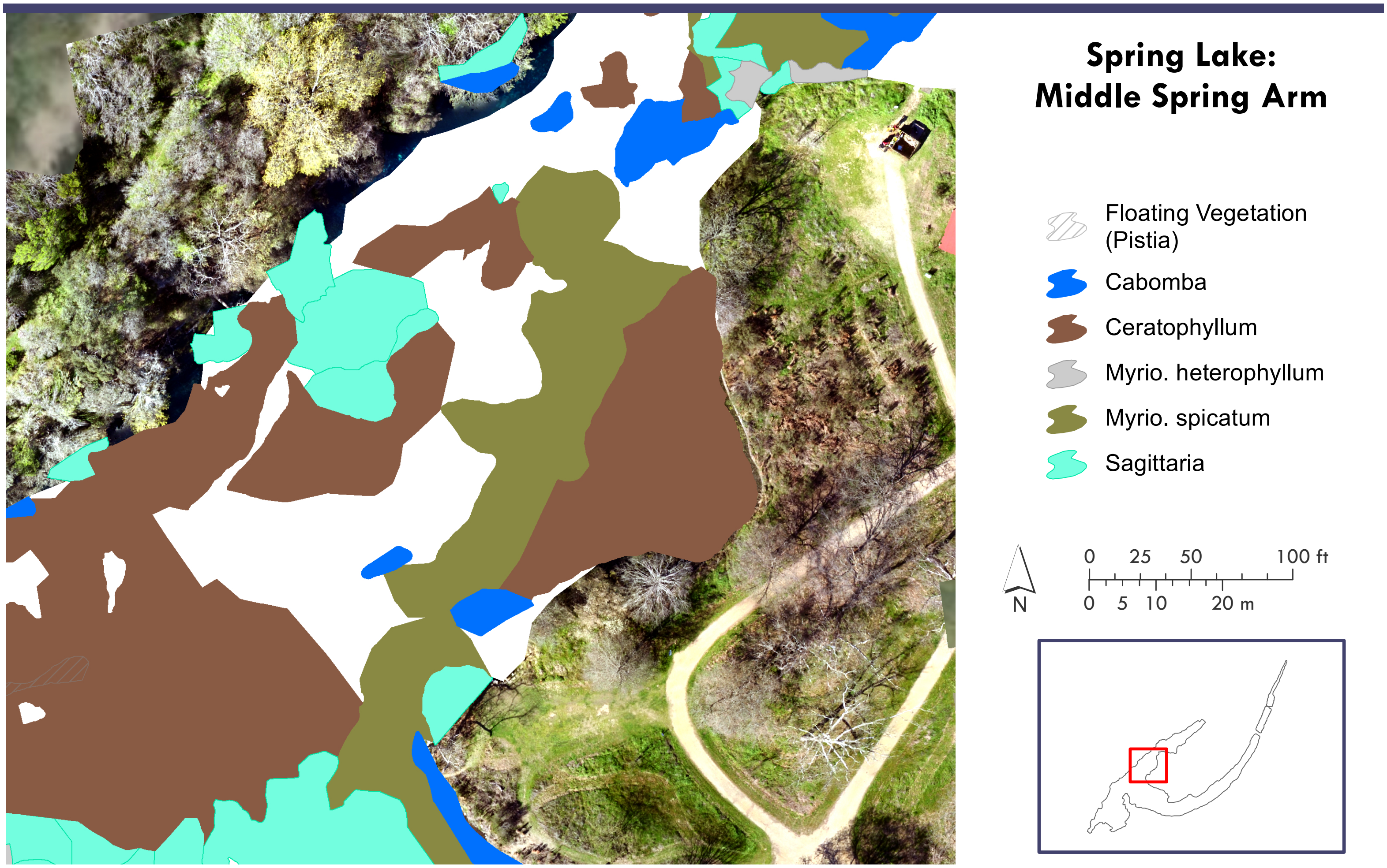

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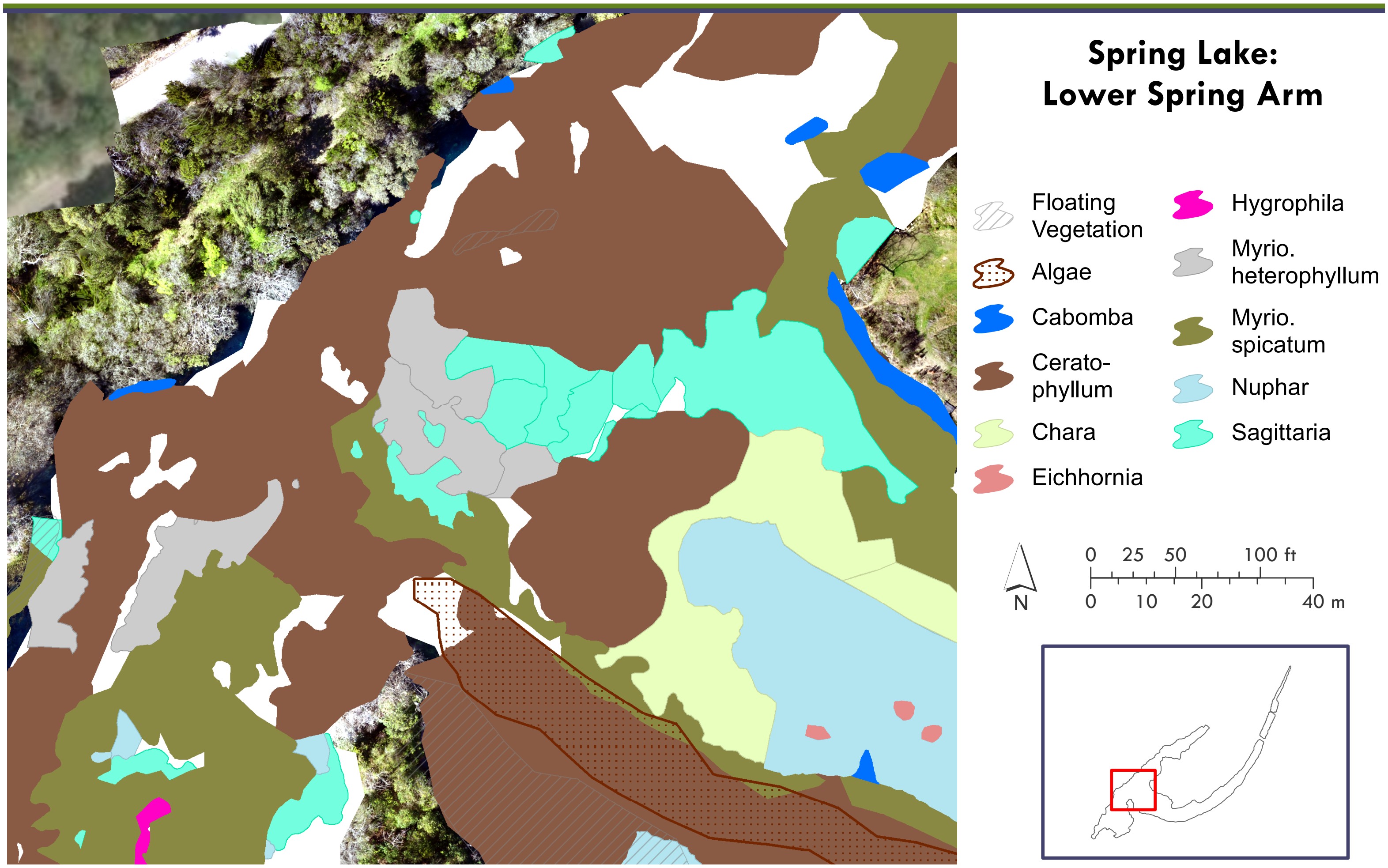

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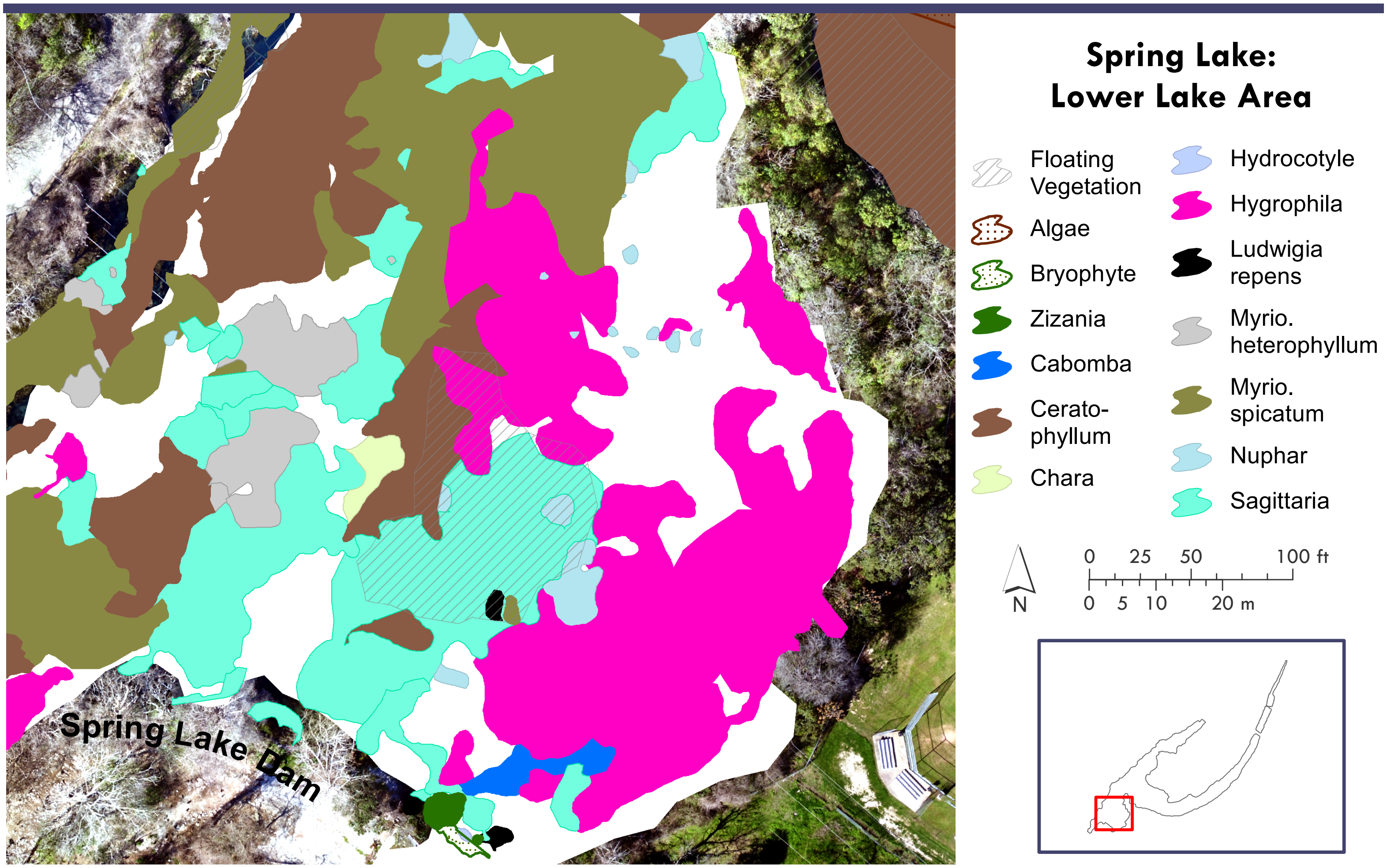

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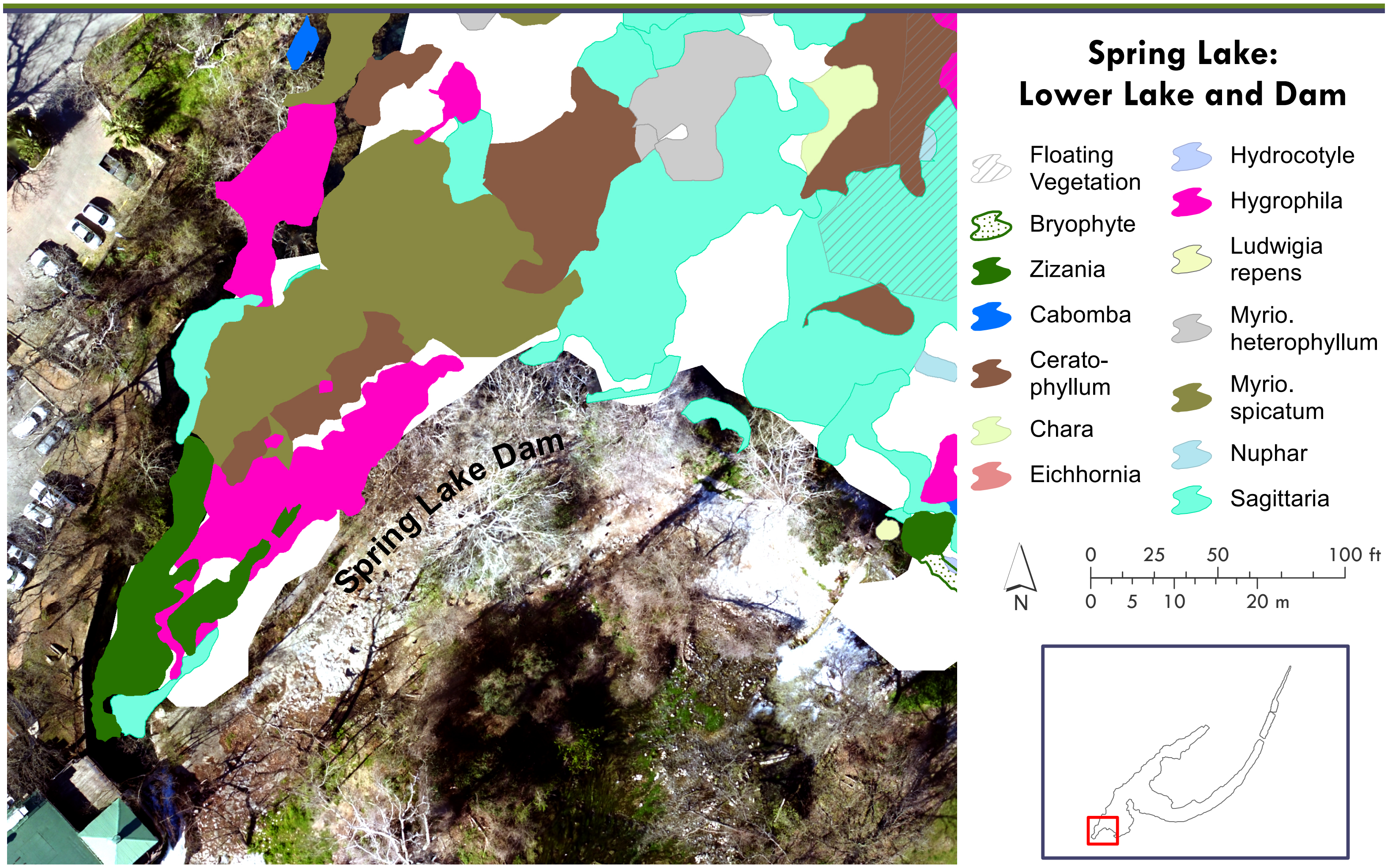

