Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow On Biological Resources in the San Marcos Springs/River Aquatic Ecosystem

FINAL 2007 ANNUAL REPORT

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Submitted: March 2008

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EXECUTIVE SUMMARY

This annual summary report presents a synopsis of methodology used and an account of sampling activities including sampling conditions, locations, and data obtained during two sampling events (Comprehensive Monitoring Effort) conducted on the San Marcos Springs/River ecosystem in 2007. Limited recharge in the river in 2006 led to decreased flows in the system to start 2007, which is when the lowest discharge in the river was recorded this year. Significant precipitation events in winter and summer resulted in flows well above the historical average throughout the year. Monthly average discharge peaked in August and declined through the fall months, but was still above average to end the year.

Thermistor data revealed near constant water temperatures near spring inputs, and more variable readings further downstream. The highest temperatures recorded took place in Sessom's Creek, a stream in an urban area that can become stagnant when precipitation events are infrequent. The lowest temperatures occurred at downstream sites in February after a cold weather event with extremely low temperatures and rain and sleet. No water temperatures exceeded 26.67 ˚C, the water quality standard specified by the Texas Commission on Environmental Quality (TCEQ).

For the fountain darter (*Etheostoma fonticola*), habitat use is largely influenced by aquatic vegetation, and assessments of habitat availability were conducted by mapping this vegetation in the study reaches during each sampling event. Overall, aquatic vegetation in the San Marcos River decreased in 2006 because of direct and indirect effects of the low flows. Increased flows in 2007 appeared to stimulate growth and encourage colonization of areas that were bare as a result of mechanical disturbance in 2006. The Spring Lake Dam Reach exhibited the most rapid re-growth present in the river in 2007. One of the fastest plants to re-colonize the bare substrates was the exotic plant, *Hydrilla*. However, by fall much of it had drifted downstream to be replaced by native plants. *Potamogeton* was one of these native plants, and seemed to recover well after 2006. Texas wild-rice (*Zizania texana*) was the most vulnerable plant to mechanical disturbance in 2006 decreasing nearly 75% in this reach after people pulled out many of the leaves. Fortunately, many of the root-wads remained, and in 2007 these roots enabled the plants to recover relatively quickly in the higher flows. Texas wild-rice plants in the eastern arm of the reach increased their surface area several times, and several new plants were also found. Downstream, plants that had been disturbed in 2006 began to grow back together, and seeds could be seen by summer. Educational signs placed along the banks in this reach were a great contribution to educating the public about wild-rice and other endangered organisms in the system.

The City Park Reach exhibited a similar resurgence in vegetation area. In spring, green algae covered much of the *Hydrilla* and some bare patches in the reach. By fall, precipitation events had flushed most of these algae out of the reach. *Potamogeton* and *Hygrophila* displayed similar increases in surface area. Texas wild-rice continued to flourish in this reach with many of the larger plants continuing to increase in area. With the increased flows of 2007, recreation effects appeared to be far less damaging compared to 2006. *Cabomba* in the I-35 Reach declined in 2007 due to the higher flows, which must be monitored because this vegetation type provides the highest-quality fountain darter habitat (of those sampled quantitatively) in the San Marcos River. It is susceptible to high flows because it can be loosely rooted in silty substrates. *Hydrilla* also decreased in this reach because stands in shallow water were likely scoured out during higher flows. Texas wild-rice in this reach increased slightly when several plants grew together.

Texas wild-rice experienced declines throughout much of the river over the course of 2006 due to recreational damage and other factors. High-flows present throughout much of the year in the San Marcos River appeared to stimulate wild-rice growth. Total surface area of wild-rice in the entire river increased to its largest number since the study's inception. Rapid re-growth in the Spring Lake Dam Reach, and large plants growing together in the Sewell Park area contributed substantially to this increase. With the increased flows, vegetation mats were observed on wild-rice plants infrequently. As a result, fewer achlorotic plants were observed, and reproductive culms were able to more easily push out of the water. At the furthest downstream extent of the wild-rice a substantial decrease in area and the number of plants was observed. These plants are located in a normally shallow area, and with the higher flows may have been scoured out during significant precipitation events in early summer. Increased discharge in the system also contributed to lower amounts of herbivory and increased flowering during the summer months. As flows began to decrease in late summer, herbivory and coverage of vegetation mats increased slightly at some of the vulnerable plants measured in this study.

Direct sampling of the fountain darter occurred in the same reaches as mapped for aquatic vegetation, with the most recent mapping determining the stratified random sample locations. The suitability of the various vegetation types (as measured by fountain darter density) is considerably lower in the San Marcos River when compared with the Comal River. As expected, fountain darter densities were highest in *Cabomba* and surprisingly, *Hydrilla*. It is unclear why *Hydrilla* was a preferred habitat in 2007, but further monitoring may provide an answer. Similar to previous years, the smallest darters were captured in spring indicating a spring reproductive peak. Of the dip net sampling locations, the Hotel Reach provided the most darters likely a result of a high concentration of filamentous algae, which are preferred habitat for darters. Overall, normalized estimates of fountain darters were slightly higher than the previous two years.

Exotic species continue to inhabit the San Marcos River, but did not appear to have any noticeable impacts during 2007. San Marcos salamanders (*Eurycea nana*) continued to be common in Spring Lake where large areas are covered in filamentous algae. Salamander density below Spring Lake Dam was near the highest observed since the inception of this study.

Following an extremely low flow year (2006) in the San Marcos River, the biological communities responded well in 2007. Texas wild-rice re-colonized several areas where it had been previously stripped, and estimates of fountain darters continued to be high. Constant monitoring of this system will provide knowledge on the organisms' interactions with variable flows, and also temporal responses that can only be detected over an extended period of time. Long-term monitoring will continue to give us insight into these rare and endangered species and give us the knowledge to manage these species far into the future.

METHODS

Study Location

The upper San Marcos River is part of the Edwards Aquifer system, and extends approximately 3 kilometers (km) from it's origin as a series of springs welling in Spring Lake to it's confluence with the Blanco River in Hays County. The upper portion of the river is characterized by near constant water temperatures (21°C ± 2°C, Ono et al. 1983) and relatively constant flow. This portion of the river also included several endemic organisms that are federally listed as threatened or endangered including Texas wild-rice, San Marcos Salamander, San Marcos Gambusia (*Gambusia georgei*), Comal Springs Riffle Beetle (*Heterelmis comalensis*) and fountain darter. This section of the river is located within an urban area, and is subjected to a substantial amount of recreation use. As such, sites were chosen in this section of the river to better understand the interactions between the biota, the surrounding environment, and recreational users of this unique ecosystem (Figure 1).

During 2007, two full sampling efforts were conducted in the San Marcos River system. They both corresponded to the regular comprehensive sampling events (spring and fall) because higher flows (compared to 2006) did not trigger any critical period events. The 2007 sampling schedule included the following components two times during spring and fall unless otherwise noted:

Aquatic Vegetation Mapping
- Texas wild-rice annual survey (summer only)

Water Quality
- Thermistor Placement
- Thermistor Retrieval
- Fixed Station Photography
- Point Water Quality Measurements

San Marcos Salamander Observations

Texas Wild-Rice Physical Observations
- Cross-section data
- Physical measurements

Fountain Darter Sampling
- Drop Nets
- Dip Nets
- Visual Observations

Low-Flow Sampling

There were no low-flow sampling events in 2007.

High-Flow Sampling

There were no high-flow sampling events in 2007.

San Marcos Springflow

All discharge data were acquired from the United States Geologic Survey (USGS) water resources division. The data are provisional as indicated in the disclaimer on the USGS website and, as such, may be subject to revision at a later date. According to the disclaimer, "recent data provided by the USGS in

Texas – including stream discharge, water levels, precipitation, and components from water-quality monitors – are preliminary and have not received final approval" (USGS 2007). The discharge data for the San Marcos River were taken from USGS gage 08170500 at the University Drive Bridge. This site represents the cumulative discharge of the springs that form the San Marcos River system. In addition to the cumulative discharge measurements that were used to characterize this ecosystem during sampling, spot measurements of water velocity were taken during each sampling event using a Marsh McBirney model 2000 portable flowmeter.

San Marcos Water Quality

The objectives of the water quality analysis are: delineating and tracking water chemistry throughout the ecosystem; monitoring controlling variables (i.e., flow, temperature) with respect to the biology of each ecosystem; monitoring any alterations in water chemistry that may be attributed to anthropogenic activities; and evaluating consistency with historical water quality information. The water quality component of this study was reduced in 2003, but the two components necessary for maintenance of long-term baseline data, temperature loggers (thermistors) and fixed station photography, were continued in 2007. In addition, conventional physico-chemical parameters (water temperature, conductivity compensated to 25°C, pH, dissolved oxygen, water depth at sampling point, and observations of local conditions) were taken at the surface and near the bottom in all drop-net sampling sites using a Hydrolab Quanta. When conditions trigger Critical Period events in the future, the full range of water quality sampling parameters will be employed, including water quality grab samples and standard parameters from each of the water quality sites in the San Marcos River (Figure 1).

Thermistors were placed in select water quality stations along the San Marcos River and downloaded at regular intervals to provide continuous monitoring (recording data every 10 minutes) of water temperatures in these areas. The thermistor locations will not be described in detail here to minimize the potential for thermistor tampering.

In addition to the water quality collection effort, a long-term record of habitat conditions has been maintained with fixed station photography. Fixed station photographs allowed for temporal habitat evaluations and included an upstream, a cross-stream, and a downstream picture; these were taken at each water quality site depicted in Figure 1.

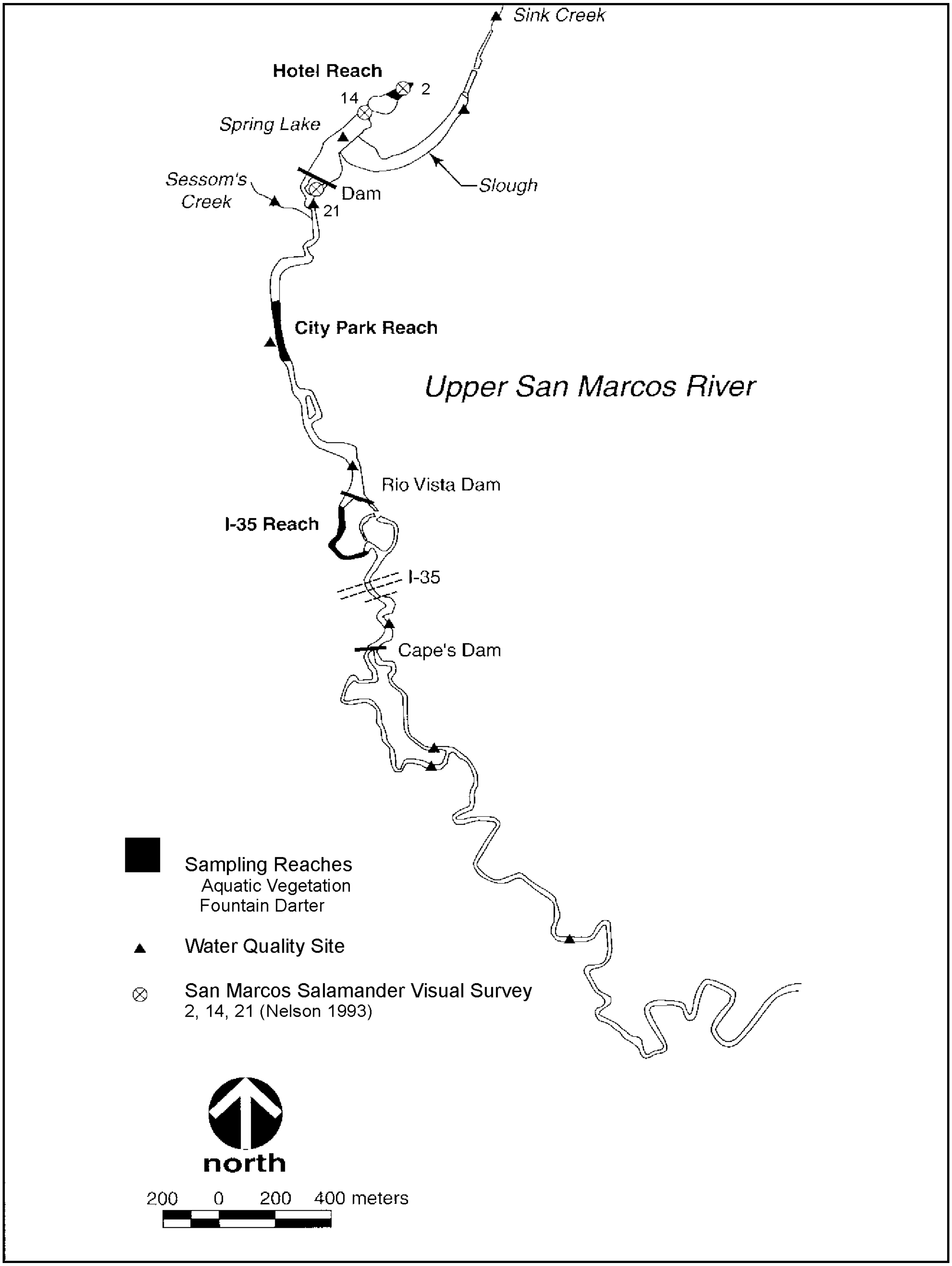


Figure 1. Upper San Marcos River water quality and biological sampling areas.