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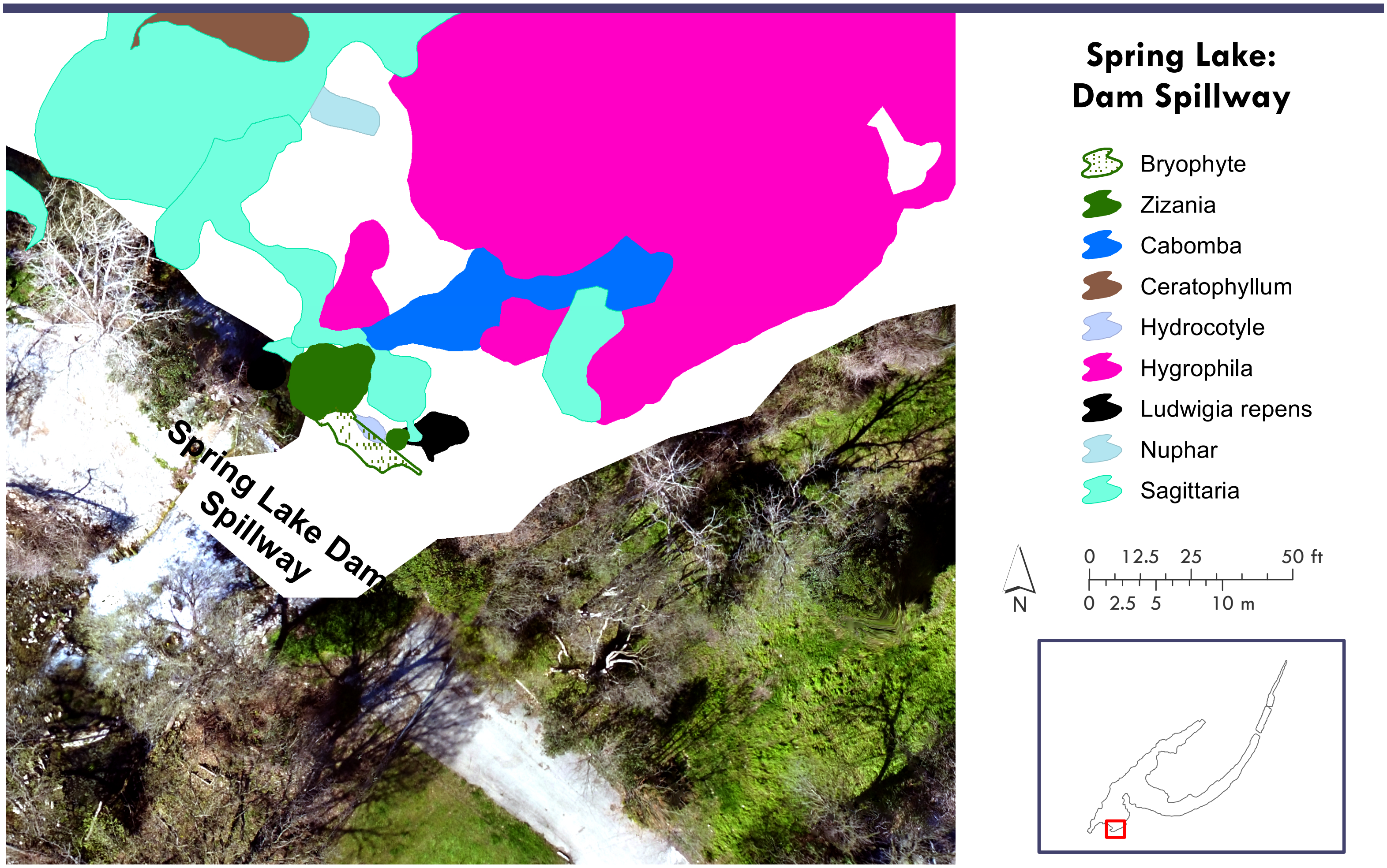

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Appendix 2 Selected Field Photographs

Figure 6 (top) The native milfoil *Myriophyllum heterophyllum* compared to *Myriophyllum spicatum* a non-native milfoil (bottom).

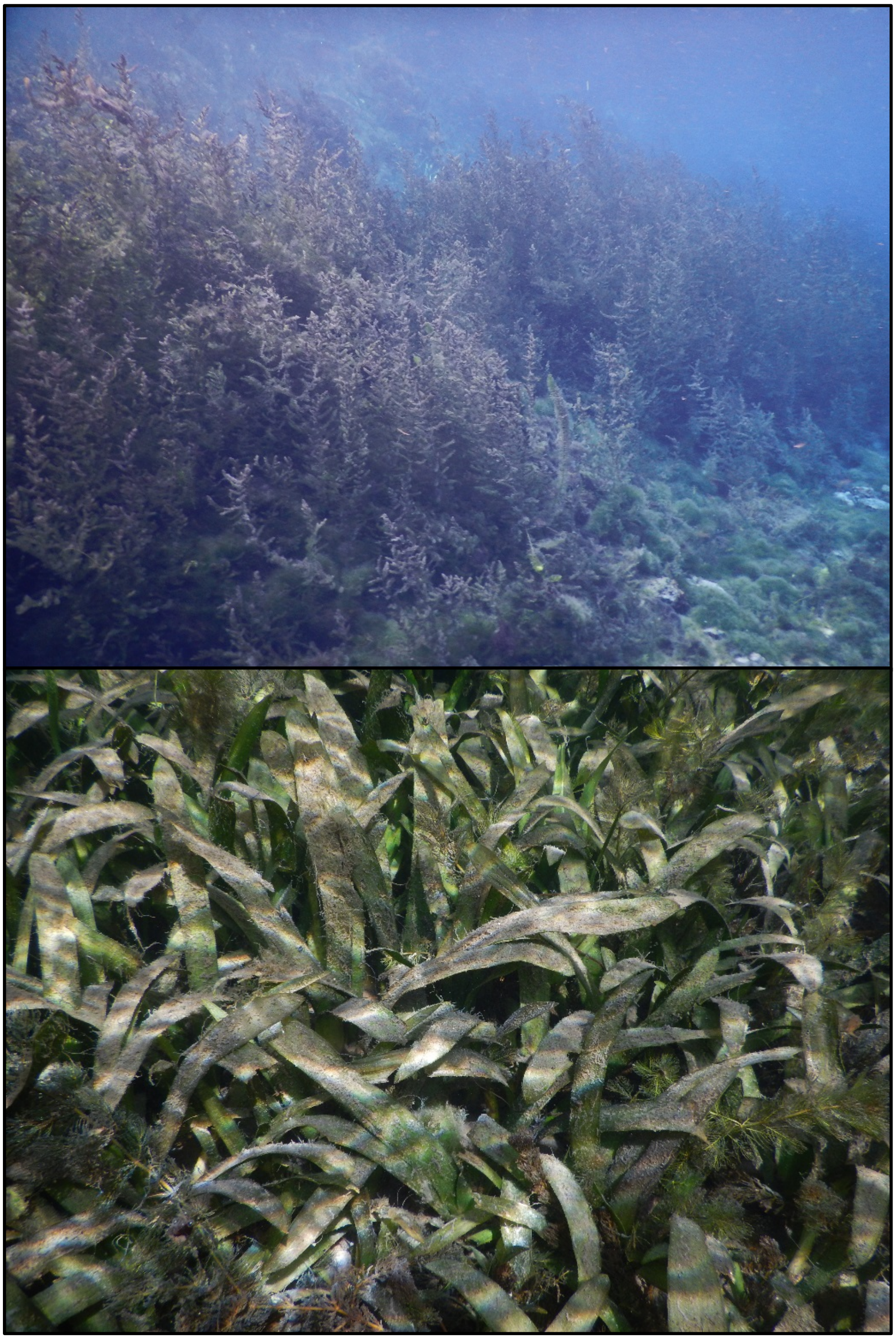

Figure 7. (top) Colony of *Ceratophyllum demersum* a non-rooted but attached macrophyte. (bottom) *Sagittaria platyphylla* creates dense low growing turf like colonies.

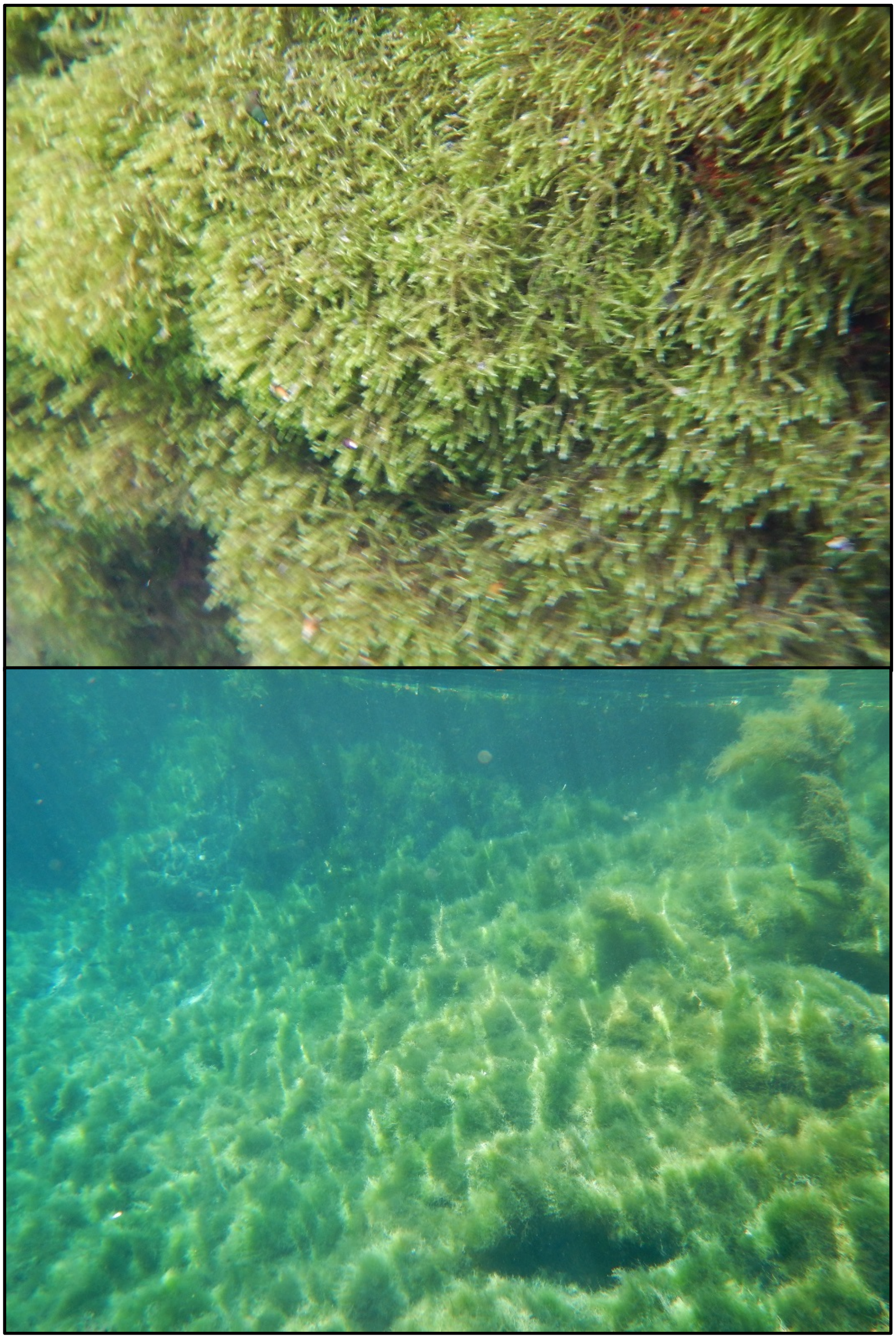

Figure 8. (top) *Hygroamblystegium varium* is an aquatic moss found in the area of the headwaters. (bottom) Filamentous algae was commonly covering other vegetation and submerged structure in the Slough Arm.

Appendix 3

Spring Lake Aquatic Vegetation Mapping Project and Historical Assessment

January 2011

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Data and Information provided by

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Glass bottomed boat on Spring Lake

Abstract: From September 2009 to January 2010 field technicians from the River Systems Institute conducted an intense aquatic vegetation inventory and mapping project as part of the San Marcos River Observing System. This survey included collecting, identifying and recording the location of all obligate aquatic plants that live along the San Marcos River System. As part of this project the aquatic vegetation of Spring Lake was mapped in GIS for the first time providing a solid baseline for future restoration projects.

Spring Lake, Hays County Texas is the headwaters of the San Marcos River. Impounded in 1849 this small reservoir is considered critical habitat for several endangered and threatened species including the fountain darter, Etheostoma fonticola; San Marcos salamander, Eurycea nana and Texas blind salamander, Typhlomolge rathbuni. Texas wild rice, Zizania texana, historically has inhabited the area now inundated by Spring Lake but its distribution is now restricted to a few locals within the lake. Several introduced species including Myriophyllum spicatum, Hygrophila polysperma, and Colocasia esculenta are now common. Historical data suggests that the number of introduced plant species has increased from two, identified in 1930, to the present number of thirteen.

Survey protocols included identifying plant species, collecting voucher specimens for the Texas State University Herbarium, delineating vegetation stands via snorkel/kayak and tracing stands with a Trimble HQ gps mapping unit to produce a vegetation polygon shape file viewed in ARCview by ESRI.

Introduction:

From September 2009 to January 2010 field technicians from the River Systems Institute conducted an intense aquatic vegetation inventory and mapping project as part of the San Marcos River Observing System. This survey included collecting, identifying and recording the location of all obligate aquatic plants that live along the San Marcos River System. As part of this project the aquatic vegetation of Spring Lake, the headwaters of the San Marcos River, was mapped for the first time in ARCview by ESRI providing a solid baseline for future restoration projects.

Covering approximately 22 surface acres (9 hectares), Spring Lake (Figure 1.) is formed from the impoundment of the San Marcos Springs, which provide base flow to the San Marcos River (Mathews, 2005). This small reservoir is situated over the Balcones fault zone and is fed by an artesian spring system issuing from the karstic Edwards Aquifer. The San Marcos Springs are the second largest spring system in Texas producing an average of 167 ft^3/sec. ($5m^3$/ sec.) and experienced a minimum flow of 46 ft^3/sec. ($1.3m^3$/sec.) in August of 1956 (Saunders et al, 2001). Spring Lake can be divided into 3 major sections, the spring section; slough section and the lower lake section. The spring section or Western arm contains the major spring openings and most minor springs. It is characterized by exceptional water quality, clear water and consistent water flow. It is also the section most utilized by scuba divers and glass bottomed boats. This is also the deepest section of Spring Lake reaching a maximum of 26 feet (8 meters). The slough section or Eastern arm, is the region consisting of flooded Sink Creek. This section is fed by surface runoff and is characterized by higher variability in water quality and flows dependent on weather conditions. Depths here can reach up to 19 feet (6 meters). The lower lake zone, is the area immediately above the Spring Lake dam. This section is identified as the confluence of the spring arm and the slough arm and is characterized as mostly shallow, with strong water flow. This section is the only area of the lake where the endangered Texas wild rice, *Zizania texana*, can still be found. Spring lake is considered critical habitat by the U.S Fish and Wildlife Service (USFWS, 1996) for the fountain darter*, Etheostoma fonticola*, San Marcos salamander, *Eurycea nana*, and the Texas blind salamander, *Eurycea rathbuni.*

Besides its environmental importance Spring Lake has a colorful history of human occupation, and utilization. Archeological evidence suggests that San Marcos Springs have been inhabited by humans for 10,000 to 12,000 bp, and Spanish discovery of the springs is recorded around 1691 (Kimmel, 2006)(Saunders et al., 2001). While a Republic of Texas Post was established in 1840, main use of the site for recreation came about after the lake was impounded in 1849. Through the 1900's Spring Lake was the site of construction for the Spring Lake Hotel, 1929, and later Texas' first amusement park, Aquarena Springs. Currently Spring Lake and surrounding area is owned and operated by Texas State University-San Marcos as an interactive educational park, providing underwater views of Spring Lake via glass bottomed boat tours and research area for Texas State University-San Marcos (Kimmel, 2006).

Figure 1. An aerial photograph of Spring lake looking northeast. The Spring section is located on the left, while the Slough section is located on the right. Courtesy of Texas Water Development Board

Background of Project:

The aquatic plant inventory and mapping project was carried out as part of the San Marcos Observing System funded by River Systems Institute at Texas State University-San Marcos. The San Marcos Observing System (SMOS) has been established within the upper 5 miles of the San Marcos River (first 7.4 km) and associated watershed as a long-term effort to integrate physical, hydrologic, chemical, and biological monitoring to further the scientific understanding of the responses of aquatic resources to variation in flow regimes, anthropogenic impacts from watershed development, and interactions between native and introduced flora and fauna. The SMOS includes a public information and education outreach emphasis. This effort includes a comprehensive watershed characterization system based on land use/cover, terrestrial/aquatic vegetation, impervious layers, stream gages, water quality sampling locations, aquifer monitoring wells, meteorological stations, demographics, economics, and other important spatially explicit data. These data are being used to develop education modules for a number of school curriculums and includes a drainage level standardized watershed characteristic report and supports on-going stakeholder driven strategic watershed planning and protection efforts. In addition the San Marcos River system is also included in the Edwards Aquifer Habitat Conservation Plan.

Survey Methods :

Figure 2. Voucher specimen of *Sagittaria platyphylla*

Inventory and mapping were conducted between September 2009 and January 2010. Inventory portion of this project included identifying all obligate aquatic plant species; including emersed, submersed, floating and floating leaved plants; labeling plant species based on their Wetland Indicator Status (USFWS, 1998) and collecting voucher specimens of each species from Spring Lake. Herbarium vouchers were placed in the Texas State University Herbarium and duplicate vouchers are also on file at the Botanical Research Institute of Texas, Fort Worth. A digital herbarium is also available at http://picasaweb.google.com/cw1107/DigitalHerbarium?feat=directlink#.

The mapping portion of this project was conducted using Trimble Geo XH Geoexplorer 2008 series gps units. Vegetation patches greater than 1 meter in diameter were delineated using several methods including wading, kayaking and snorkeling. Polygons were produced by tracing the perimeter of plant stands with the gps unit. Plants were identified to species in the field and percent cover per species was visually estimated for mixed patches. Substrate percentages and types within patches were also recorded. Total cover of each species in square meters was calculated by multiplying the percentage of the species in a mixed patch by the total area of the patch to produce a coverage amount of each species in square meters. These coverages were then summed for all patches to produce a total coverage amount per species (Table 1.).

Results and Discussion:

Historical Plant Assemblages

Several studies have been conducted on the plant communities of Spring Lake. Gustav Watkins was the first to produce a plant list and map of the lake in 1930. Subsequent thesis studies in 1940, 1973, 1997 and 2002 further documented the aquatic vegetation of the reservoir. These historical records provide somewhat reliable information regarding the loss and gain of aquatic plant species over time.

Through the last eighty years the total number of aquatic species has changed. Watkins (1930) identified 31 non-woody aquatic plant species while Devall (1940) identified 35 and Bruchmiller (1972) Identified 47. Recent thesis studies by Seaman (1997) and Towns (2002) limited their scope of study to mostly submerged and floating leaved aquatic vegetation identifying 20 aquatic plant species in each study. Our current inventory and mapping project lists 51 species. While there seems to be an increase of total species from 1930 to 2010 it is hard to say for certain. These differences could be an artifact of deviation in scope of study between the authors, changes in access to Spring Lake, and author's mistake in identification of plant species. Nevertheless Spring Lake has seen an increase in the number of introduced aquatic plant species from 1930 to present.

Table 1. Species coverage in Spring Lake in square meters.

Species	msq
Cabomba	21403.68
Ceratophyllum	10892.97
M. heterophyllum	10189.22
Sagittaria	7227.559
M. spicatum	6394.021
Nuphar	4096.61
Hygrophila	1280.971
Utricularia	1245.438
Chara	1235.667
Pistia	911.5038
Typha	822.2781
Colocasia	799.6028
Moss	512.5983
algae	235.184
Ludwigia	214.0475
Ceratopteris	115.0433
Iris	32.56316
Acmellia	16.72866
Hydrocotyle	3.621247
Vallisneria	3.557716
Zizania	1.34396
Juncus	0.422683
Schoenoplectus	0.395053

One non native aquatic species, *Pistia stratiotes,* was listed by Watkins in 1930. However, pictures of Spring Lake as early as 1901 clearly show *Colocasia esculenta* present in the headwaters. By 1940 Devall identified four definitive introduced species, *Pistia stratiotes*, *Colocaisia antiquorum(esculenta*), *Piaropus(Eichhornia)* crassipes and *Canna indica*. Questionable introduced species included *Cabomba caroliniana, Pontedaria cordata, Elodea canadense* and

Nymphae odorata. Bruchmiller (1972) listed eight non-native species with the first inclusion of *Ceratopteris thalictroides*. Studies in 1997 and 2002 (Seaman and Towns respectively) each identified seven introduced species. These included the first listing of *Hydrilla verticillata* and *Hygrophila polysperma.*

Additionally, Seaman and Towns also calculated percent cover of certain aquatic species (Appendix I) showing a dramatic decrease *in Hydrilla verticillata* since 1997 and an increase in *Cabomba caroliniana*. This substantial change was due in part to Aquarena Center's Underwater Gardening program which utilized SCUBA divers to remove the invasive *Hydrilla verticillata* and replant species such as *Cabomba caroliniana*.

Current Plant Assemblage

Our aquatic plant inventory identified 51 aquatic plant species with 13 introduced species. These include the first known documentation *of Iris pseudacoris, Alternanthera philoxeroides,* and *Vallisneria spiralis* for Spring Lake. Although these species have been noticed occurring in Spring Lake for several years.

Eight aquatic species were identified as dominant in Spring Lake. These included *Cabomba caroliniana,. Ceratophyllum demursum, Myriophyllum heterophylum, Sagittaria platyphylla, Myriophyllum spicatum, Nuphar advena, Ceratophyllum demersum, Utricularia gibba* and *Chara* species. *Cabomba caroliniana* was common in all sections of the lake while other species were more limited in their distribution. *Myriophyllum spicatum, Hygrophila polysperma* and *Sagittaria platyphylla* were more common in the spring arm of the lake. Other species such as *Nuphar advena, Myriophyllum heterophyllum* and *Pistia stratiotes* were limited to the slough arm and lake basin. Table 1. lists these species and their respective coverage in meters. Further discussion of species coverages are noted in some of the species descriptions below. For a complete list of species, species coverage and species maps of Spring Lake see Appendix I.

Selected Species

Cabomba caroliniana- *Cabomba caroliniana* is the most common submerged plant in Spring Lake. Coverage from Seaman's study in 1997 only reached 4 percent while Town's indicated a coverage of 2 percent. Current coverage reaches 32 percent. This dramatic increase stems from the intentional planting of *Cabomba* after *Hydrilla* was removed in 2002. Although Texas is included in its native range *Cabomba* is relatively rare in Texas and the possibility of its introduction into Spring Lake or the San Marcos River cannot be ruled out. In his article for the San Marcos Record, My River of Innocence, C.W. Wimberely wrote "While several species of aquatic plants were being gathered from across the lake and river to be marketed across the nation for decorative use in aquariums, the underwater flowering cabomba, with other marketable species were introduced to these waters…" (article undated).

Vallisneria spiralis- This species name is historically synonomous with *Vallisneria americana*. However the true species *V. spiralis* is native to Europe. This species in not common in Spring Lake and the only significant patch exists above the dam spillway. It also occurs sporadically around deeper areas of the lake and has been collected around Blue Hole spring approximately 27 feet (8 meters) deep. However, *Vallisneria* has been planted into Spring Lake as part of several restoration efforts only to be eaten by turtles and other wildlife (Wallendorf, pers. com.)[1].

Previously identified as the native *Vallisneri. americana* this species has been confirmed as the European species, commonly referred to as Italian Val, by Dr. Don Les at the University of Connecticut by genetic analysis. This is the first documented case of this species in North America (Les, pers. com.)[2] A native of Italy, Southern Europe and North Africa, historical documents indicate this plant was introduced into the San Marcos River System for the aquarium plant trade.

Myriophyllum spicatum- Another common introduced species in Spring Lake. Bruchmiller and Seaman listed *Myriophyllum brasiliense* (*M. aquaticum*) for Spring Lake referring to it as parrot's feather. Towns was first to list *Myriophyllum spicatum* in her study. While *M. aquaticum* is found in the San Marcos River, it has not recently been found in Spring Lake. The estimated coverage of *M. spicatum* by Towns in 2002 was 4%. The estimated coverage of *M. spicatum* in 2010 is 9%.

Hydrilla verticillata/Egeria densa/Elodea canadensis- The presence of these three species is one of contention*. Elodea canadensis*, a North American native, was listed and photographed (Figure 3.) by Devall who stated that " Since being planted in the lake some ten or eleven years ago, Elodea canadensis has spread over the entire lake and is found to be more abundant than any other single form." However, the USDA PLANTS database does not list this species as occurring in Texas and no Texas record exists in the Lundell Herbarium,

Figure 3. Devall's purposed *Elodea canadensis*. The large blooms on the plant indicate *Egeria densa*.

[1] Aaron Wallendorf, Aquatic Maintenance Supervisor, Aquarena Center. 2010
[2] Dr. Don Les, Plant Systematics, University of Connecticut, 2010

University of Texas or the Texas State University Herbarium. Since *Elodea canadense* is very similar in appearance to *Egeria densa,* a South American native, it is possible there is a point of confusion between the two species (Bowles and Bowles, 2001). Several herbarium vouchers exist in the Lundell Herbarium for *Egeria densa* collected from Spring Lake, the latest collected in 1962. Bruchmiller(1973) was the first to list *Egeria densa* in the flora of Spring Lake and provided a key to its identification but no further records exist for *Egeria densa* in Spring Lake.

Historical articles from the San Marcos Daily Record (1977) suggest *Hydrilla verticillata,* another South American native, was first recorded in the San Marcos River by Ben Hannan in 1967, however Bowles and Bowles(2001) list its appearance in 1970. *Hydrilla verticillata* (hydrilla) was not listed in Spring Lake until Seaman's study in 1997. At that time Seaman calculated coverage of hydrilla at 26%. By 2002 Towns had estimated hydrilla cover at 47%. Between 2002 and 2003 the Scientific Diving Program at Aquarena Center used SCUBA divers to remove hydrilla and replace the areas with *Cabomba caroliniana* and *Sagittaria platyphylla*. This program successfully limited hydrilla in Spring Lake and coverage is now estimated at less than 1% (Wallendorf, pers. com.)[1].

Alternanthera philoxeroides- This species was identified at *97°55'53.54"W, 29°53'30.016"N* . It has not been observed blooming and has not noticeably spread. Alligator weed has been identified recently on the Upper San Marcos River (Owens et al, 2010). No previous works or herbarium vouchers record this species as occurring in Spring Lake or the San Marcos River. Alligator weed is listed as a state noxious weed with potential for invasion. However, the author has noted and positively identified *Vogtia malloi,* a moth released for biological control of the species, in stands of Alligator weed along the lower San Marcos River.

Zizania texana- Historically *Zizania texana* has had a strong presence in Spring Lake. It is presumed that before impoundment this aquatic grass was wide spread and could be found along the entire spring run now inundated. Even after Spring Lake was formed several authors noted its continued presence. In his article on *Zizania* Harold Beaty refered to Silveus' writing in 1932 noting that the grass was " so luxuriant that the irrigation company had difficulty in keeping the artificial lake (Spring Lake) and ditches clear" and that cows regularly stuck their head into the water to graze on the grass (1975). Watkins and Devall provided a map (Appendix I) and photographs (Figure 4.) indicating wild rice was still largely distributed in the lower section of the lake above the dam, but by 1967 Dr. W. H. P. Emery noted only one plant in Spring Lake. By this time Aquarena Springs was cutting aquatic vegetation to keep Spring Lake clear for the glass bottomed boats. Emery suggested shading from this cut and floating debris as the main cause for this decline. Our current inventory mapped two stands of *Zizania texana* in Spring Lake. One located in the middle of the mill race at 97°56'4.397"W , 29°*53'24.88"N* and the other located immediately above the dam spillway at *97°56'0.683"W 29°53'25.261"N.*

Figure 4. a 1901 postcard clearly showing Colocasia's presence. Courtesy of edwardsaquifer.net

Colocasia esculenta- *Colocasia eculenta* or Taro is an invasive emergent plant from Africa that has become well established in Spring Lake. Pictures of Spring Lake (Figure 4.) taken around 1900 clearly show this plant had already taken hold of the lake margins indicating this was one of the first exotic plants introduced to the San Marcos River. Ackridge and Fonteyn were the first to report on the species occurring in Texas (1981). Taro is predominantly found in the wetland area of the slough section and the lower lake section. It is intermittently found along the western edges of the lake. Taro has potentially displaced several native emergent species such as *Zizaniopsis milicea, Leersia oryzoides, and Echinocloa walteri.* Although the Giant Elephant Ear, *Xanthosoma saggitifolium*, can be found at the Spring Lake dam it is not widespread.