Aquatic Vegetation Mapping

The aquatic vegetation mapping effort consisted of mapping all of the vegetation in each of three study reaches (Spring Lake Dam, City Park, and I-35). Mapping was conducted using a Trimble Pro-XH global positioning system (GPS) unit with real-time differential correction capable of sub-meter accuracy. The Pro XH receiver was linked to a Trimble Recon Windows CE device with TerraSync software that displays field data as they are gathered and improves efficiency and accuracy. The GPS unit was placed in a 10-meter (m) Perception Swifty kayak with the GPS antenna mounted on the bow. The aquatic vegetation was identified and mapped by gathering coordinates while maneuvering the kayak around the perimeter of each vegetation type at the water's surface. Vegetation stands that measured between 0.5 and 1.0 m in diameter were mapped by recording a single point. Vegetation stands less than 0.5 m in diameter were not mapped.

GPS and kayak setup used during aquatic vegetation mapping

Texas Wild-Rice Physical Observations

The aerial coverage of Texas wild-rice stands in vulnerable locations were determined by GPS mapping (described above), but some smaller stands were measured using maximum length and maximum width. The length measurement was taken at the water surface parallel to streamflow and included the distance between the base of the roots to the tip of the longest leaf. The width was measured at the widest point perpendicular to the stream current (this usually did not include roots). The length and width measurements were used to calculate the area of each stand according to a method used by the Texas Parks and Wildlife Department (J. Poole, TPWD, pers. comm.) in which percent cover was estimated for the imaginary rectangle created from the maximum length and maximum width measurements.

Texas Wild-rice seeds at Sewell Park

Qualitative observations were also made on the condition of each Texas wild-rice stand. These qualitative measurements included the following categories: the percent of the stand that was emergent (and how much of that was in seed), the percent covered with vegetation mats or algae buildup, any evidence of foliage predation, and a categorical estimation of root exposure. Notes were also made regarding the observed (or presumed) impacts of recreational activities. Each category was assigned a number from 1 to 10 for each stand, with 10 representing the most significant impact.

Flow measurements were taken at the upstream edge of each Texas wild-rice stand and depth was measured at the shallowest point in the stand. Data on velocity, depth, and substrate composition were collected at 1-m intervals along cross-sections in the river in each area where Texas wild-rice plants are monitored. To complement all of the measurements made during each survey, several photo sets were made for each of the comprehensive sampling events in 2007.

Fountain Darter Sampling

Drop Netting Technique

A drop net is a type of sampling device previously used by the U.S. Fish and Wildlife Service (USFWS) to sample fountain darters and other fish species in the Comal and San Marcos Springs/River ecosystems. The design of the net is such that it encloses a known area (2 square meters [m^2]) and allows thorough sampling by preventing escape of fishes occupying that area. A large dip net (1 m^2) is used within the drop net and is swept along the length of the river substrate 15 times to ensure complete enumeration of all fish trapped within the net. For sampling during this study, a drop net was placed in randomly selected sites within specific aquatic vegetation types. The vegetation types used in each reach were defined at the beginning of the study as the dominant species found in that reach. Sampling sites were randomly selected per dominant vegetation type for each comprehensive event from a grid overlain on the most recent map (created using GPS-collected data during the previous week) of that reach.

Typical drop-net setup (left) and the endangered fountain darter (right)

At each location the vegetation type, height, and areal coverage were recorded, along with substrate type, mean column velocity, velocity at 15 cm above the bottom, water temperature, conductivity, pH, and dissolved oxygen. In addition, vegetation type, height, and areal coverage, along with substrate type, were noted for all adjacent 3-m cell areas. Fountain darters were identified, enumerated, measured for total length, and returned to the river at the point of collection. The same measurements were taken for all other fish species, except abundant species for which only the first 25 were measured, and the rest were simply counted. Fish species not readily identifiable in the field were preserved for identification in the laboratory. All live giant ramshorn snails (*Marisa cornuarietis*) were counted, measured, and destroyed, while a categorical abundance was recorded (i.e., none, slight, moderate, or heavy) for the exotic Asian snails (*Melanoides tuberculata* and *Thiara granifera*) and the Asian clam (*Corbicula* sp.). A total count of crayfish (*Procambarus* sp.) and grass shrimp (*Palaemontes* sp.) was also recorded for each dip net sweep.

Drop Net Data Analysis

The fisheries data collected with drop nets were analyzed in several ways. Calculations of fountain darter density in the various vegetation types during 2000-2007 provide valuable data on species/habitat relationships. These average density values were also used with aquatic vegetation mapping data on total coverage of each vegetation type by sampling effort to create estimates of the population abundance in each reach (fountain darter density within a vegetation type x total coverage of that vegetation type in the given reach). Because there were generally only two drop net samples in each vegetation type within each reach, density estimates between sampling efforts had great variation and population estimates based on those densities would be greatly influenced by this variation. Part of the variation would be due to changes in environmental conditions (discharge, temperature, etc.) that had occurred since the last sample, but part was due to natural variation between samples. Without adding samples (the total number is limited by federal permit and time constraints) it is impossible to tell how much of the variation is attributed to each source within a given sampling effort. Using the average density of fountain darters across all samples for a given vegetation type does not account for changes in density across samples (differences associated with changes in environmental conditions), but the increased sample size substantially reduces the high natural variability. This type of comparison between samples, where density values are held constant across all samples, is based entirely upon changes in vegetation composition and abundance between sampling efforts. Because these abundance estimates use the same density values across sites and seasons, and do not include estimates of fountain darters found in vegetation types that are not sampled with drop nets, the absolute numbers generated with this method have some uncertainty associated with them. Thus, the estimates are presented as relative comparisons by normalizing the data to the maximum estimate (the absolute value of all samples are converted to a percentage of the maximum value).

Dip Netting Technique

In addition to drop net sampling for fountain darters, a dip net of approximately 40 cm x 40 cm (1.6-millimeter [mm] mesh) was used to sample all habitat types within each reach. Collecting was generally done while moving upstream through a reach. An attempt was made to sample all habitat types within a reach. Habitats thought to contain fountain darters, such as along or in clumps of certain types of aquatic vegetation, were targeted and received the most effort. Areas deeper than 1.4 m were not sampled. Fountain darters collected by this means were identified, measured, recorded as number per dip net sweep, and returned to the river at the point of collection. The numbers of native and exotic snails were also enumerated and recorded for each dip.

To balance the effort expended across sampling events, a predetermined time constraint was used for each reach (Hotel Reach – 0.5 hour, City Park Reach – 1.0 hour, I-35 Reach – 1.0 hour). The areas of fountain darter collection were marked on a base map of the reach. Though information relating the number of fountain darters by vegetation type was not gathered by this method (as in the drop net sampling) it did permit a more thorough exploration of various habitats within the reach. Also, spending a comparable length of time sampling the entirety of each reach allowed comparisons to be made between the data gathered during each sampling event.

Dip Net Data Analysis

Dip net data were used to identify periods of fountain darter reproductive activity since this method was more likely to sample small fountain darters (<15 mm) along shoreline habitats. This size-class is indicative of recent reproduction since fountain darters of this size should be <60 days old (Brandt et al. 1993). The dip net data were also useful for identifying trends in edge habitat use by fountain darters since this method focused on that habitat type. In some instances, changes that were observed in fountain darter distribution and abundance in the main channel were not observed in the edge habitat. In that way, the dip net data provided a valuable second method of sampling fountain darters in the same sample reaches as drop netting, which allowed a more complete characterization of fountain darter dynamics in a sample reach. The dip net data were analyzed by visually evaluating graphs of length-frequency distribution for each sample reach.

Dip Net Techniques Evaluation

In 2007, presence/absence dip netting was conducted on the San Marcos River during the spring (April 24) and fall (October 12) Comprehensive sampling events. During each sample, fifty sites were distributed among the four sample reaches based on total area, diversity of vegetation, previous fountain darter abundance estimates, and overall biological importance of each reach (Table 1). In most cases, sites were randomly selected from a grid overlain on the most recent vegetation map of that reach. However, occasionally, where certain vegetation types exhibited limited coverage, sites were specifically chosen to fall within the desired vegetation type. Due to decreases in coverage of *Hygrophila* within the Spring Lake Dam Reach, sites previously conducted in a *Potamogeton*/*Hygrophila* mixture were simply *Potamogeton* in fall 2007.

Four dips were conducted at each site for a total of 200 dips per sample period. After each dip, presence or absence of fountain darters was noted and the entire contents of the net were placed into a plastic tub filled with river water to avoid recapturing organisms. After all dips were completed at a site, all organisms were released at the site of capture and time of day was recorded.

Table 1. Distribution of 50 dip net sites among three reaches and three vegetation types in 2007.

SPRING LAKE DAM REACH	CITY PARK REACH	I - 35 REACH
Hygrophila (2)	*Hygrophila* (2)	*Hygrophila* (2)
Hydrilla (6)	*Hydrilla* (10)	*Hydrilla* (6)
Potamogeton (6)	*Potamogeton/Hygrophila* (10)	*Cabomba* (6)
Total (14)	**Total (22)**	**Total (14)**

San Marcos Salamander Visual Observations

Visual observations were made in areas previously described as habitat for San Marcos salamanders (Nelson 1993). All surveys were conducted at the head of the San Marcos River and included two areas in Spring Lake and one area below Spring Lake Dam adjacent to the Clear Springs Apartments. The upstream-most area in the lake was adjacent to the old hotel (known as the Hotel Reach) and was identified as site 2 in Nelson (1993). The other site in Spring Lake was deeper (~6 m) and located directly across from the Aquarena Springs boat dock. This site was identified as site 14 in Nelson (1993). The final sampling area was located just below Spring Lake Dam in the eastern spillway (site 21, Nelson 1993) and was subdivided into four smaller areas for a greater coverage of suitable habitat. San Marcos salamander densities in the four subdivisions below Spring Lake Dam were averaged as one.

SCUBA gear was used to sample habitats in Spring Lake, while a mask and snorkel were used in the site below Spring Lake Dam. For each sample, an area of macrophyte-free rock was outlined using flagging tape, and three timed surveys (5 minutes each) were conducted by turning over rocks >5 cm wide and noting the number of San Marcos salamanders observed underneath. Following each timed search, the total number of rocks surveyed was noted in order to estimate the number of San Marcos salamanders per rock in the area searched. The three surveys were averaged to yield the number of San Marcos salamanders per rock. The density of suitable sized rocks at each sampling site was determined by using a square frame constructed out of steel rod to take random samples within the area. Three random samples were taken in each area by blindly throwing the 0.25 m^2 frame into the sampling area and counting the number of appropriately sized rocks. The three samples were then averaged to yield a density estimate of the rocks in the sampling area. The area of each sampling area was determined with a grid measurement on a GPS with real-time differential correction. This was accomplished by attaching the unit to a kayak and towing it around the flagged sampling area.