Hygrophila polysperma- *Hygrophila polysperma* is a native to India and southern Asia. It is listed as a Federal noxious weed, but is not listed by the state of Texas. It was first listed by Towns in 2002 but Seaman (1997) listed *Hygrophila lacustris* which could be a mis-identification. Currently *Hygrophila polysperma* has a limited distribution in Spring Lake. However, fragments have been observed rooting in new areas in the spring section and lower lake section indicating its spread is probably imminent (Wallendorf, pers. com.)[1]. It is tolerant of a wide range of growing conditions including reduced light, slow moving waters and variable pH. It has brittle stems which fragment and root easily (Spencer and Bowes, 1984) and has reportedly begun to replace hydrilla in areas of Florida (Sutton, 1995) and is resistant to available herbicides (Cuda and Sutton, 2000).

Acknowledgments:

We would like to acknowledge several people who aided or provided information for this report. First, we would like to thank the San Marcos Public Library and librarians who proved access to folders, article clippings and pictures. We would also like to thank Deborah Lane and Aaron Wallendorf at Aquarena Center who allowed us access for our mapping project including use of glass bottomed boats for ground truthing . Also, thank you to the River Systems Institute and the Edwards Aquifer Recovery and Implementation Program for funding. Finally, thank you to Dr. David Lemke, director of the Texas State University Herbarium, for his help and advice in identifying plant species and producing voucher specimens.

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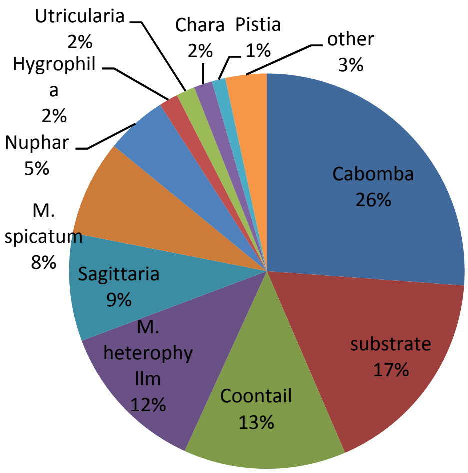
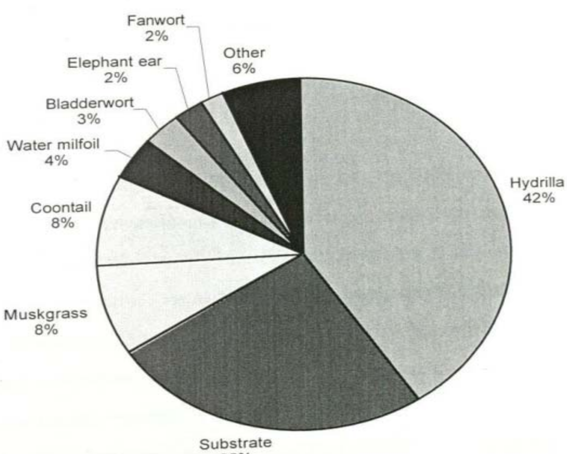
Appendix I

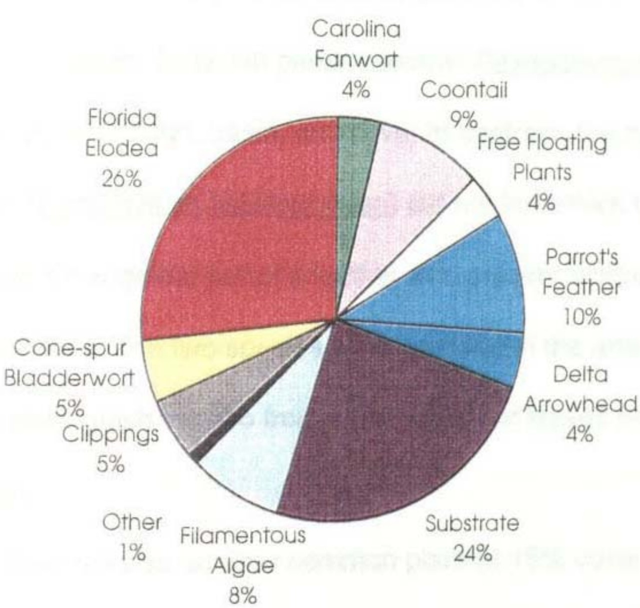
Percent Vegetation Cover 2009



Percent Vegetation Cover 2002



Percent Vegetation Cover 1997



Historical Plant Lists

Watkins, 1930

Typha latifolia
Zizaniopsis milicea
Echinochloa walteri
Hamalocenchrus oryzoides-Leersia oryzoides
Andropogon glomeratus
Cyperus ferax-Cyperus odoratus
Eleocharis arenicola-Eleocharis montevidensis
Willugbaeya scandens-Mikania scandens
Bidens laevis
Sagittaria platyphylla
Salix nigra
Populus deltoides
Scirpus lacustris
Myriophyllum heterophyllum
Ceratophyllum demersum
Zannichellia palustris
Najas guadalupensis
Jussiaea diffusa
Jussiaea suffruticosa
Persicaria opelousana
Potamogeton americanus
Zizania aquatic-Zizania texana
Nymphaea advena-Nuphar advena
Amblystegium riparium
Pistia stratiotes
Spirodela polyrrhiza
Wolffia papulifera
Wolffiella floridana
Lemna minor
Utricularia subulata
Roripa nasturtium-Nasturtium officinale
Azolla caroliniana
Riccia fluitans

Devall, 1940

Alisma subcardatum
Cabomba caroliniana
Canna indica
Ceratophyllum demersum
Colocasia antiquorum
Diantheria americana
Elodea Canadensis
Jussiaea decurrens
Jussiaea diffusa
Lemna minor
Lophotocarpus calycinus
Ludwigia natans
Myriophyllum heterophyllum
Najas guadalupensis
Nympha advena
Nymphaea Castalia-Nymphaea odorata
Potamogeton natans
P. crispus
P. pectinatus
P. pusillus
Phragmites australis
Piaropus crassipes
Pistia stratiotes
Pontedaria cordata
Roripa nasturtium
Sagittaria platyphylla
Scirpus validus
Spirodela polyrrhiza
Typha latifolia
Vallisneria spiralis
Wolffia Columbiana
Zannechellia palustris
Zizania texana
Zizaniopsis mileacia

Note: Some species names have changed.

J. P. Bruchmiller, 1973

Leptodictyum riparium
Riccia fluitans
Azolla caroliniana
Ceratopteris thalictroides
Typha domingensis
Typha latifolia
Potamogeton crispus
Potamogeton illinoensis
Najas guadalupensis
Echinodorus rostratus
Sagittaria platyphylla
Egeria densa
Vallisneria americana
Andropogon glomeratus
Echinochloa colona
Echinochloa walteri
Leersia oryzoides
Paspalum dilatatum
Paspalum pubiflorum
Zizaniopsis milacea
Carex altata
Cyperus acumintus
Cyperus odoratus
Eleocharis montevidensis
Fuirena simplex
Scirpus validus
Colocasia atiquorum- Colocasia esculenta
Lemna minor
Spirodela polyrhiza
Wolffia papulifera
Eichornia crassipes
Heteranthera dubia
Juncus texanus
Persicaria punctata
Ceratophyllum demersum
Cabomba caroliniana
Nuphar luteum
Ludwigia octovalvis
Ludwigia repens
Myriophyllum brasiliense
Myriophyllum heterophyllum
Hydrocotyle verticillata
Samolus parviflorus
Bacopa monnieri
Limnophila sessiliflora
Utricularia gibba
Plantago major
Eclipta alba
Mikania scandens

Seaman, 1997

Amblystegium riparium
Azolla caroliniana
Cabomba caroliniana
Ceratopteris thalictroides
Colocasia esculenta
Eichornia crassipes
Hydrilla verticillata
Hygrophila polysperma
Lemna minor
Myriophyllum brasiliense
Myriophyllum heterophyllum
Nuphar luteum
Pistia stratiotes
Riccia fluitans
Sagittaria platyphylla
Spirodela polyrhiza
Utricularia gibba
Wolffia papulifera
Zizania texana

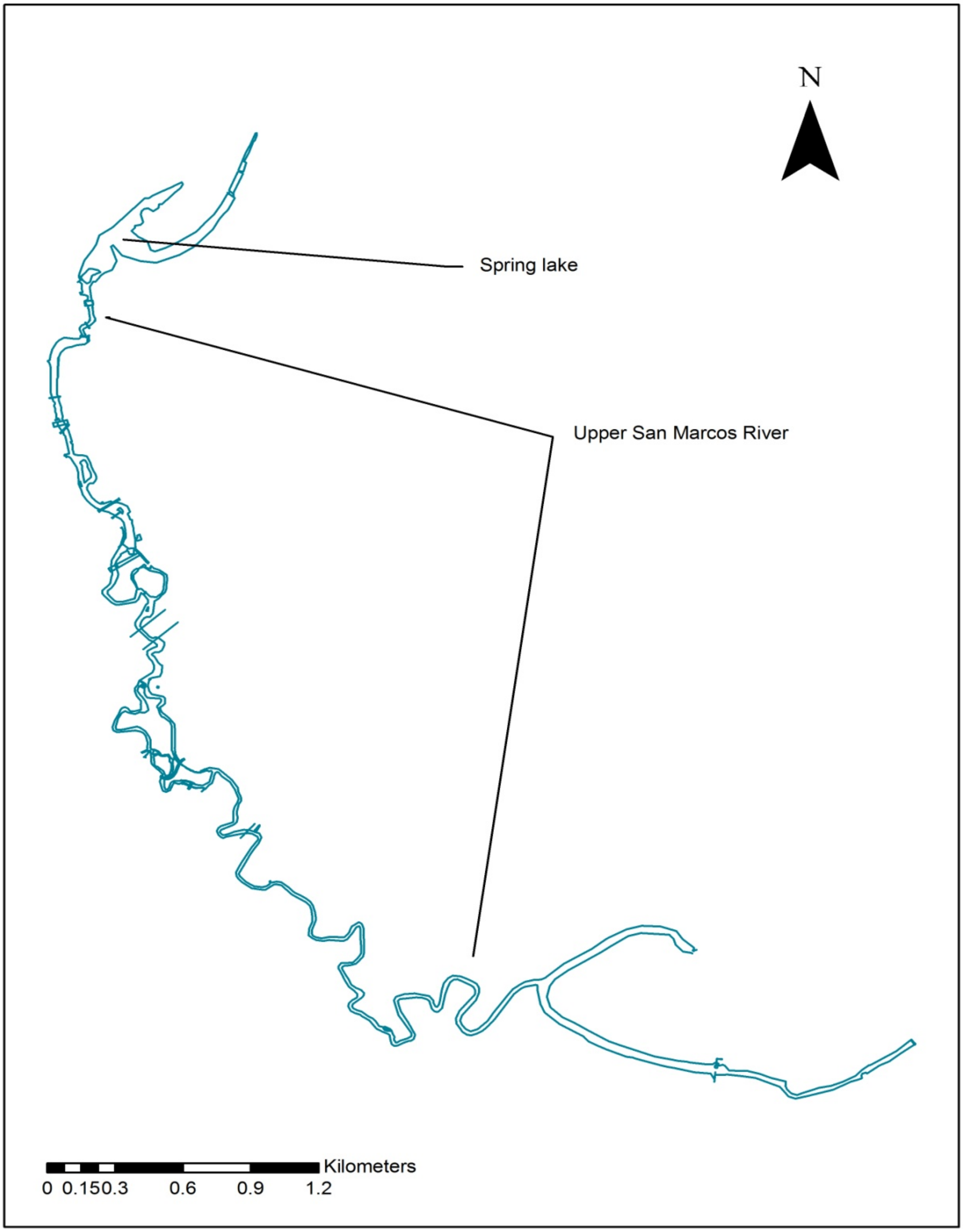
Towns, 2002

Azolla caroliniana
Cabomba caroliniana
Ceratophyllum demersum
Ceratopteris thalictroides
Chara sp.
Colocasia esculenta
Eichornia crassipes
Hydrilla verticillata
Hygrophila polysperma
Lemna minor
Ludwigia repens
Myriophyllum heterophyllum
Myriophyllum spicatum
Nuphar luteum
Pistia stratiotes
Sagittaria platyphylla
Spirodela polyrhiza
Typha latifolia
Utricularia gibba
Wolffia papulifera