An important note about these San Marcos salamander density estimates is that extrapolating beyond the area sampled into surrounding habitats would not necessarily yield accurate values, particularly in the Hotel Reach. This is because the area sampled was selected based on the presence of silt-free rocks and relatively low algal coverage (compared to adjacent areas) during each survey. Much of the habitat surrounding the sampling areas is usually densely covered with aquatic macrophytes and algae, and provides a three-dimensional habitat structure that support different densities of San Marcos salamanders. The estimates created from this work are valuable for comparing between trips, but any estimates of a total population size derived from this work should be viewed with caution.

OBSERVATIONS

The BIO-WEST project team conducted the study components for the 2007 comprehensive sampling events as shown in Table 2.

Table 2. Study components of the 2007 sampling events.

EVENT	DATES	EVENT	DATES
Spring Sampling		**Fall Sampling**	
Vegetation Mapping	Apr 16 - 19	Vegetation Mapping	Oct 8 - 11
Texas wild-rice Physical Observations	Apr 23	Texas wild-rice Physical Observations	Oct 10
Fountain Darter Sampling	Apr 25 - 26	Fountain Darter Sampling	Oct 15 - 16
San Marcos Salamander Observations	Apr 26	San Marcos Salamander Observations	Nov 1
Summer Sampling			
Texas wild-rice Annual Survey	Aug 1 - 8		

San Marcos Springflow

Unlike the low flows observed throughout 2006, springflows increased in early 2007 and did not show a significant decrease until mid-August (Figure 2). In fact, the lowest mean daily discharge recorded occurred on the first day of 2007 (Table 3). Shortly thereafter, rain events occurred in early spring and soaking rains across the region continued well into late summer. Mean monthly discharge peaked in August then declined for the rest of the year, but mean monthly discharge in December (239 cfs) was higher than in January (154 cfs, Figure 3). The highest discharge recorded in 2007 was 981 cfs after a large rainstorm on July 21, though flows decreased rapidly after this event. Rain events continued into the fall, resulting in discharge well above historic conditions as 2007 came to an end. As a result, no Critical Period Low-flow events were triggered in 2007. High-flows present in the river in 2007 were substantial enough at times to trigger High-flow Critical Period sampling events, however, site investigations determined that biological conditions were not altered to an extent that warranted a full sampling event.

Water level and flow conditions in the Sewell Park reach in August 2006 (left) and July 2007 (right)

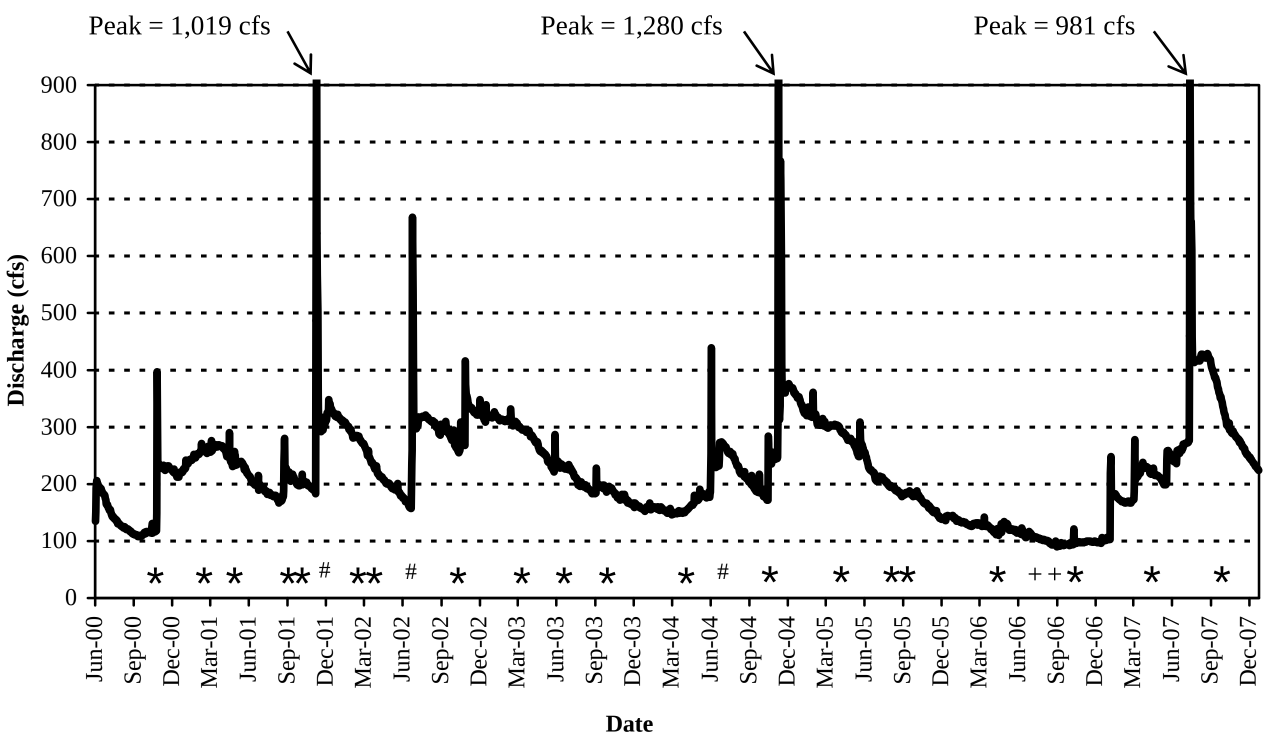


Figure 2. Mean daily discharge in the San Marcos River during the study period; approximate dates for quarterly (*), high-flow (#), and low-flow sampling efforts (+) are indicated.

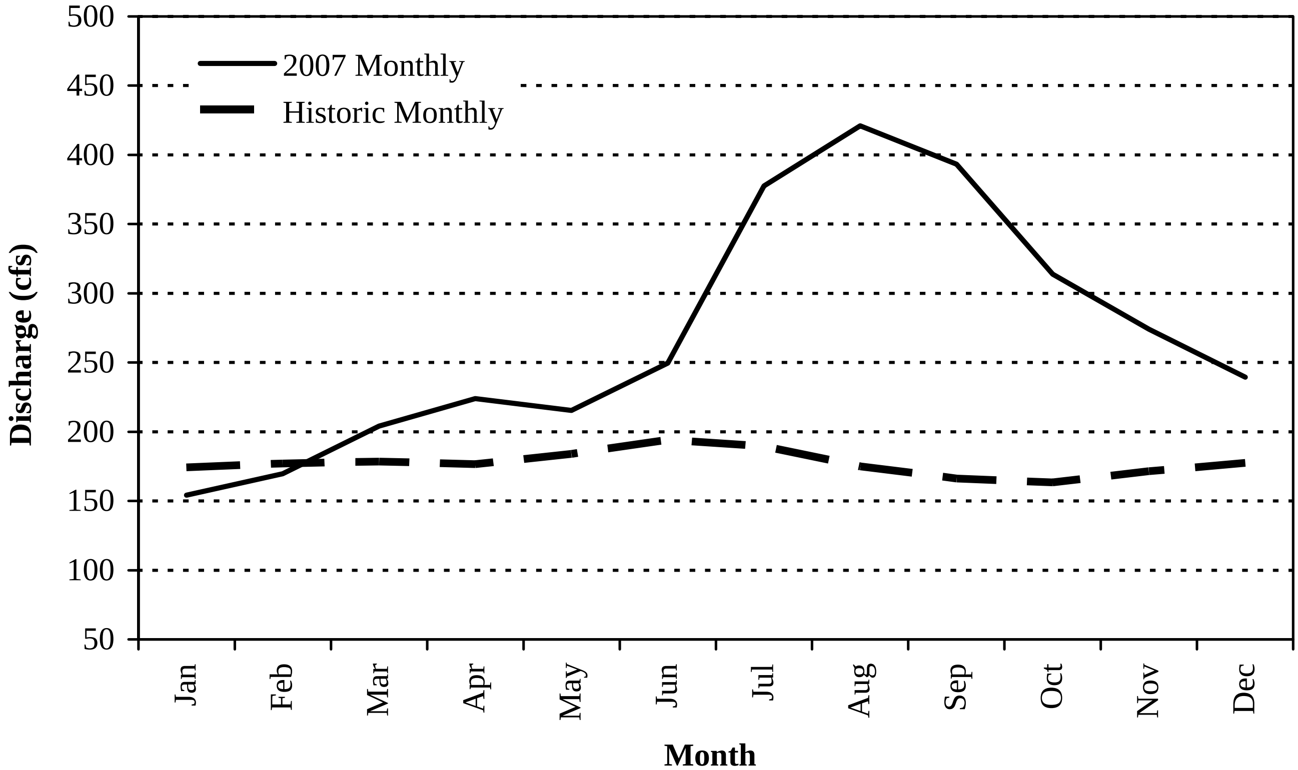


Figure 3. Mean monthly discharge in the San Marcos River during the 1956-2007 period of record.

Table 3. Lowest discharge (cfs) during each year of the study and the date on which it occurred.

Year	Discharge	Date
2000	108	Sept. 18
2001	167	Aug. 19
2002	157	Jun. 28
2003	156	Dec. 29
2004	146	Mar. 8
2005	136	Dec. 17
2006	90	Sept. 8
2007	101	Jan. 1

San Marcos Water Quality

The thermistor temperature data for the City Park and I-35 reaches are presented in Figure 4, and additional graphs can be found in Appendix B. The continuously sampled water temperature data provide a significant amount of information regarding fluctuations due to atmospheric conditions and springflow influences in the San Marcos River. In many places the temperature remained nearly constant due to nearby spring inputs, while other locations (typically further away from spring influences) were more substantially affected by atmospheric conditions. At times, it appears that precipitation can have acute impacts (typically very cold rainfall) in some locations, but these are generally short-lived and the overall relationship at these sites is more directly associated with air temperature (also, air temperatures strongly influence precipitation temperatures).

As in previous years, water temperatures were most stable in the areas closest to the springheads (Dam and Chute tailraces). As water moves downstream, temperatures become less stable as a result of inputs (creeks, culverts) from outside sources and distance from the near-constant temperatures of the springs. At these downstream sites, temperatures in February delved below 18 ˚C due to a cold weather event with extremely low air temperatures and cold rain and sleet. Water temperatures did not exceed the TCEQ water quality standards value (26.67 ˚C) in 2007. The highest temperature recorded in 2007 was 26.18˚C at Sessom's Creek in August. The Sessom's Creek site often exhibits extreme temperatures because it is a flashy stream draining an urban area. Fountain darters are not found at this site.