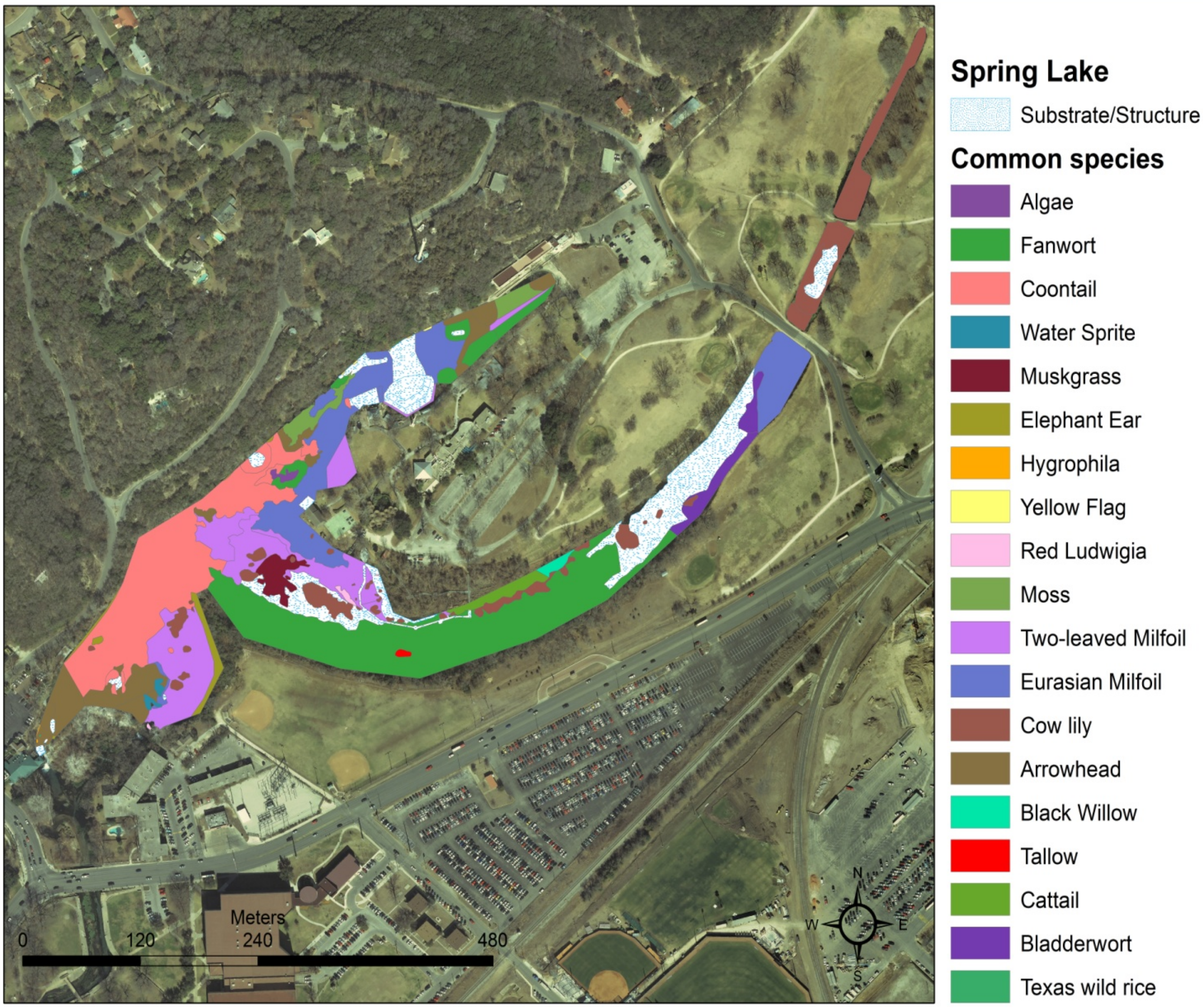
Spring Lake Species List 2009

Scientific Name	Common Name	Wetland indicator status NCRIS Region 6
Acmella oppositifolia	Creeping spot flower	NI
Alternanthera philoxeroides	Alligator weed	OBL
Amblystegium riparium *	water moss	OBL
Andropogon glomeratus	Brushy bluestem	FACW+
Azolla caroliniana	mosquito fern	OBL
Bacopa monnieri	Coastal water hyssop	FACW
Boehmeria cylindrica	False nettle	OBL
Cabomba caroliniana	Fanwort	OBL
Carex brevior	shortbeak sedge	OBL
Canna hybrid	Red Canna	NA
Carex crus-corvi	Ravenfoot sedge	OBL
Cephalanthus occidentalis	Buttonbush	OBL
Ceratophyllum demersum	Hornwort	OBL
Ceratopteris thalictroides	Water sprite	OBL
Chara sp.	Muskgrass	NA
Colocasia esculenta	Elephant ear, Taro	NI
Eleocharis montevidensis	Spikerush	
Eichornia crassipes	water hyacinth	OBL
Equisetum hyemale	Horsetail rush	FACW
Fissidens fontanus	water moss	OBL
Hydrilla verticillata	Hydrilla	OBL
Hydrocotyle umbellata	Water pennywort	OBL
Hydrocotyle verticillata var. triradiata	Verticillate pennywort	OBL
Hygrophila polysperma	Hygro	OBL
Iris psuedacoris	Yellow flag	OBL
Juncus texanus	Texas rush	OBL
Justicia americana	Water willow	OBL
Lippia nodiflora	Frogfruit	
Lemna sp.	Duckweed	OBL
Ludwigia repens	Round leaf seedbox	OBL
Ludwigia octovalvis		
Marsilea macropoda	Water clover	OBL
Myriophyllum heterophyllum	Water milfoil	OBL
Myriophyllum spicatum	Euarasian water milfoil	OBL
Najas guadalupensis	Southern naiad	OBL
Nasturtium officinale	water Cress	OBL
Nuphar advena	Yellow cow lily	OBL
Pistia stratiotes	Water lettuce	OBL
Pluchea odorata		
Ranunculus scleratus	cursed buttercup	OBL
Riccia fluitans	Floating liverwort	OBL
Sagittaria platyphylla	Delta Arrowhead	OBL
Schoenoplectus tabernaemontani	Great Bullrush	OBL
Spirodela polyrhiza	Giant Duckweed	OBL
Teucrium canadense	Canadian Germander	FACW-
Typha latifolia	Cat tail	OBL
Utricularia gibba	Bladderwort	OBL
Vallisneria spiralis	European eelgrass	OBL
Zizania texana	Texas wildrice	OBL
Zizaniopsis miliacea	Southern wildrice	OBL

Location of Spring Lake in Relation to the San Marcos River

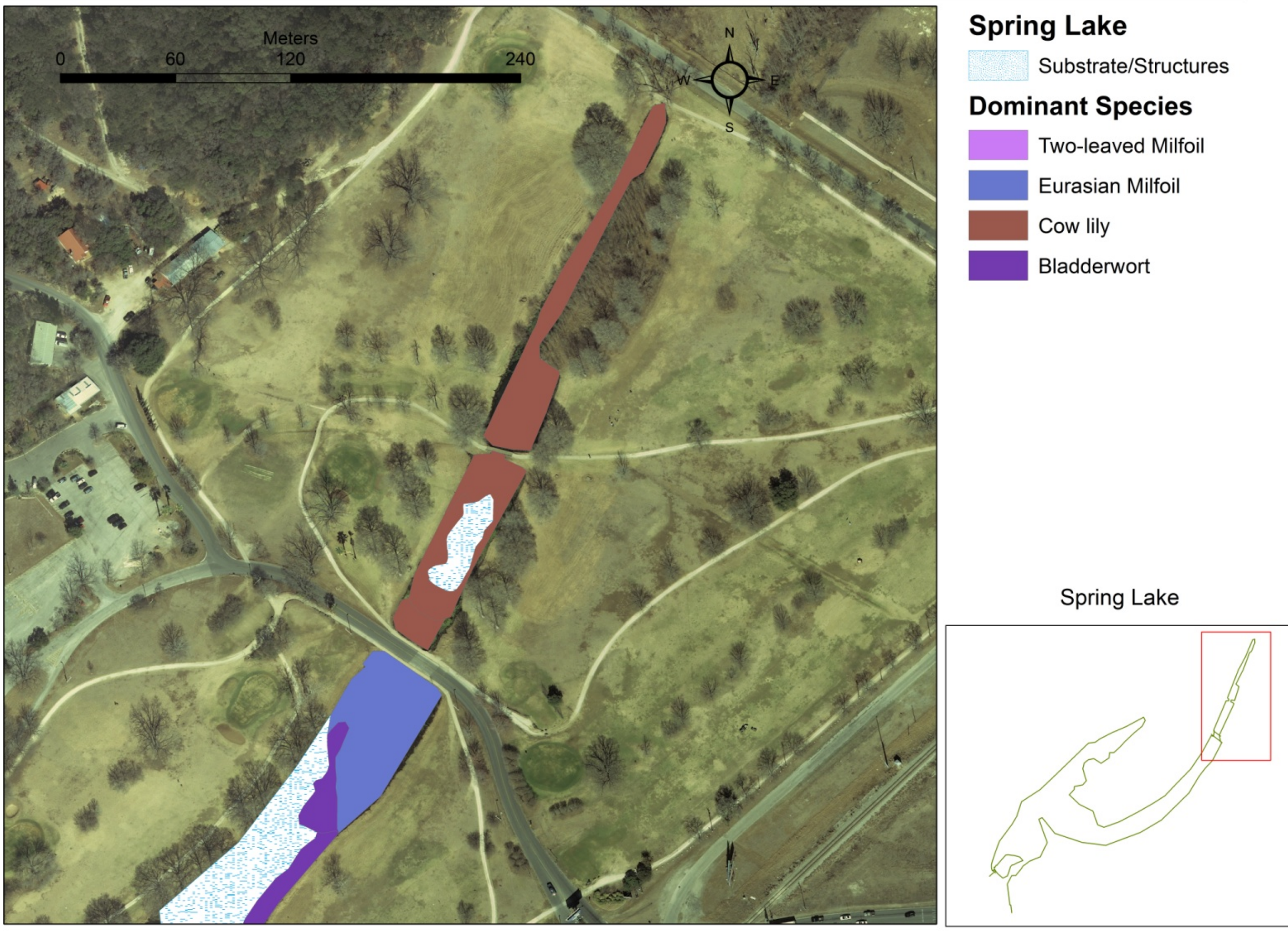


Aquatic Vegetation of Spring Lake



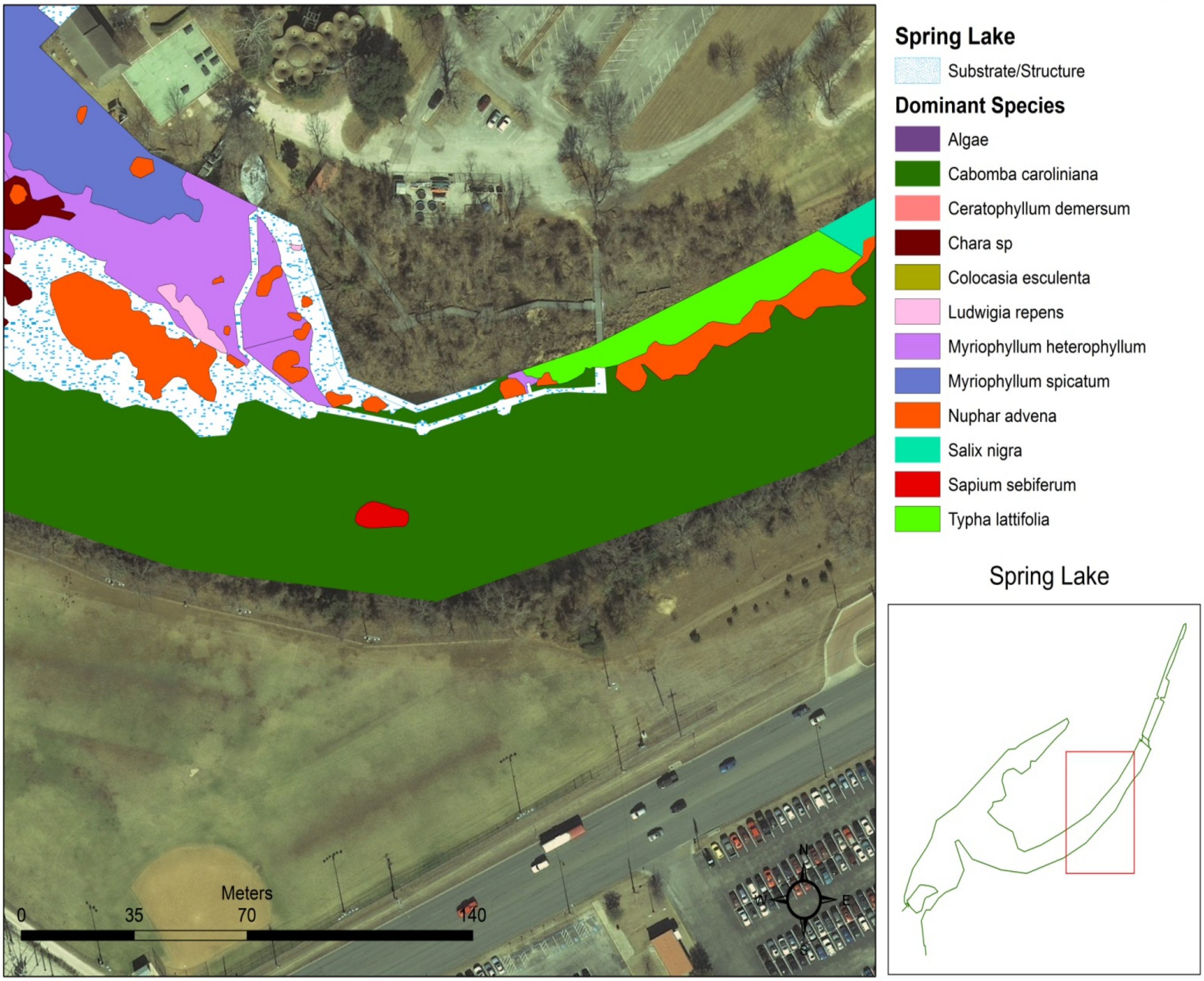
Casey R. Williams 2010 Data provided by River Systems Institute

Aquatic Vegetation of Spring Lake-Upper Slough



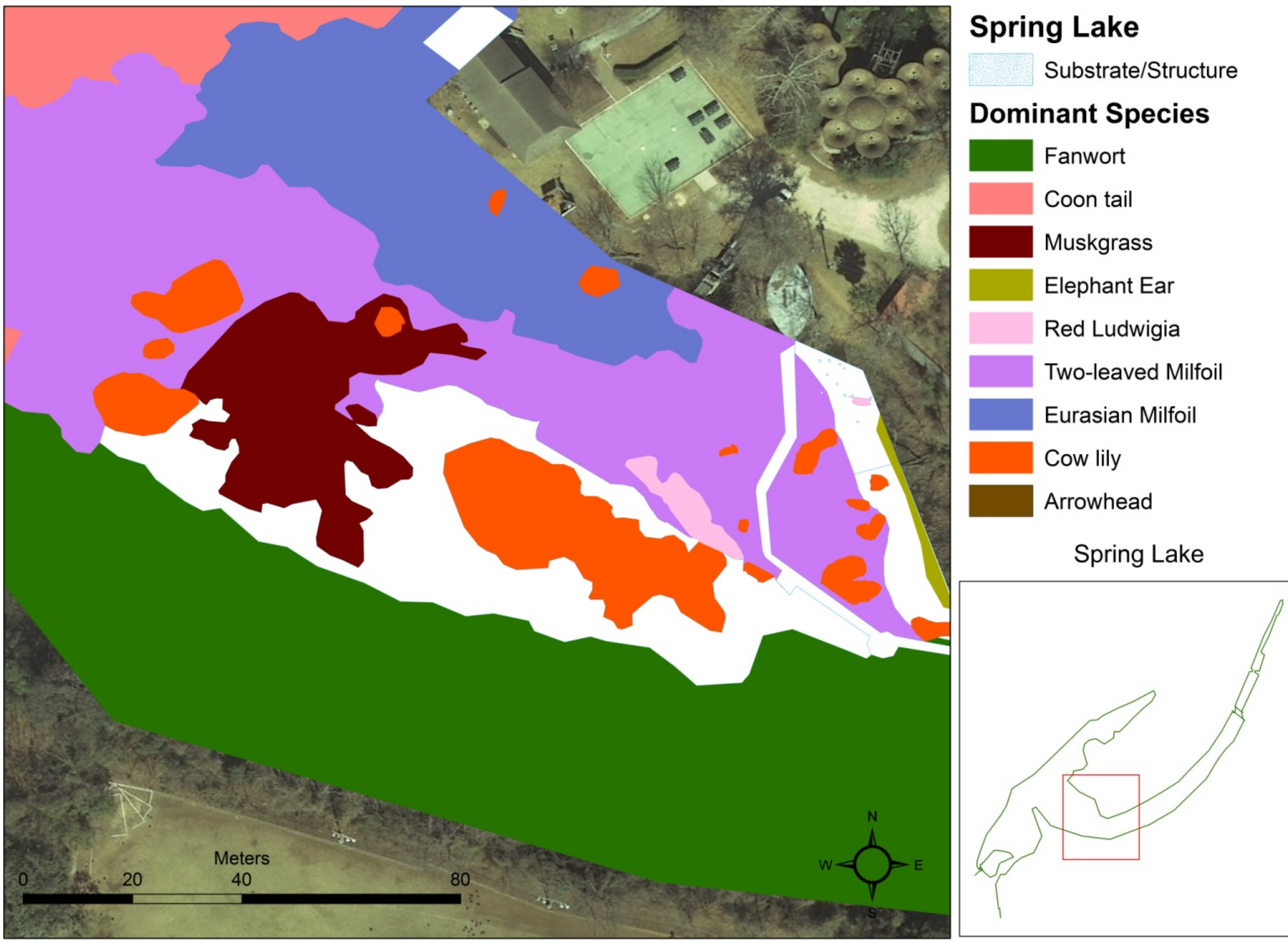
Casey R. Williams 2010 Data provided by River Systems Institute