Thermistor temperature logger

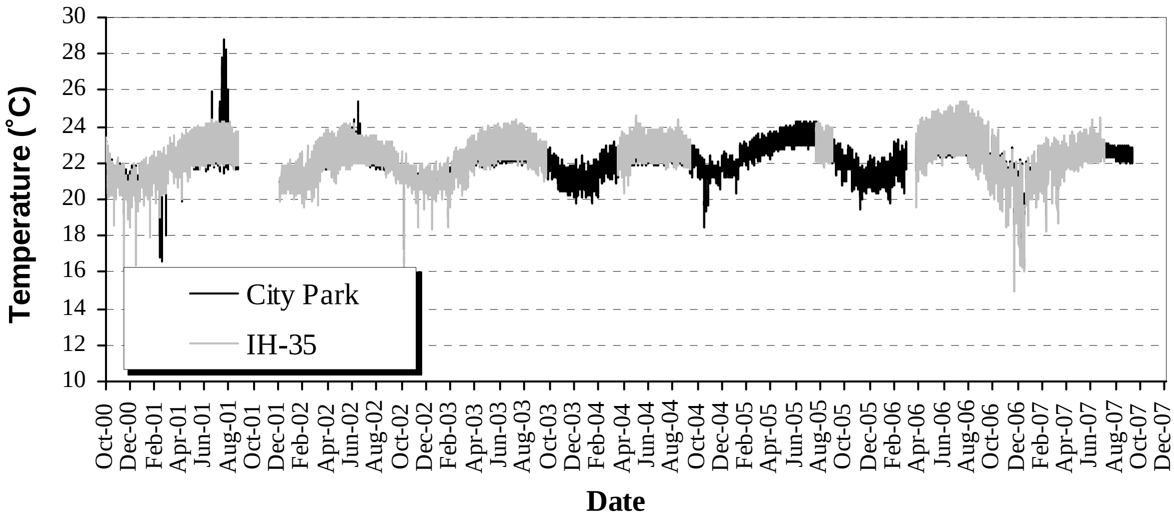


Figure 4. Thermistor data from the City Park and I-35 Reaches for the entire study period.

Aquatic Vegetation mapping

Maps of the aquatic vegetation observed during each sample effort can be found in the Appendix A map pockets. The maps are organized by individual reach with successive sampling trips in order by date of occurrence. It is difficult to make sweeping generalizations about seasonal and other trip-to-trip characteristics since most changes occur in such fine detail; however, some of the more interesting observations are described below.

Spring Lake Dam Reach

Significant changes in vegetation areas occurred in the Spring Lake Dam Reach in 2006 largely due to recreational impacts in late summer. This left several areas of bare substrate on the river bottom heading into 2007 leaving space for plants to recolonize and grow. In addition, increased flows in 2007 resulted in water inundating more of BobDog Island (area of recent sedimentation near the mouth of Sessom's Creek). As a result of these changes, total vegetation increased substantially from fall of 2006 (1,061.1 m^2) to spring 2007 (1,384.5 m^2). With its ability to attach itself to the substrate and other plants, *Hydrilla* quickly colonized areas that were previously bare and mixed with other stands of vegetation (most notably *Potamogeton*). This includes much of the area where the two spillways below the dam converge, and where in 2006 much of the Texas wild-rice was pulled out. This led to *Hydrilla* stands increasing nearly 5X from November 2006 (45.6 m^2 to 227.9 m^2). By fall, many of the areas where *Hydrilla* dominated became bare or in some cases colonized by small wild-rice plants. *Potamogeton* stands decreased in area from 2006 (318.5 m^2) to spring 2007 (174.4 m^2) because pure stands of *Potamogeton* were colonized by *Hydrilla*. *Potamogeton* recovered slightly by fall 2007 (209.1 m^2) as *Hydrilla* plants were scoured out and uprooted. Hygrophila stands increased slightly in the upper reaches of the site in spring (25.0 m^2), but by fall were near their 2006 levels (16.6 m^2 and 16.1 m^2, respectively).

In September 2006, Texas wild-rice plants in the eastern spillway decreased dramatically due to mechanical disturbance. This disturbance included many of the leaves of the plants having been pulled out by people during lower than average flows. As a result, Texas wild-rice decreased by over 73% in surface area in this reach (BIO-WEST 2007). With flows increasing over average monthly levels in 2007, colonization of wild-rice seemed to begin in earnest. From November 2006 (107.2 m^2) to April 2007 (283.2 m^2) surface area of these plants more than doubled when Texas wild-rice plants colonized and grew from root wads in the eastern arm of the reach where they had been culled the previous September. Growth was also apparent downstream where the two spillways flow together. By fall, the plants had nearly recovered to the total that was recorded prior to the disturbance (298.4 m^2 in fall 2007 and 323.3 m^2 in July 2006). Again, growth took place in areas where disturbance had occurred last year. Possible reasons for this growth include higher flows that reduced recreational activity enabling plants to colonize and growth of leaves from rootwads that were not pulled out. In addition, signs put up by Texas State University and collaborators informed the public of the importance of these plants and what can be done by the general public to preserve this unique ecosystem.

City Park Reach

Increased flows in early 2007 led to many of the bare patches present in 2006 to be colonized by plants. In addition, the decreased recreational use over winter contributed to increased growth of the vegetation in this reach including *Hydrilla*/algae growing over the walking path that is usually present in the middle of the reach. The most notable plants to take over several bare patches were green algae. These plants often increase quickly in an area after extended periods of warm sunny weather. In addition, alga will attach to other plants as it passively floats downstream. *Hydrilla* plants often "catch" algae as they float downstream because of their highly serrate leaves. As a result this *Hydrilla*/algae mix increased greatly in area. By spring 2007, 1,498.5 m^2 of the City Park reach were covered in this mix, which decreased stands of "pure" *Hydrilla* in spring 2007 (11.4 m^2) compared to the fall of 2006 (1,169.1 m^2). By fall, all of the algae were gone and *Hydrilla* (1,520.5 m^2) had increased substantially from 2006. In spring, *Hygrophila* and *Hydrilla* occupied several areas that were previously pure *Potamegeton* stands. *Hygrophila* surface area nearly doubled from 2006 (125.6 m^2) to the spring of 2007 (220.7 m^2), but decreased by fall (91.4 m^2). Although the area near the outfall of the culvert was colonized by algae in the spring of 2007, this area once again became bare of any vegetation likely due to scouring from large rain events like the one observed in July.

In 2006, Texas wild-rice exhibited dramatic decreases in surface area in this reach due to lower flows and increased recreational use where wild-rice plants are found. The increased flows of early 2007 and the decreased recreation use during winter led to much growth in Texas wild-rice plants. In spring, several plants grew together nearly doubling the surface area (238.6 m^2) as compared to the fall of 2006 (168.0 m^2). This growth continued throughout 2007 possibly due to continued high flows. More plants grew together, and several new plants became anchored in several locations leading to higher total surface areas of Texas wild-rice (272.6 m^2).

I-35 Reach

This reach presents difficulties in obtaining accurate GPS coordinates when the canopy is dense (i.e., spring and summer); therefore, small discrepancies are apparent in the exact location of individual stands between samples. In addition, some estimates of total coverage may be less precise than in other reaches. Following a small increase in overall aquatic vegetation cover between the fall 2006 and spring 2007 mapping efforts, conditions experienced during 2007 contributed to an overall decline of approximately 12% in total vegetation area for the year. Higher discharges throughout the summer re-submerged areas that were partially exposed along the bank in 2006 and increased velocities in most areas of this reach.

While algae had been abundant in 2006, algal growth declined in 2007 and was absent from the I-35 study reach by the fall. *Hygrophila* increased slightly from fall 2006 to spring 2007 (70.2 m^2 and 97.5 m^2, respectively), and then decreased dramatically by fall 2007 (51.1 m^2). *Cabomba* occurs in this reach because of suitable conditions along the outside bends in the river (lentic backwaters, deep silty substrates). This vegetation type is important because it provides the highest-quality fountain darter habitat (of those sampled quantitatively) in the San Marcos River, but it is also highly susceptible to flood events. Likely a result of the increasing flows since fall 2006, approximately 23% of the total area of *Cabomba* was lost between 2006 and 2007. Texas wild-rice area increased both between fall 2006 to spring 2007 (120.1 and 139.3 m^2, respectively) and again into the fall (146.4 m^2), due to the growth of several already established plant stands.

A notable decrease in *Hydrilla* occurred between 2006 and spring 2007 (332.6 m^2 and 175.5 m^2, respectively), mainly in shallow areas near the bank at the top of the site and a shallow run in the middle of the site. Following this decline, patches of growth occurred within the middle and lower parts of the reach, but where much of the *Hydrilla* in the spring had algae growth within the stands, algae were no longer present by the fall.

Texas Wild-Rice Surveys

Maps generated from the annual Texas wild-rice mapping survey in 2007 of the San Marcos River (downstream of Spring Lake) can be found in Appendix A.

Texas wild-rice recovered from much of the damage it sustained from low-flows and subsequent increased recreation pressure in 2006. The increased flows of 2007 (and decreased recreation opportunities near vulnerable plants) led to the highest total surface area (3,646.4 m^2) of Texas wild-rice measured by BIO-WEST since the studies inception (Table 4). Considering how much damage was observed in 2006, the increase shows the resiliency of this endangered plant. Much of this recovery and growth took place in the upper reaches of the San Marcos River (Map 1, Appendix A), where rice area increased by 24% compared to the fall of 2006. Much of this growth was observed within the Spring Lake Dam Reach where most of the damage (leaves of the plant were pulled out, leaving only the roots in many areas) to the wild-rice occurred last year. There are two explanations for this recovery (and it is likely a result of some combination). First, increased flows meant that areas within the Spring Lake Dam Reach and Sewell Park that were shallow last year (and occasionally dry) were under water. Combined with strong currents, this likely led to less recreation damage of vulnerable plants, which allowed them to grow and develop stronger root structures. In addition, signs were put up along the shore at the Spring Lake Dam Reach near where the plants had been pulled out in 2006. These signs educate river users by explaining the importance of the endangered animals and plants in the river and the detrimental effects habitat degradation can have in the river. These signs likely led to a more conscious effort of river users to take part in sustaining these plant populations. Several plants in Sewell Park that were isolated due to low-flows last year grew together increasing coverage in this area.

Table 4. Total coverage of Texas wild-rice (m^2) in the San Marcos River as measured by the TPWD for 1996-2006 and BIO-WEST in 2001-2007.

YEAR/EVENT	1998	1999	2000	2001[a]	High-Flow[a]	2002	2003	2004	2005	2006[b]	Low-Flow[c]	2007
TPWD	1,949.0	1,644.9	1,791.1	1,895.6		1,916.3	2,776.0	3,390.0	3,992.7	4161.1		
BIO-WEST				1,901.2	1,765.9	1,913.2	2,560.7	3,145.3	2,949.7	3,335.7	3,000.4	3,646.4

[a]Total coverage values obtained in this study are included for the summer and high-flow events in 2001.

[b]Total coverage values obtained during a Critical Period low-flow event (July 27 – August 5, 2006).

[c]Total coverage values obtained during a second Critical Period low-flow event (September 20 – October 3, 2006).

Texas wild-rice also increased in coverage in the City Park Reach and downstream by 142.7 m^2 compared to 2006 (Map 2, Appendix A). Most of the growth took place in City Park because plants vulnerable during the low-flows of 2006 were much deeper and less prone to recreation impacts. Wild-rice plants further downstream (Map 3, Appendix A) increased slightly when two new plants were discovered. These plants were located behind a tall stand of emergent vegetation. At lower flows it is difficult to walk in this vegetation, but with the increased flows of 2007 the area opened up making it possible to kayak behind the stand. In this area between vegetation and an island, two new plants were found. Total wild-rice coverage in the I-35 Reach and downstream increased slightly in area (4.0 m^2) from 2006 to 2007 (Map 4 Appendix A). Further downstream, there are few Texas wild-rice plants present, and little changed from 2006 (Maps 5-6, Appendix A). A significant decrease in total coverage was observed at the furthest downstream reach where in 2003 several plants had been planted by the TPWD. From 2006 to 2007 surface area decreased by over half (39.2 m^2, Map 7, Appendix A). These plants are more vulnerable than others because velocities are higher here and there are no other vegetation types to protect them from scouring. Large rain events (like on July 21, 2007) created flow conditions that likely uprooted many of the plants in this area as there were far fewer present at the time they were mapped. In addition, on the day this section was mapped this area was far deeper and turbid compared to other years.

With increased flows and more frequent flushing events present throughout much of 2007, vegetation mats were not observed in many of the areas where they had been previously common (Sewell Park, City Park). When these mats cover wild-rice plants for extended periods of time it can lead to achlorotic leaves and a decrease in the ability of the plants to reproduce. The lack of these large, heavy mats in 2007 is another reason why a dramatic increase in growth of Texas wild-rice was observed throughout the San Marcos River.

Texas Wild-Rice Physical Observations

Total coverage of Texas wild-rice observed during 2007 in each "vulnerable" stand is presented in Table 5, and observations on trends in areal coverage are discussed by reach below. More detailed graphs on observations of root exposure, herbivory, emergence, etc. are found in Appendix B. Physical observations were conducted two times in 2007 at each of the vulnerable stands.

Sewell Park Reach

As flows increased in 2007, water level rose in Sewell Park and increased both water level and point flow measurements at all vulnerable stands in this reach. Total area of Texas wild-rice displayed an increasing trend that resulted in a gain of 19.1 m^2 between the spring and fall sampling periods of 2007.

Discharge conditions in 2007 resulted in a decrease in the amount of emergent stands and the areas of shallow water (<0.5 feet) that were prevalent in 2006. During the spring comprehensive sampling event, none of the Texas wild-rice in this section was found in water less than 0.5 feet, and the vegetation mats covered only 7% of the stands (Appendix B). Root exposure and plant herbivory appeared to be minimal, and 55% of the vulnerable stands appeared to be flowering and/or seeding. Due to the water depth, only 47% of the stands were emergent and some plants were flowering or seeding while submerged.

Table 5. Texas wild-rice areal coverage (m^2) for each stand by sampling period (2007 only).

REACH-STAND NO.[a]	Spring 2007[a]	Fall 2007[b]
Sewell Park-1	0.3	0.4
Sewell Park-2 Sewell Park-3	180.0	182.7
Sewell Park-4 Sewell Park-5	47.0	33.8
Sewell Park-6	47.9	63.4
Sewell Park-7 Sewell Park-8	294.5	308.7
Total Area	**569.7**	**588.8**
I-35-1	0.7	0.7
I-35-2	1.0	0.2
I-35-3	0.8	2.5
I-35-4	0.9	2.3
I-35-5	2.5	2.7
I-35-6 I-35-7	37.8	37.4
I-35-8	175.3	185.0
Total Area	**219.0**	**230.8**
Thompson's Island - 1	-	-
Thompson's Island - 2	2.9	4.6
Thompson's Island – 2a	1.1	0.9
Thompson's Island – 3	2.2	2.5
Thompson's Island – 3a	0.4	1.0
Total Area	**6.6**	**8.9**

[a]Many stands grew together to form individual stands after the first sampling period. [b]Areas reflect results of cross-section measurements and not GPS mapping at Thompson's Island.

By the fall comprehensive sampling event, water levels were still high, and no Texas wild-rice was found in water less than 0.5 feet deep. The amount of flowering plants decreased in the fall (25%), although this species continued to reproduce through most of the year. Emergence was also beginning to decrease, but vegetation mats covered a higher amount (27%) of the stands than in the spring. Floating vegetation that has dislocated from upstream areas is easily caught on Texas wild-rice leaves and stems in the shallower areas. Thick vegetation mats covering plants in vulnerable areas can have detrimental effects (see picture below), as they can lead to reproductive failure due to the mats limiting emergence of culms, and reduce photosynthesis by blocking sunlight resulting in achlorotic leaves (Power 1996). Root exposure and plant herbivory increased only slightly in the fall, and was still lower than levels observed in 2006 (Appendix B).

Vegetation mats covering Texas wild-rice in the Sewell Park Reach

IH-35 Reach

Average areal coverage of Texas wild-rice "vulnerable" stands in the I-35 reach increased from fall 2006 (195.6 m^2) to spring 2007 (219.0 m^2), and increased further during 2007 to 230.8 m^2. Plants in this reach were relatively unaffected by recreation because this reach is farther away from recreational areas (City Park, Sewell Park). As a result of less recreation in this reach, Texas wild-rice plants were much less fragmented by mechanical disturbance. Emergence in this reach remained relatively constant between spring and fall 2007, at approximately 20% (Appendix B). Most of the emergent plants were plants 6, 7, and 8 because they are in a very shallow area of the reach. However, with the 2007 discharge conditions, water level in this reach was higher than in 2006 and no plants were found in water <0.5 feet deep.

Flowering culms were observed on all of the plants and were more pronounced in the spring, but flowering and seeding continued into the fall. Very few vegetation mats were present in the spring, but the coverage of the wild-rice by these mats increased by the fall. Herbivory increased slightly through 2007, but most of it was concentrated in plants 6, 7, and 8 because these are found in shallow waters. Root exposure was relatively low throughout the year (Appendix B).

Thompson's Island Reach (Natural)

The average coverage of Texas wild-rice in "vulnerable" areas within this reach increased from fall 2006 (4.0 m^2) to spring 2007 (6.6 m^2), and continued to increase to 8.9 m^2 in the fall. In fall 2006, a new plant was discovered next to existing plant 2 in this reach and was assigned the number 2a. In spring 2007, another new plant was discovered in front of existing plant 3 and was assigned the number 3a. Both of these new plants will continue to be measured in future sampling events.

Due to higher discharge conditions and subsequent higher water levels, none of the plants in this reach were found in water <0.5 feet deep. None of the plants exhibited emergence throughout the year, and none were observed to have flowering or seeding culms (Appendix B). As a result, herbivory decreased in this area because the plants were not exposed and remained in relatively swiftly moving water. Root exposure decreased from 2006 to 2007, and continued to decrease in 2007, perhaps due to increased health of the plants as they experienced slightly higher water levels.

Fountain Darter Observations

Drop Net Sampling

The number of drop net sites and vegetation types sampled per reach is presented in Table 6. The drop net site locations are depicted on the aquatic vegetation maps (Appendix A) for the respective reaches per sampling event and resulting data sheets are found in Appendix C.

Table 6. Drop net sites and vegetation types sampled within each reach.

CITY PARK REACH	I-35 REACH
Bare Substrate (2)	Bare Substrate (2)
Hygrophila (2)	*Hygrophila* (2)
Hydrilla (2)	*Hydrilla* (2)
Potamogeton/ *Hygrophila* (2)	*Cabomba* (2)
Total (8)	**Total (8)**

Aquatic vegetation is a critical component of fountain darter habitat in the San Marcos River. The variety of vegetation types present provide fountain darter habitat with a range of suitability. For example, fountain darter densities calculated from drop netting data are highest in the native vegetation type *Cabomba* (5.7/m^2), and similar numbers are observed in non-native plants like *Hygrophila* (4.7/m^2) and *Hydrilla* (5.6/m^2, Figure 6). Although, densities of fountain darters are similar in different vegetation types in the San Marcos River, they are considerably lower than the Comal River (BIO-WEST 2008). Higher water velocities, and lower quality habitat (no filamentous algae or bryophytes) present in the San Marcos River are likely contributors to this difference in fountain darter densities.

For example, the highest densities in the San Marcos River are found in *Cabomba* ($5.7/m^2$), while densities in filamentous algae in the Comal River are nearly five times higher ($26.3 /m^2$).

In 2007, fountain darter densities in *Hydrilla* increased drastically as a result of two samples taken in spring which contained large numbers (115 and 246) of darters. The majority of these fish were relatively small (<20 mm), representing the usual spring reproductive peak in this reach. As a result of these two samples *Hydrilla* now exhibits overall densities similar to *Cabomba*. Large numbers of darters like these in typically non-preferred vegetation highlights the variability inherent in drop net data. Although, a large number of darters were present in these two *Hydrilla* sites, sampling more places within the *Hydrilla* may not yield such high numbers. As stated earlier, the number of sites that can be sampled is constrained by permit regulations, so we can only base fountain darter densities on the sites we sample and recognize that variation is present in the data. The absence of darters in areas of bare substrate demonstrates the importance of submerged aquatic vegetation as fountain darter habitat.

The size-class distribution for fountain darters collected by drop net from the San Marcos Springs/River ecosystem during all sampling events combined in 2007 is presented in Appendix B. The distribution is similar to the distribution observed throughout the project and is typical of a healthy fish assemblage. When examined by reach and sample (Figures 7 and 8) the size-class distributions reveal trends similar to those observed in the Comal Springs/River ecosystem. Fall samples from both reaches are dominated by larger individuals while juvenile fountain darters are most abundant in spring samples suggesting a spring reproductive peak.

Presence of fewer fountain darters in the San Marcos River collections when compared to the Comal River collections is most likely a function of differences in vegetation types and current velocities in the two systems. Less suitable vegetation types as well as stronger currents limit the availability and quality of habitat in the San Marcos River. However, high quality habitats in Spring Lake exhibit extremely high abundance according to dip net data.

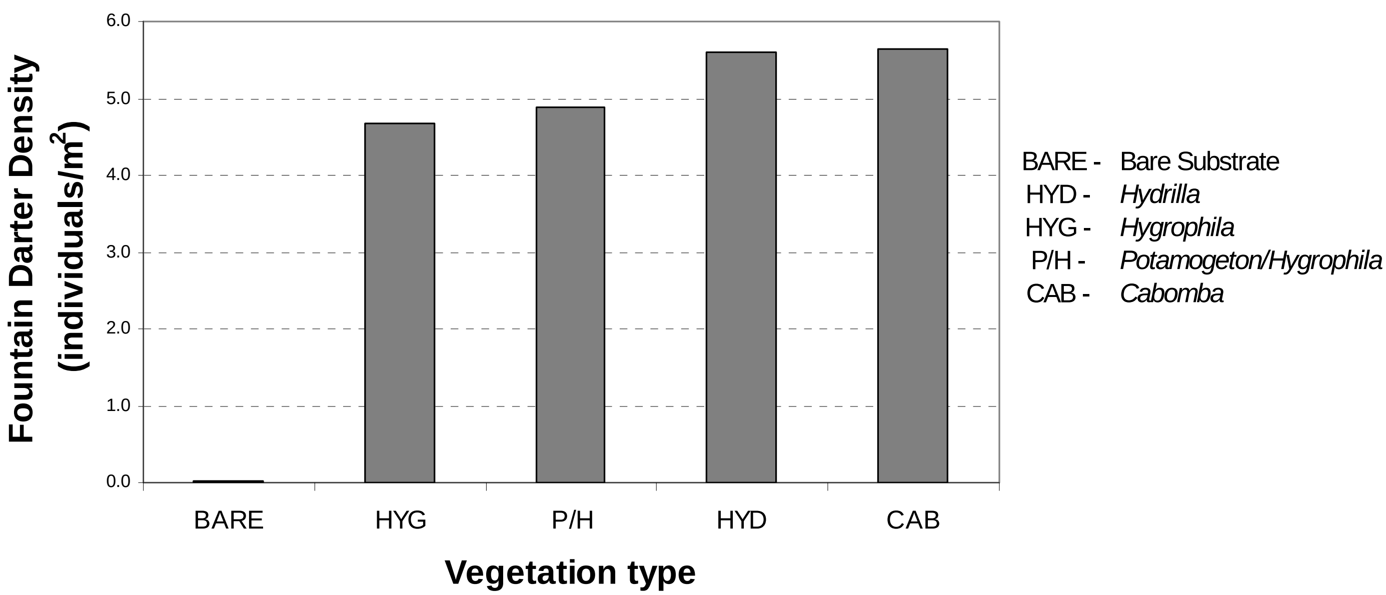
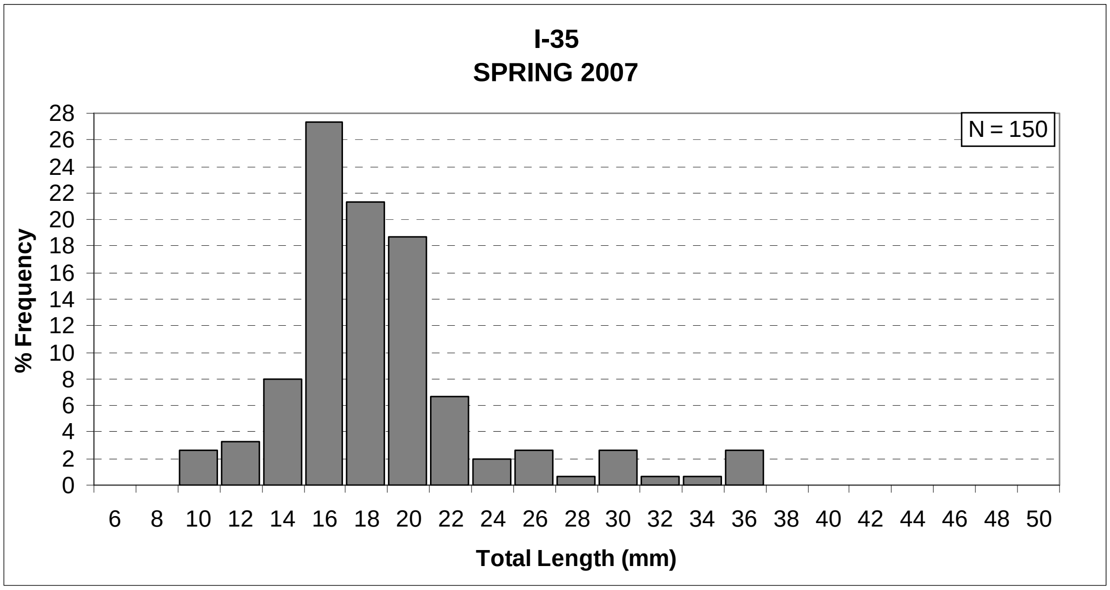


Figure 5. Density of fountain darters collected by vegetation type in the San Marcos Springs/River ecosystem (2000-2007).