Aquatic Vegetation of Spring Lake-Middle Slough



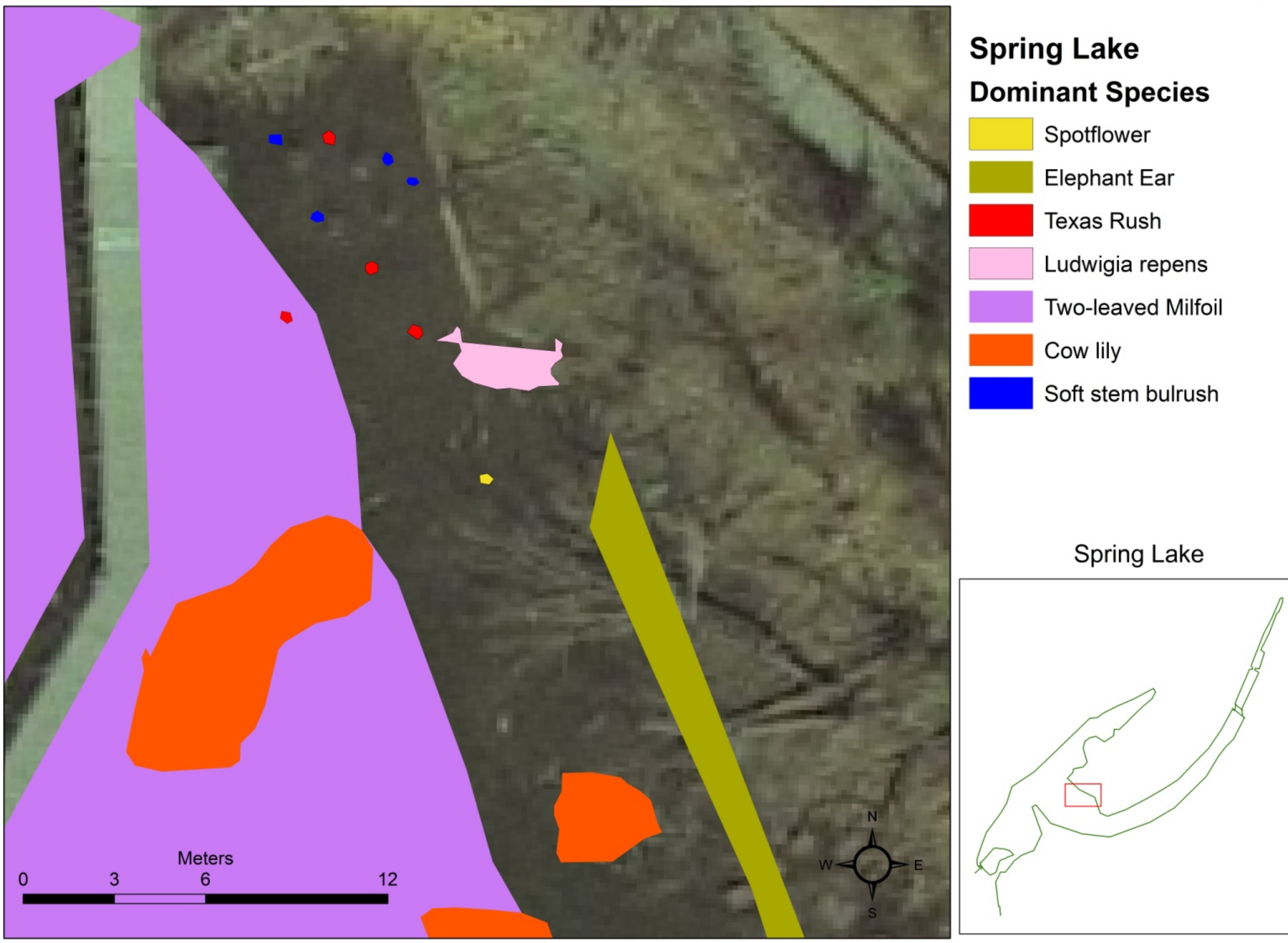
Casey R. Williams 2010 Data provided by River Systems Institute

Aquatic Vegetation of Spring Lake-Lower Slough



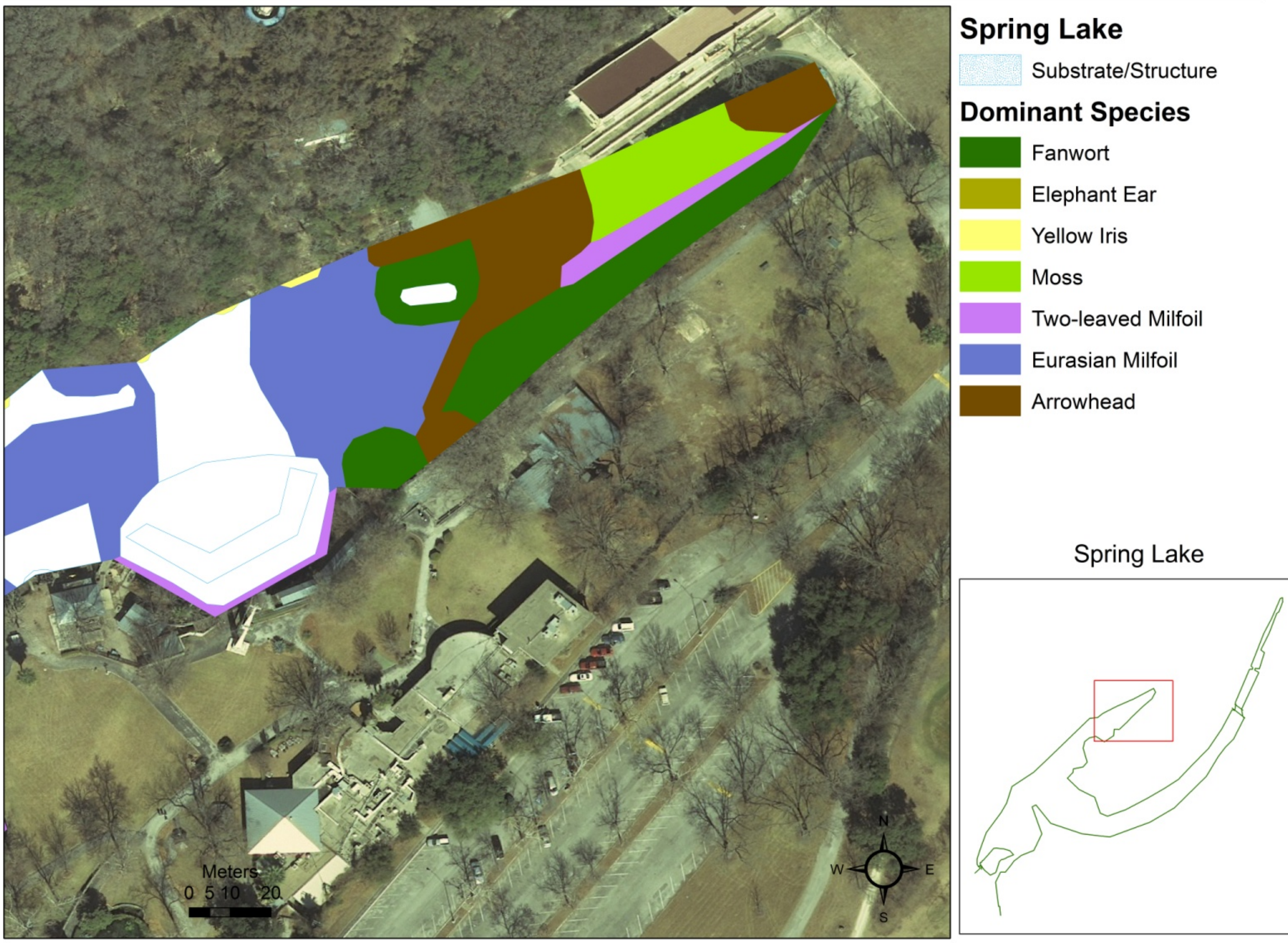
Casey R. Williams 2010 Data provided by River Systems Institute

Aquatic Vegetation of Spring Lake-Wetland Area



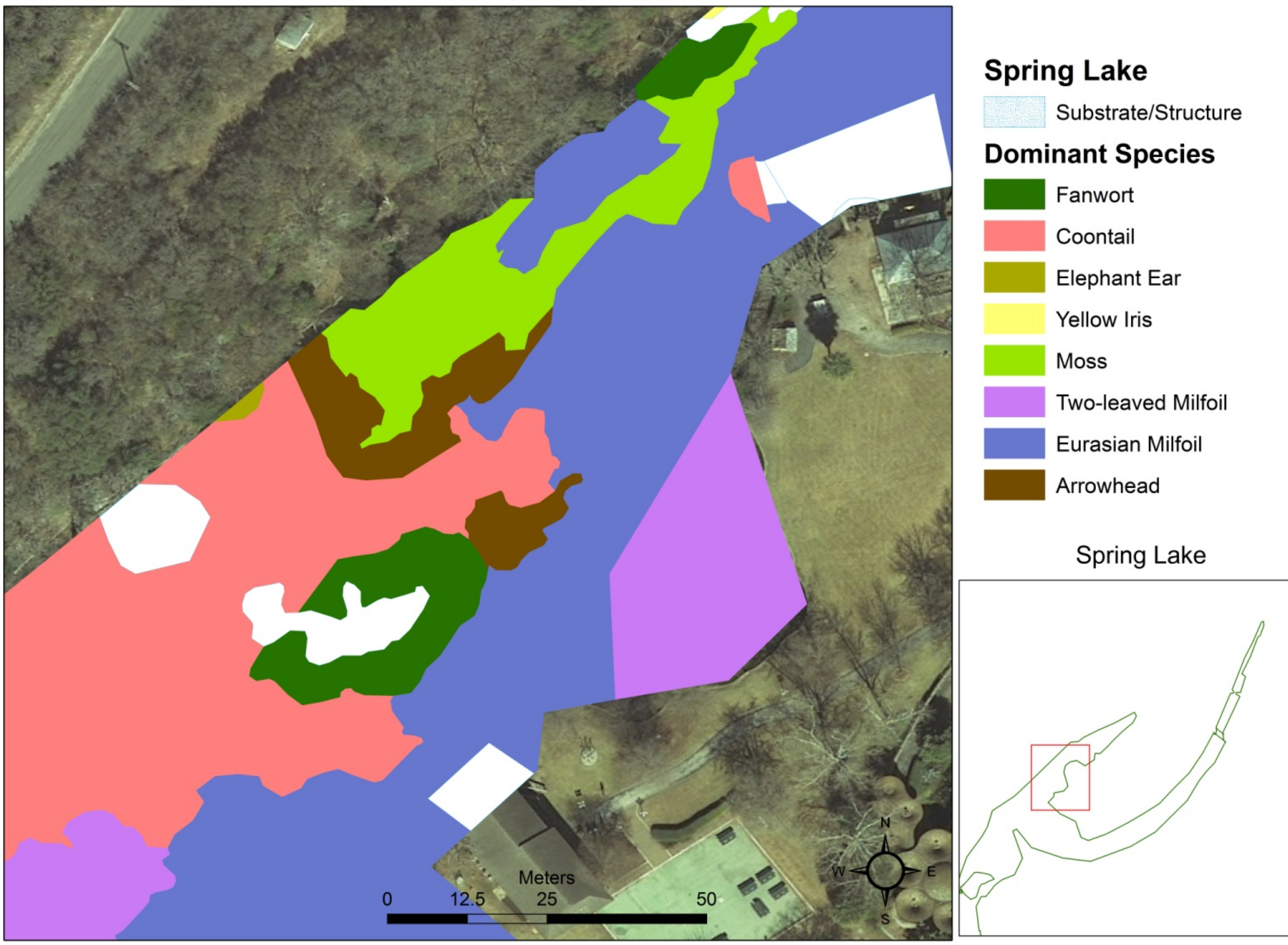
Casey R. Williams 2010 Data provided by River Systems Institute