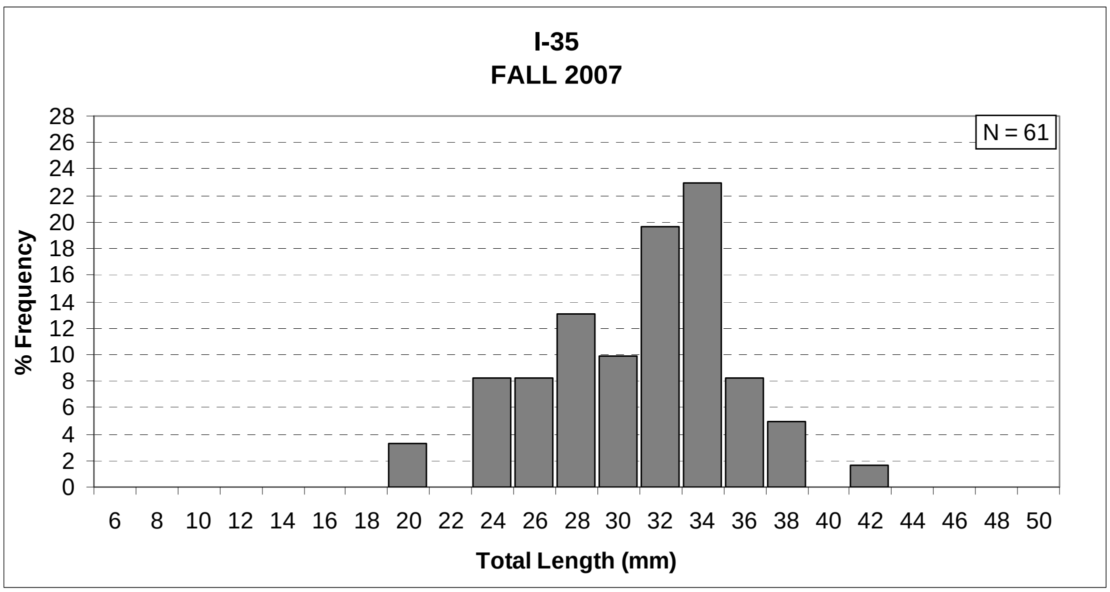
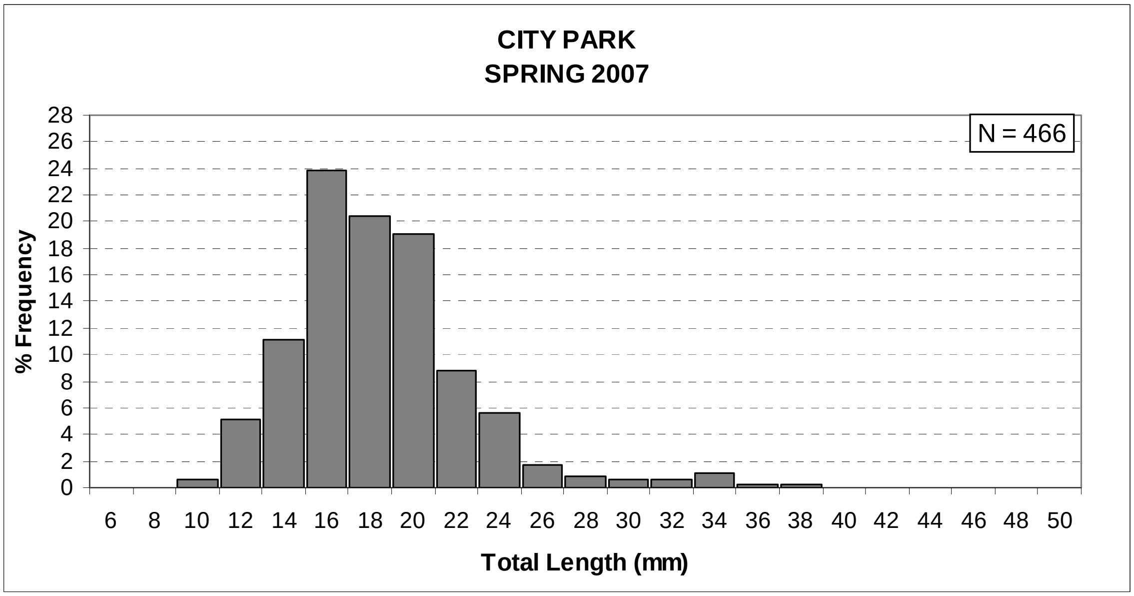


Figure 6. Length frequency distributions of fountain darters collected in each sample from the I-35 Reach in 2007.



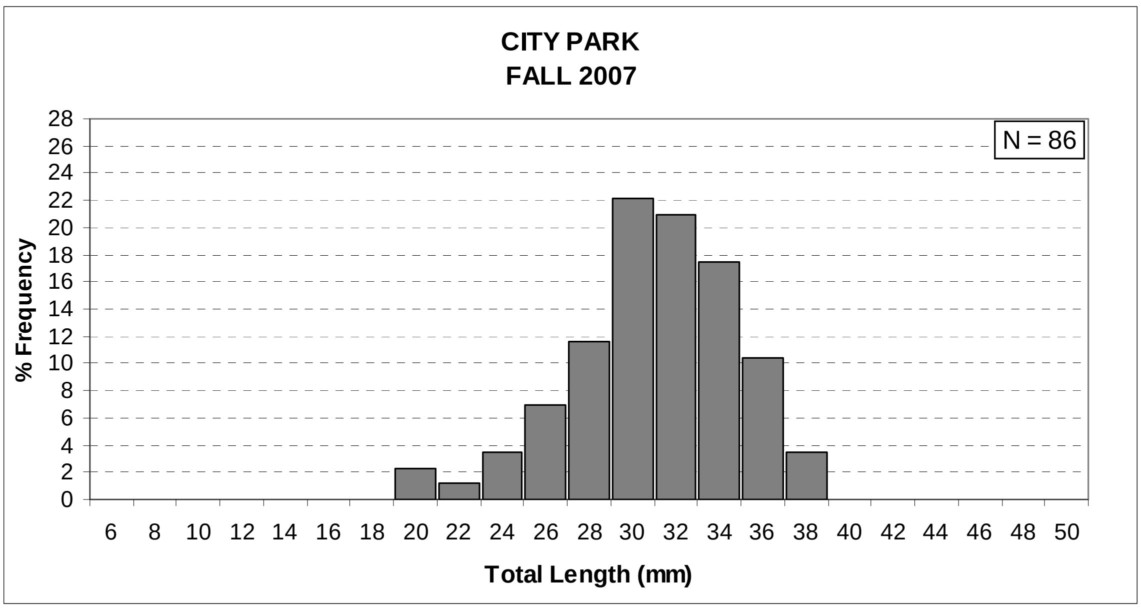


Figure 7. Length frequency distributions of fountain darters collected in each sample from the City Park Reach in 2007.

Estimates of fountain darter population abundance in the City Park and I-35 reaches were based on the changes in vegetation composition and abundance and the average density of fountain darters found in each vegetation type, as described in the methods section. Data from the Spring Lake Dam Reach were not included in these estimates because drop net sampling was not conducted there. There is less variation in the average density of fountain darters found among vegetation types in the San Marcos River when compared to the Comal River. Therefore, changes in vegetation coverage do not have dramatic impacts on fountain darter abundance, and population estimates are less variable between samples than in the Comal Springs/River ecosystem (Figure 8). As in the Comal River, high-flows usually result in decreased amounts of vegetation and thus, lower population estimates. Population estimates actually increased during low discharge conditions in 2006. Population estimates from 2007 were somewhat higher than those observed during the previous year, yet well within the variation observed over the course of the study. This could indicate clumping of fountain darters into high quality habitat under lower discharges, or could simply represent variation inherent in a random sampling design. Continued monitoring of fountain darter densities and vegetation coverage will allow further insight into any trends in the population.

In addition to fountain darters, there have been 20,068 fishes representing at least 27 other taxa collected by drop netting since 2001 (Table 7). Of these, 8 species are considered introduced or exotic to the San Marcos Springs/River ecosystem. The most abundant exotic or introduced species in the system include the rock bass (*Ambloplites rupestris*) and the sailfin molly (*Poecilia latipinna*). Another exotic species of particular concern is the suckermouth catfish (*Hypostomus sp.*). Although these fish are rarely captured in drop nets, based on visual observations they are extremely abundant in the system. This herbivorous species has the potential to drastically affect the vegetation community and thus impact fountain darter habitats and food supplies. The sheer number and varying sizes of suckermouth catfish that were removed by the U.S. Fish and Wildlife Service biologists during the reconstruction of Rio Vista Dam in 2006 (see picture below) is cause for concern and demonstrates the need for close future monitoring of this exotic species.

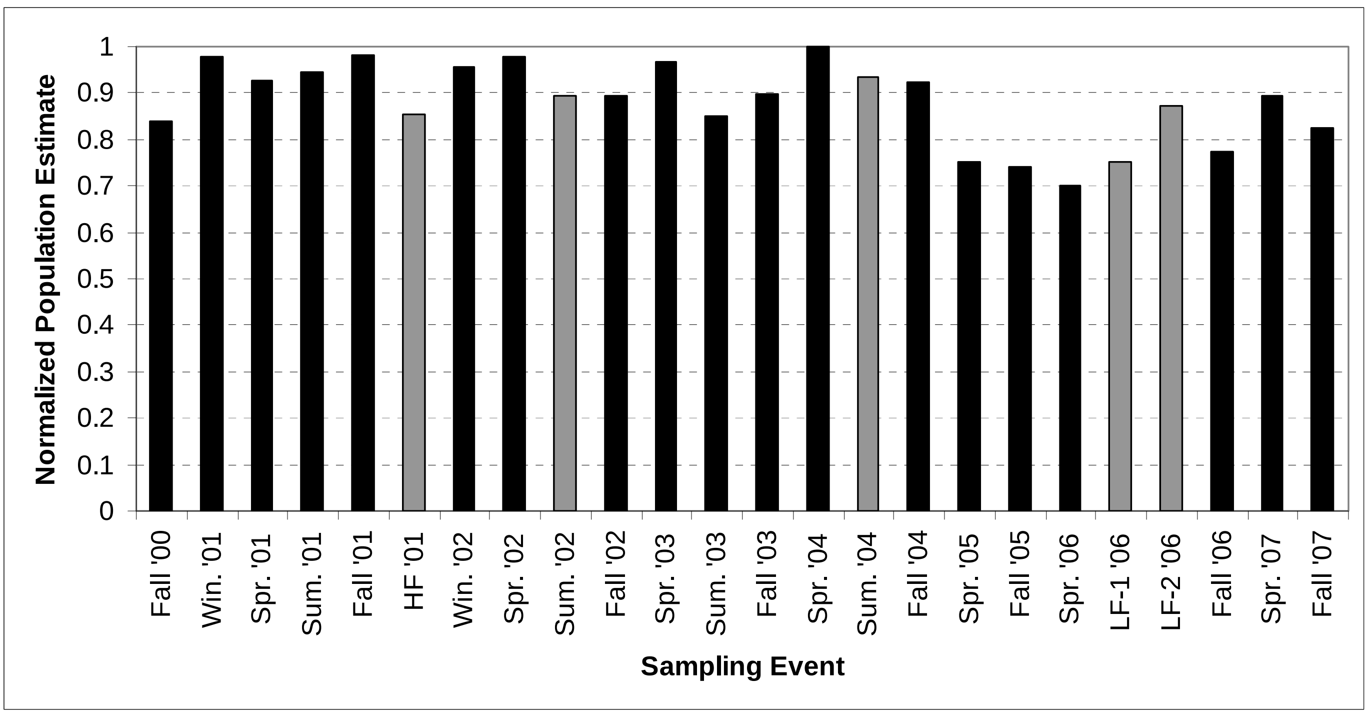


Figure 8. Population estimates of fountain darters in the City Park and I-35 reaches of the San Marcos River; values are normalized to a proportion of the maximum observed in any single sample. Light-colored bars represent Critical Period sampling events.

Table 7. Fish species and the number of each collected during drop-net sampling in the San Marcos Springs/River ecosystem.

COMMON NAME	SCIENTIFIC NAME	STATUS	NUMBER COLLECTED 2007	NUMBER COLLECTED 2001-2007
Rock bass	*Ambloplites rupestris*	Introduced	21	322
Black bullhead	*Ameiurus melas*	Native	0	2
Yellow bullhead	*Ameiurus natalis*	Native	7	71
Mexican tetra	*Astyanax mexicanus*	Introduced	4	18
Rio Grande cichlid	*Cichlasoma cyanoguttatum*	Introduced	5	39
Guadalupe roundnose minnow	*Dionda nigrotaeniata*	Native	13	39
Fountain darter	*Etheostoma fonticola*	Native	767	2376
Gambusia	*Gambusia sp.*	Native	1738	18413
Suckermouth catfish	*Hypostomus plecostomus*	Exotic	7	26
Redbreast sunfish	*Lepomis auritus*	Introduced	2	40
Green sunfish	*Lepomis cyanellus*	Native	0	5
Warmouth	*Lepomis gulosus*	Native	0	22
Bluegill	*Lepomis macrochirus*	Native	11	76
Longear sunfish	*Lepomis megalotis*	Native	0	3
Redspotted sunfish	*Lepomis miniatus*	Native	32	598
Sunfish	*Lepomis sp.*	Native/Introduced	16	126
Largemouth bass	*Micropterus salmoides*	Native	4	38
Gray redhorse	*Moxostoma congestum*	Native	0	3
Blacktail shiner	*Cyprinella venusta*	Native	0	6
Texas shiner	*Notropis amabilis*	Native	0	17
Ironcolor shiner	*Notropis chalybaeus*	Native	2	54
Unknown shiner	*Notropis sp.*	Native	0	4
Tadpole madtom	*Noturus gyrinus*	Native	0	4
Blue tilapia	*Oreochromis aurea*	Exotic	0	4
Texas logperch	*Percina carbonaria*	Native	0	2
Dusky darter	*Percina sciera*	Native	1	14
Sailfin molly	*Poecilia latipinna*	Introduced	0	92
Unknown molly	*Poecilia sp.*	Introduced	0	30

Among exotic species, the giant ramshorn snail also elicits concern because of its recent impacts (early 1990s) on aquatic vegetation in the Comal River. In the fall 2000 sample, 19 giant ramshorn snails were sampled in the San Marcos Springs/River ecosystem, but none were collected during 2001-2003. In 2004-2006, there were a total of 15 giant ramshorn snails collected in drop net sampling. No ramshorn snails were collected in 2007. Although data suggests that giant ramshorn snail numbers are extremely low, close monitoring should continue because of the impact that this exotic species can have on the vegetation community under heavier densities.

Suckermouth catfish captured in the San Marcos River near Rio Vista Dam. Photo courtesy of the U.S. Fish and Wildlife Service.

Dip Net Sampling

The boundary for each section where dip net collections were conducted is depicted on Figure 9. Section numbers are included to be consistent with the USFWS classification system for the San Marcos River. Data gathered from the Hotel Reach at Spring Lake are presented in Figure 10, and data from all other sections are graphically represented in Appendix B. The overall number of fountain darters collected in the Hotel Reach by dip nets is much greater than that found in the other two reaches. Filamentous algae present in this area provide the highest quality habitat found in the San Marcos Springs/River ecosystem. The majority of samples collected from the Hotel Reach during the study period contained individuals in the smallest size class (5-15mm). This size class represents fountain darters <58 days old (Brandt et al. 1993) and their presence in all seasons indicate year-round reproduction. However, at the City Park and I-35 reaches fountain darters in the smallest size class are usually only collected in the spring months, confirming the spring reproductive peak observed in drop net data from these locations.

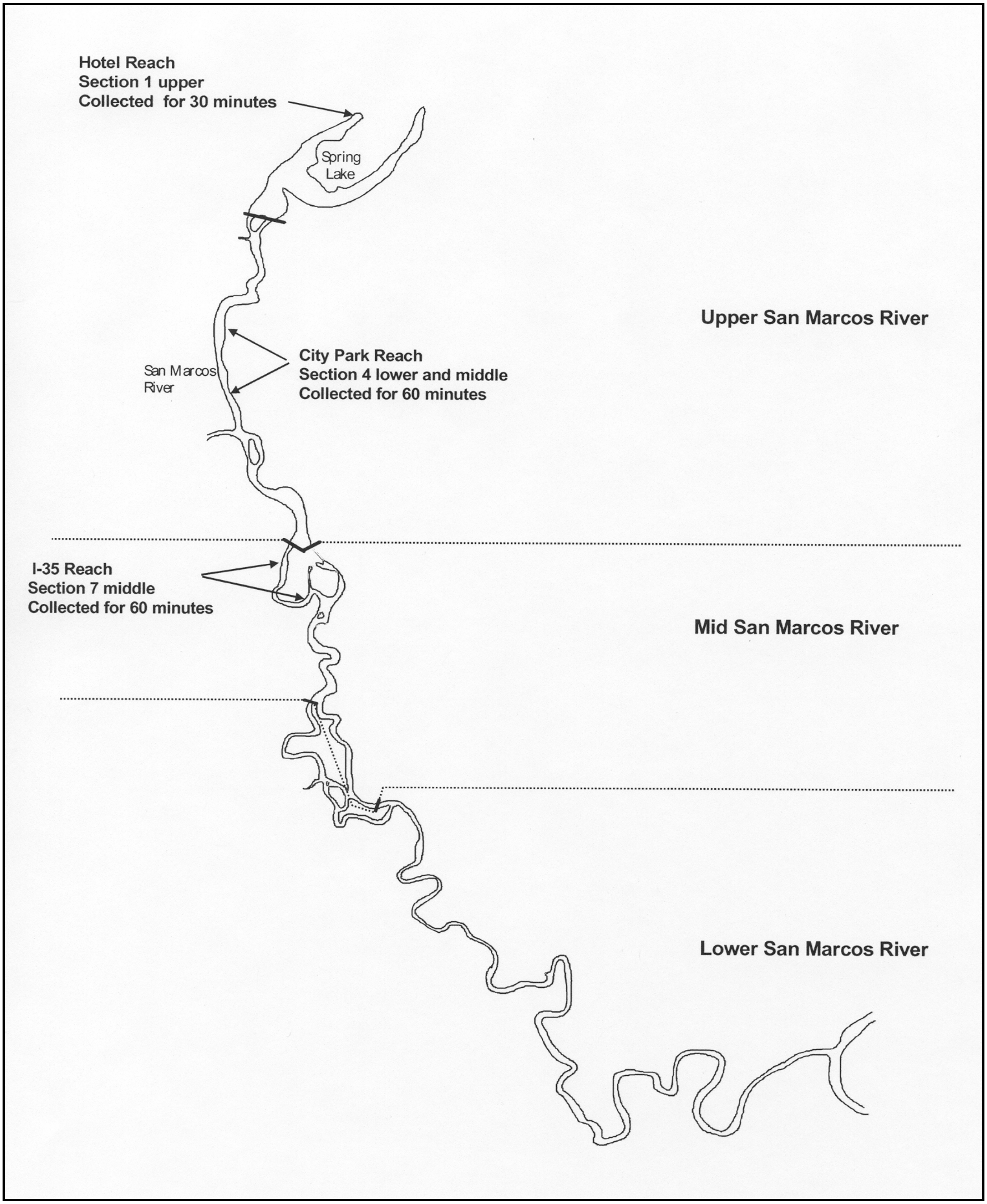


Figure 9. Map of the areas where fountain darters were collected with dip nets, measured, and released in the San Marcos River.

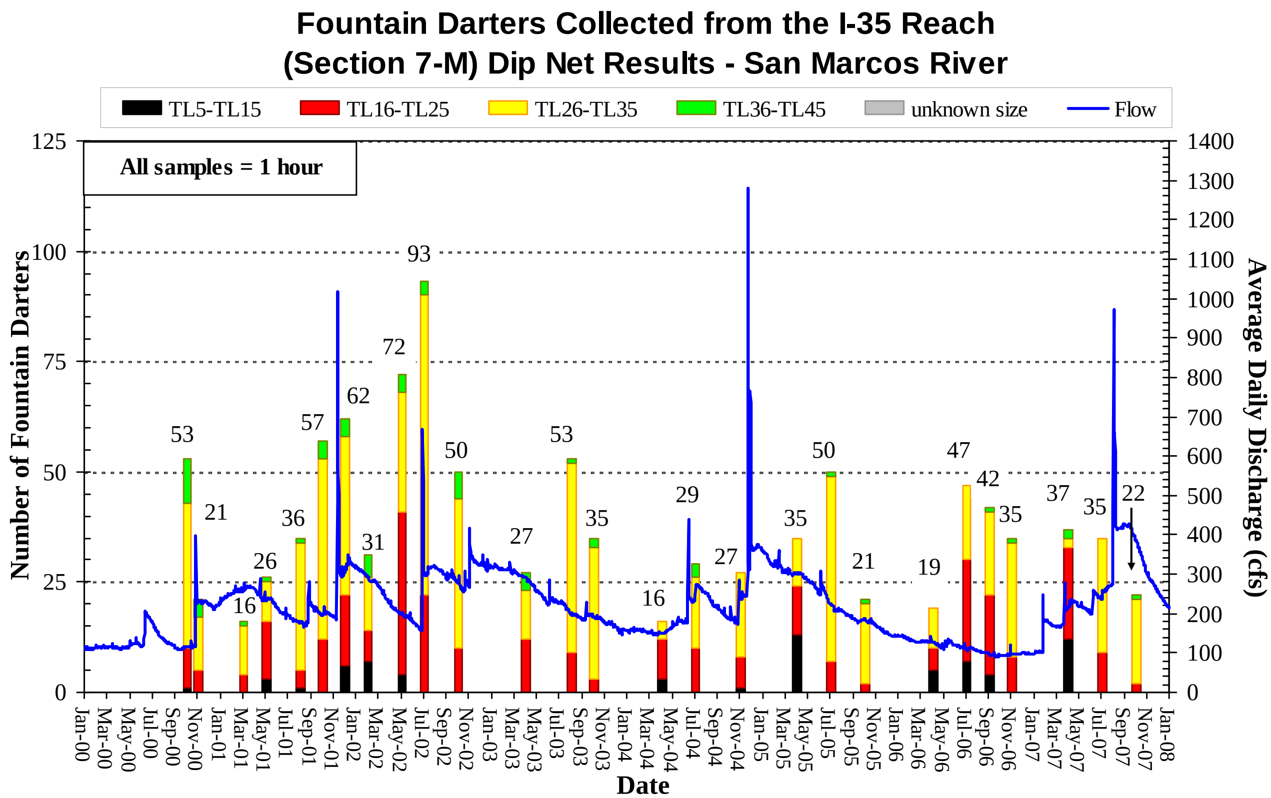


Figure 10. Number of fountain darters collected from the Hotel Reach (section 1 upper) of the San Marcos Springs/River ecosystem using dip nets.