Aquatic Vegetation of Spring Lake-Upper Spring Arm



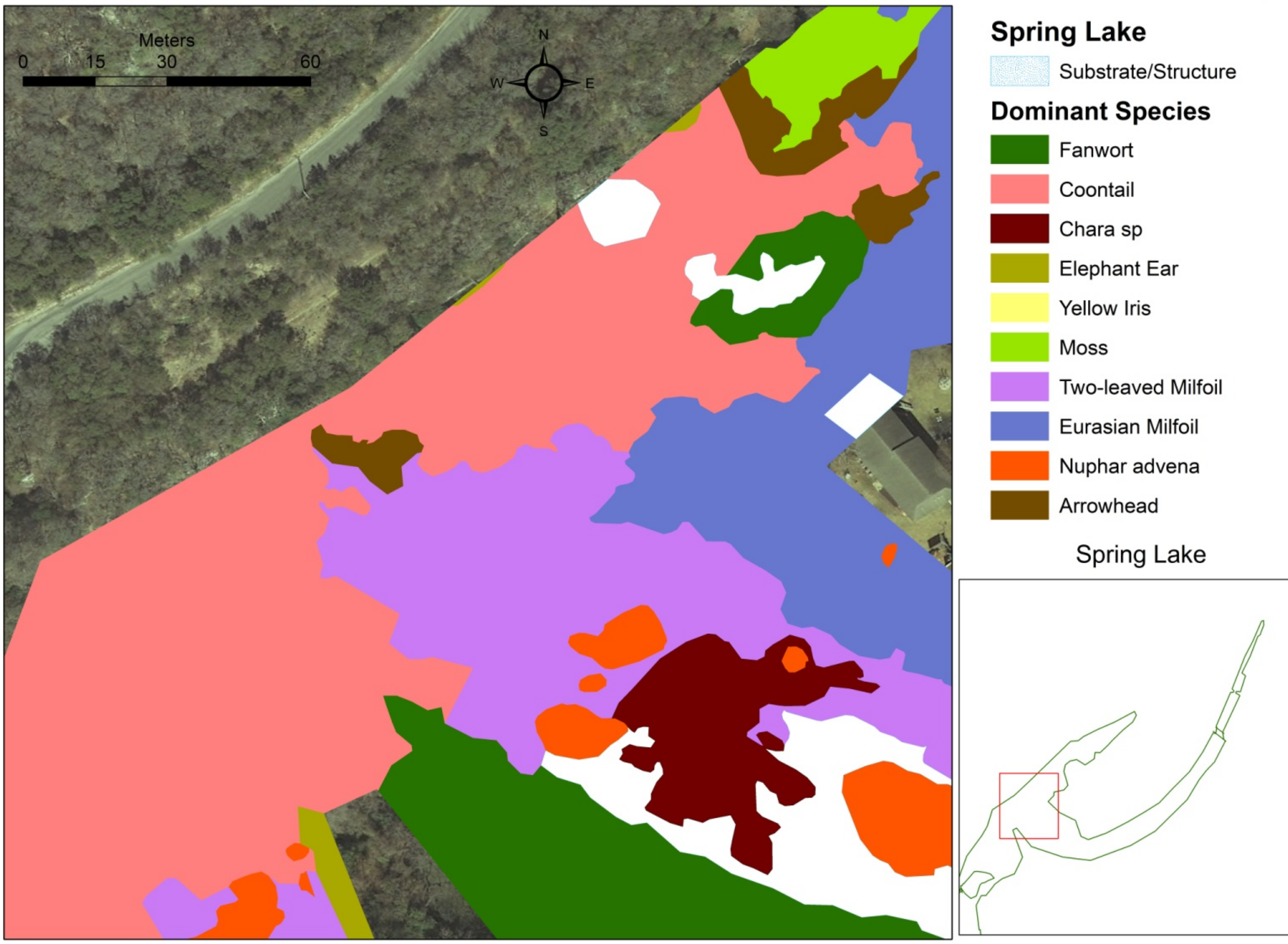
Casey R. Williams 2010 Data provided by River Systems Institute

Aquatic Vegetation of Spring Lake-Middle Spring Arm



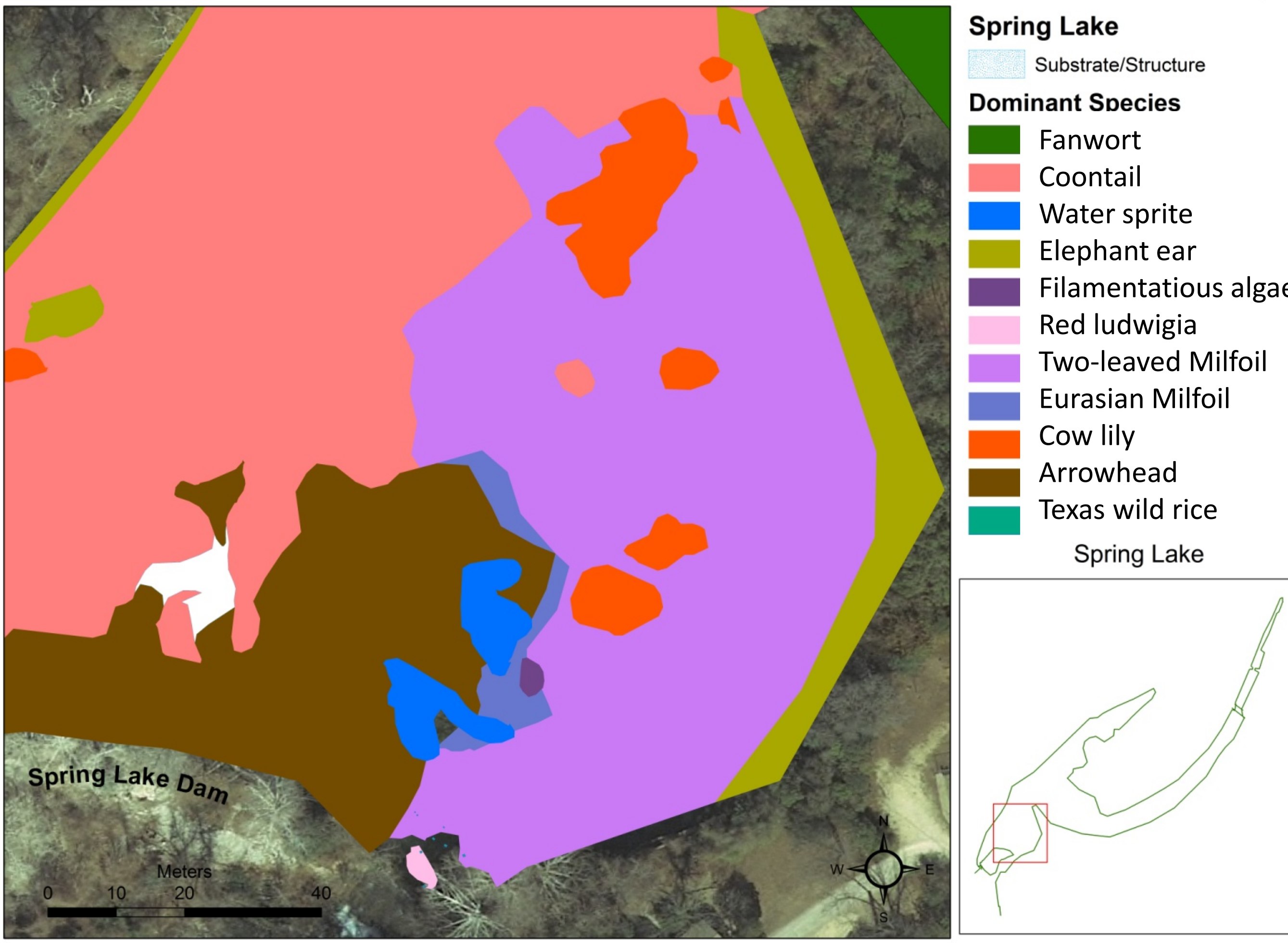
Casey R. Williams 2010 Data provided by River Systems Institute

Aquatic Vegetation of Spring Lake-Lower Spring Arm



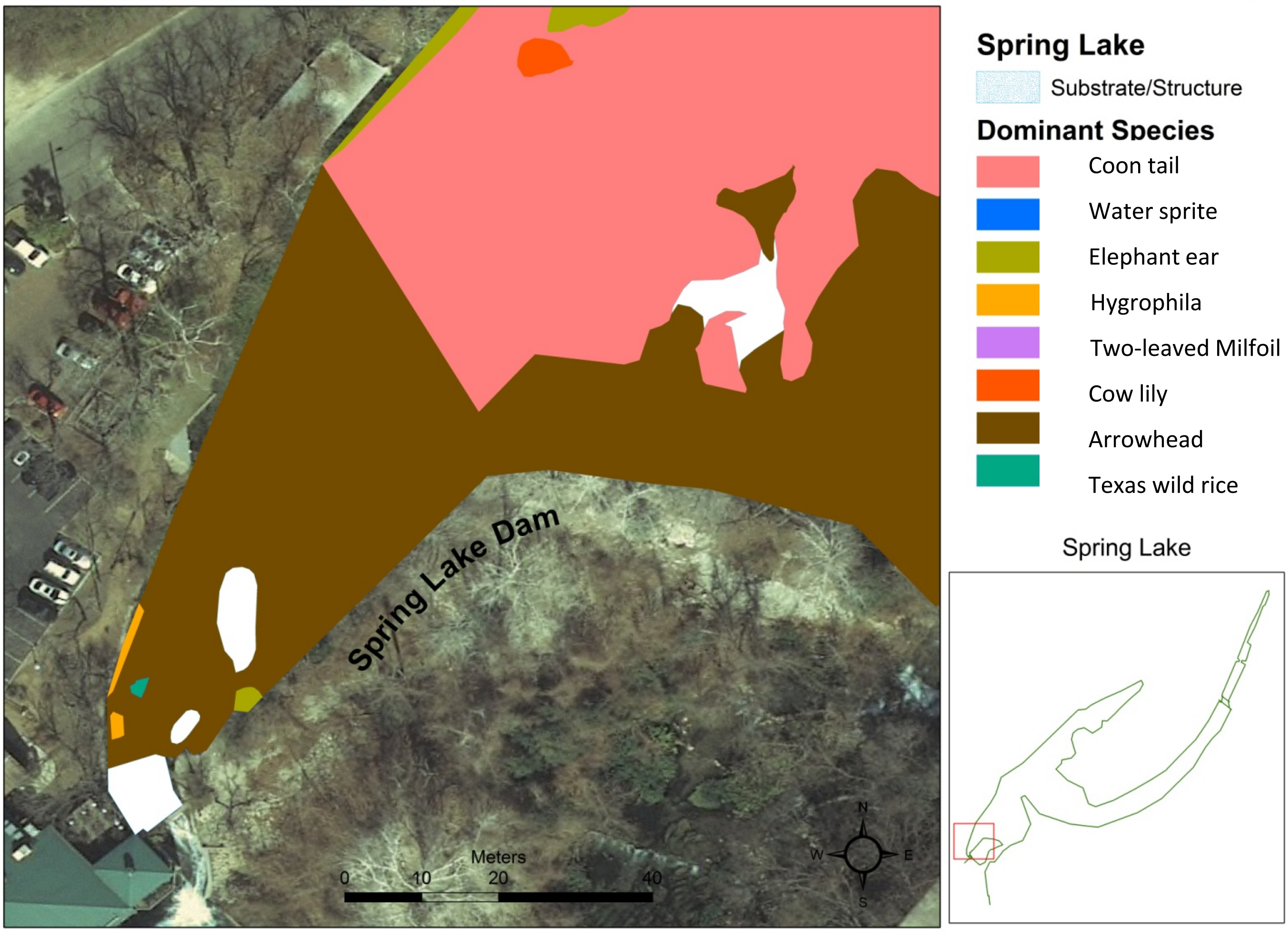
Casey R. Williams 2010 Data provided by River Systems Institute

Aquatic Vegetation of Spring Lake-Lower Lake Area

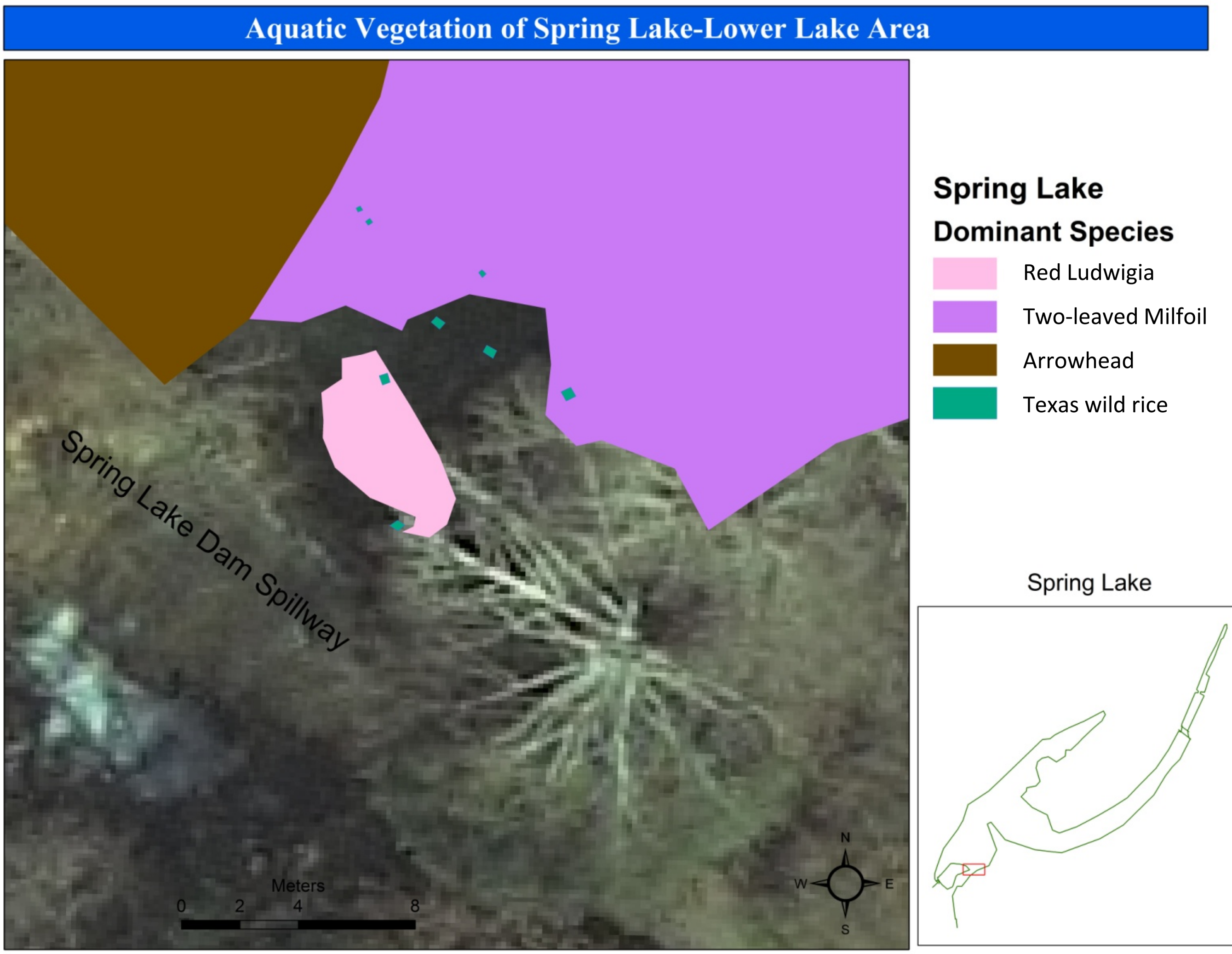


Casey R. Williams 2010 Data provided by River Systems Institute

Aquatic Vegetation of Spring Lake-Lower Lake Area

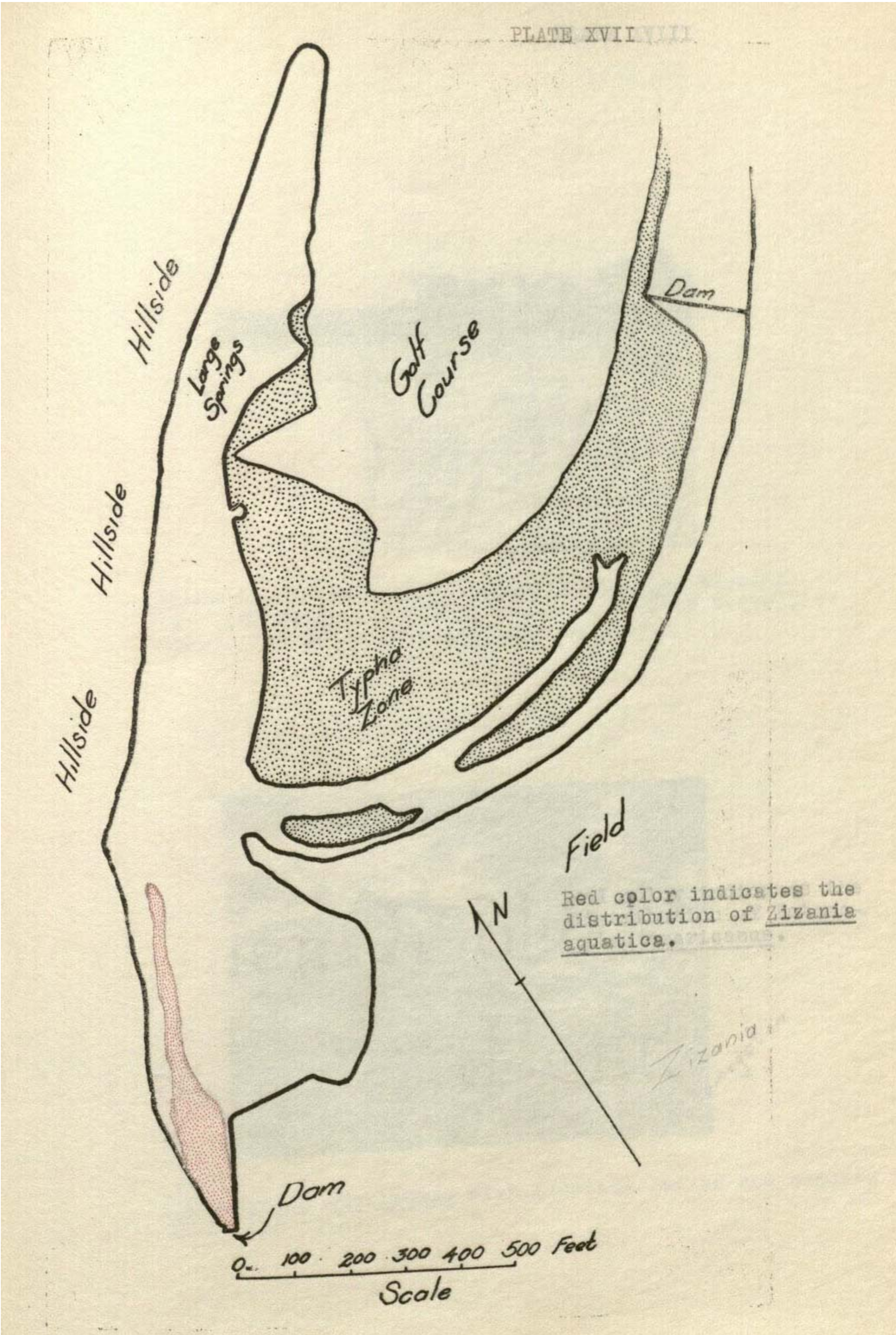


Casey R. Williams 2010 Data provided by River Systems Institute

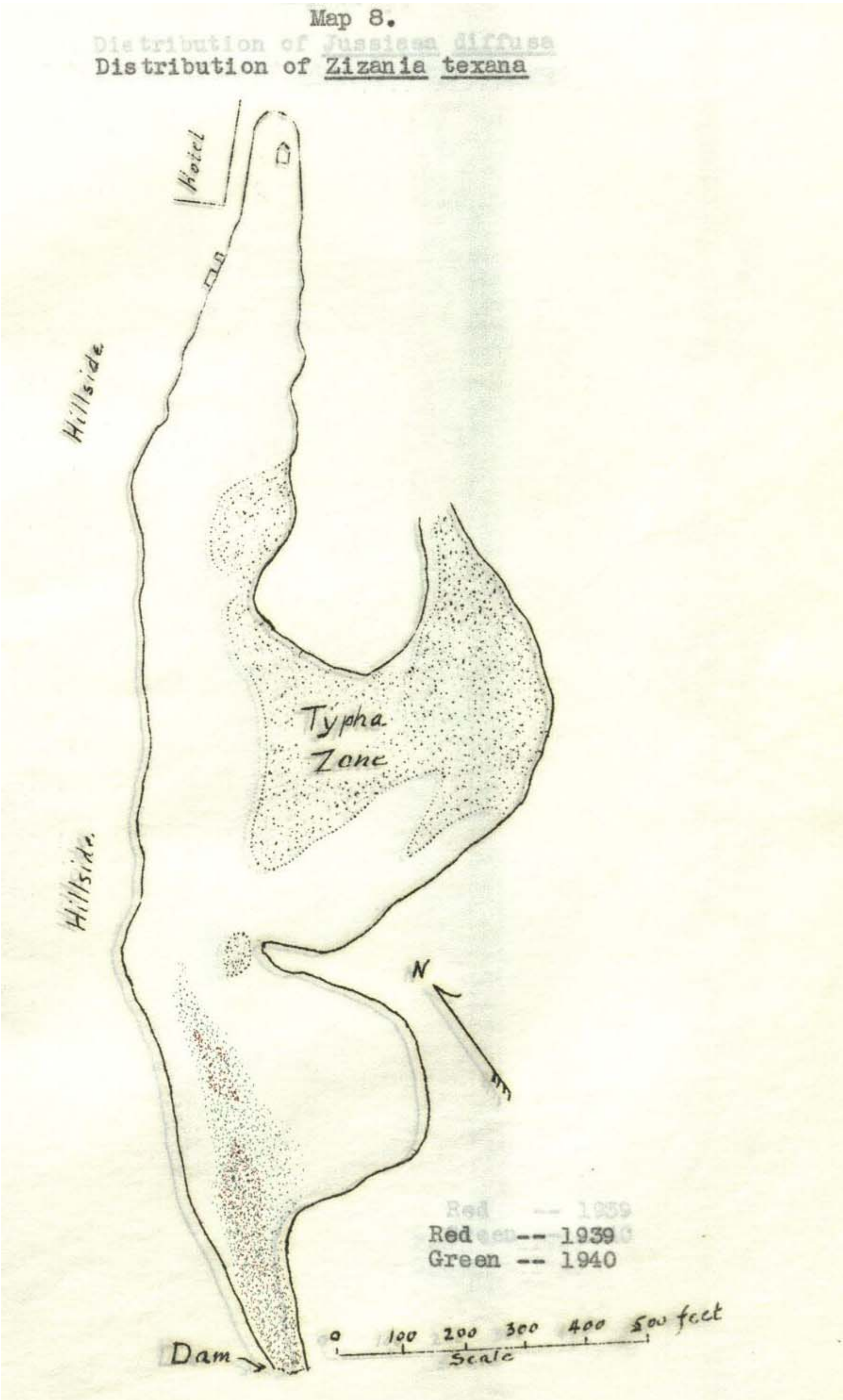


Casey R. Williams 2010 Data provided by River Systems Institute

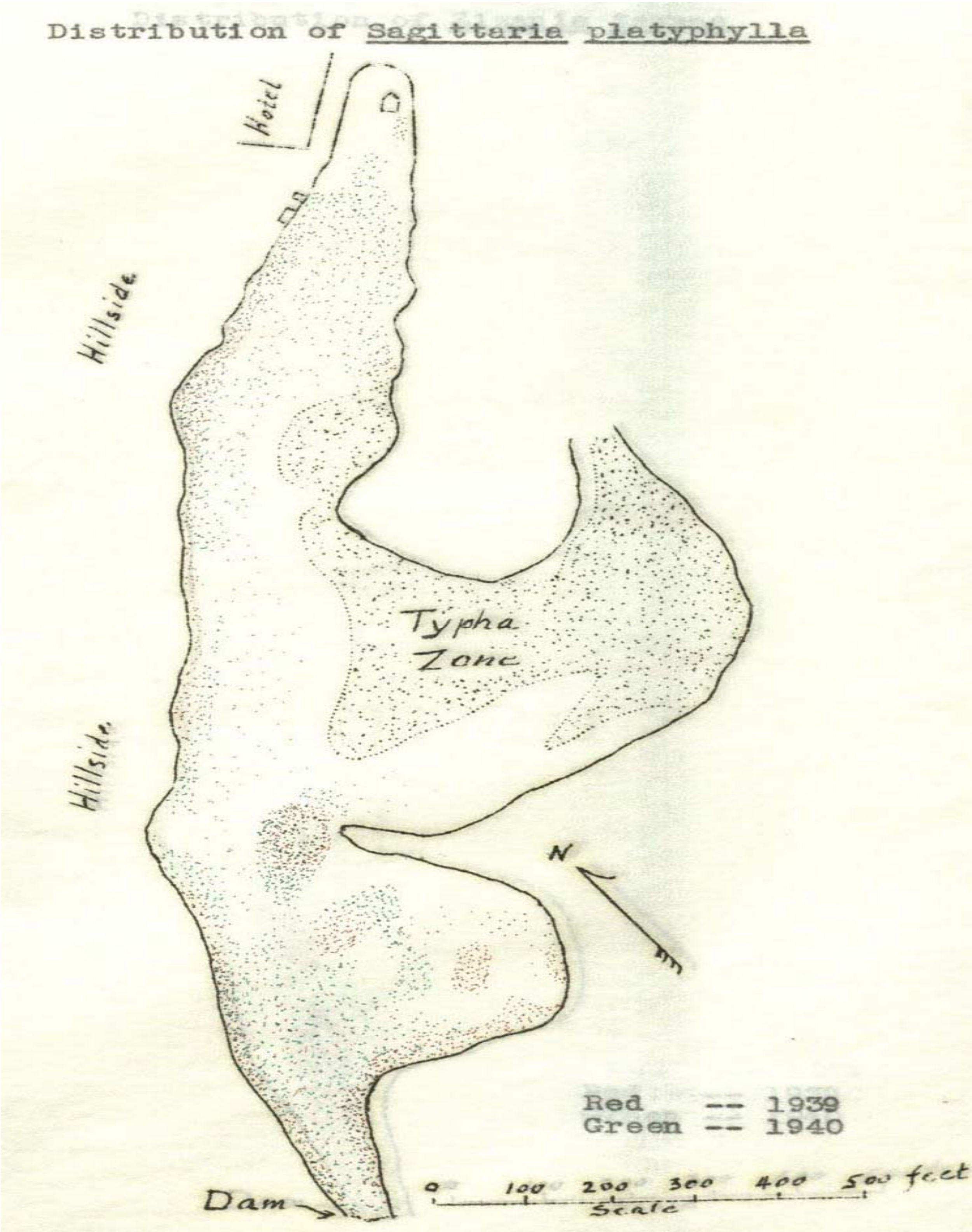
Extent of *Zizania texana* in 1930 according to Watkins' Vegetation of San Marcos Springs.



Extent of *Zizania texana* according to Devall. 1940



Extent of *Sagittaria platyphylla* according to Devall, 1940



Photographs from
Watkins, 1930

A close-up view of *Pistia stratiotes*.

Sagittaria platyphylla showing aerial leaves and inflorescences.

Flowering individuals of *Zizania aquatica* showing the inflorescences projected about 2½ feet above the water. The depth here is about 10 feet.

Photographs from
Devall,1940

PLATE II

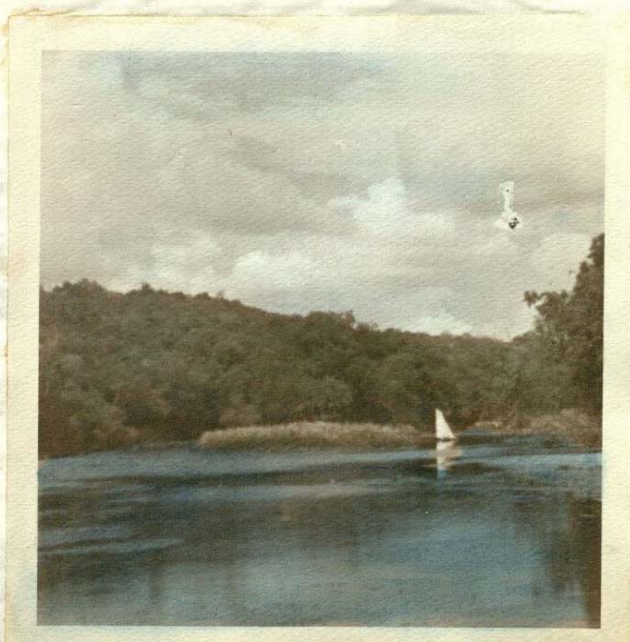
<u>Elodea canadensis</u>

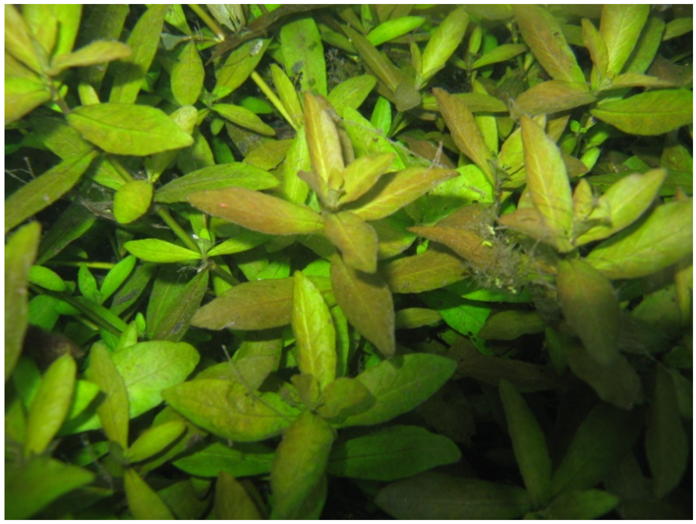
PLATE VI

<u>Zizania texana</u>

PLATE X

The Lake, Looking North, Showing <u>Typha latifolia</u> Island





Hygrophila polysperma

Spring Lake 2010. notice lack of surface vegetation compared to picture above

Aquarena Center utilizes SCUBA divers to maintain lake