Presence/Absence Dipnetting

The overall percentage of sites and percentage of dips in which fountain darters were present has varied little since initiation of this technique on the San Marcos River in spring 2006 (Figure 11). The percentage of sites (N = 50) containing darters has varied from 40-54% across six sample periods, and the percentage of dips (N = 4 @ each site = 50*4 = 200) containing darters has varied from 17-28%. These numbers are considerably lower than those from the Comal River, demonstrating the importance of high quality habitats such as those found in the upper Comal near Landa Lake.

Although this technique does not provide detailed data on habitat use, and does not allow for quantification of population estimates, it does provide a quick and less intrusive method of examining large-scale trends in the fountain darter population. Therefore, data collected thus far provide a good baseline for comparison in future critical period events.

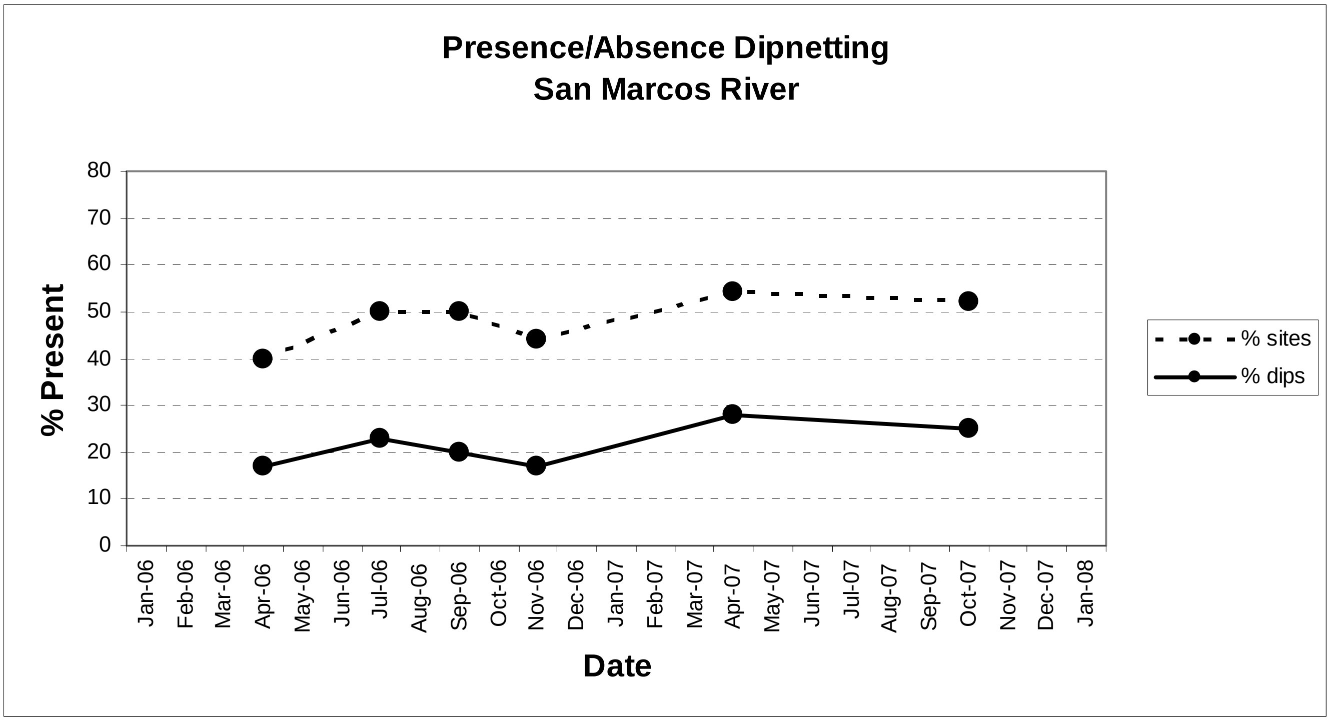


Figure 11. Percentage of sites (N = 50) and percentage of dips (N = 200) in which fountain darters were present during spring and fall 2006-2007.

San Marcos Salamander Visual Observations

As in previous years, filamentous algae covered sample sites 2 (Hotel Reach) and 14 with thick mats and coverage was relatively consistent throughout 2007. The abundance of algae potentially affected density estimates of San Marcos salamanders in these habitats because the area had to be cleared prior to sampling activities (i.e., disturbance may have startled salamanders and caused them to move). It is also possible that a significant portion of the San Marcos salamander population that would have been found under rocks was instead occupying the algae over top of the rocks during these times. Many salamanders were observed when clearing the area. In addition, the disturbance associated with cleaning the area may have alerted the San Marcos salamanders to the presence of the divers and impelled some individuals to retreat into deeper cavities within the rocks. Although this methodology reflects some uncertainty, it is consistent each year and allows valid comparisons among sites and seasons.

San Marcos salamander density estimates were lower on average at each sample area in 2007 than in 2006, with higher than average discharge conditions present in 2007 (Table 8). Salamander density at sample site 21 (below Spring Lake dam) showed a marked decrease between summer 2006 and spring 2007. Following this decline, an increase in salamander density was then measured between spring and fall 2007, and the second highest density since fall 2000 was recorded at area 21 (9.07 salamanders per m^2). Similarly, salamander numbers in sample areas 14 and 21 decreased from summer 2006 to spring 2007. However, salamander density remained constant at area 2 and continued to decline at area 14 between the spring and fall of 2007. All salamander densities measured in 2007 were within the variability observed over the past seven years.

Table 8. San Marcos salamander density per square meter (m^2) during the study period.

SAMPLING PERIOD	SAMPLE AREA 2	SAMPLE AREA 14	SAMPLE AREA 21
Fall 2000	19.4	3.4	5.2
Winter 2001	8.7	Omitted	2.6
Spring 2001	9.4	13.9	0.4
Summer 2001	16.6	11.1	1.5
Fall 2001	10.0	6.7	3.2
High-flow 2001	9.7	8.6	1.0
Winter 2002	6.1	6.5	0.9
Spring 2002	20.2	8.5	0.6
Summer/High Flow 2002	17.7	4.2	0.7
Fall 2002	16.8	8.7	3.0
Spring 2003	7.9	11.9	1.0
Summer 2003	20.1	6.8	2.0
Fall 2003	11.3	9.5	2.7
Spring 2004	14.6	9.9	7.1
Summer 2004	10.9	9.2	7.0
Fall 2004	11.7	13.7	4.5
Spring 2005	18.2	7.8	3.5
Fall 2005	11.6	12.6	12.1
Spring 2006	15.5	7.7	7.1
Critical Period 1 2006	17.4	8.4	7.9
Critical Period 2 2006	16.1	19.2	7.5
Spring 2007	8.99	13.68	2.82
Fall 2007	9.19	8.11	9.07

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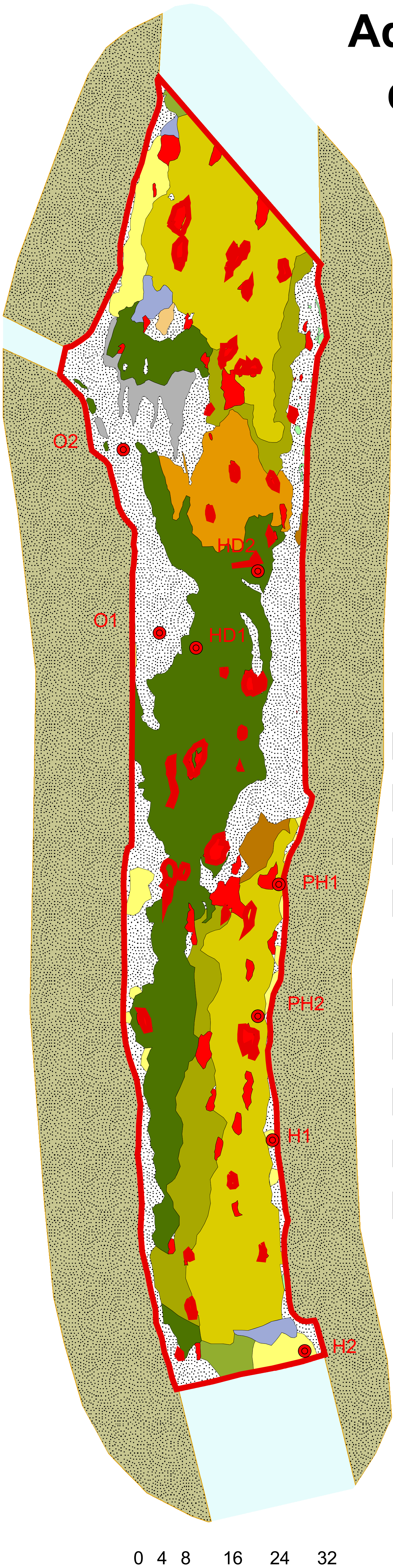
APPENDIX A:
AQUATIC VEGETATION MAPS

City Park Reach

San Marcos River Aquatic Vegetation

City Park - Spring

April 17, 2007

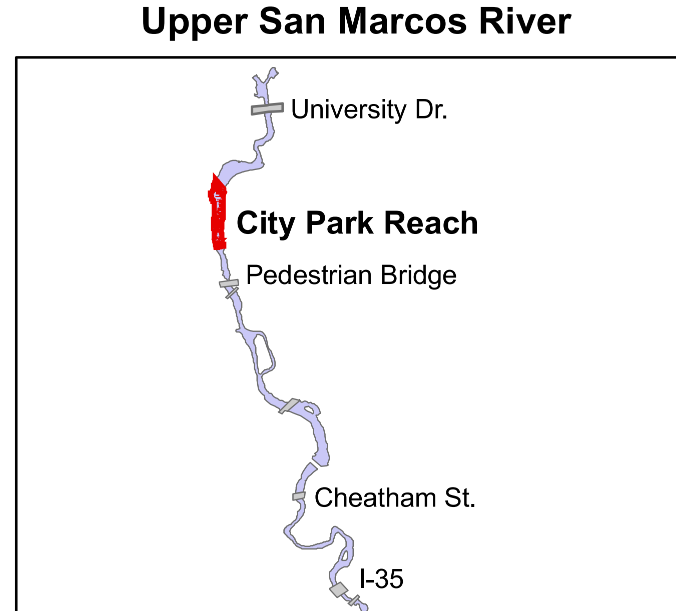


N

- Land
- Water
- Bare Substrate
- Study Area (4,616.3 m^2)
- Drop Net Sample Sites

	Total Area (m^2)
Algae	86.6
Algae / *Hydrilla*	1,498.5
Hydrilla / Potamogeton / Sagittaria	9.9
Hydrilla	11.4
Hygrophila	220.7
Potamogeton / Hydrilla	463.5
Potamogeton / Hydrilla / Algae	281.9
Potamogeton / Hygrophila	1,502.8
Potamogeton	51.2
Sagittaria / Hygrophila	62.0
Sagittaria	57.1
Zizania	238.6

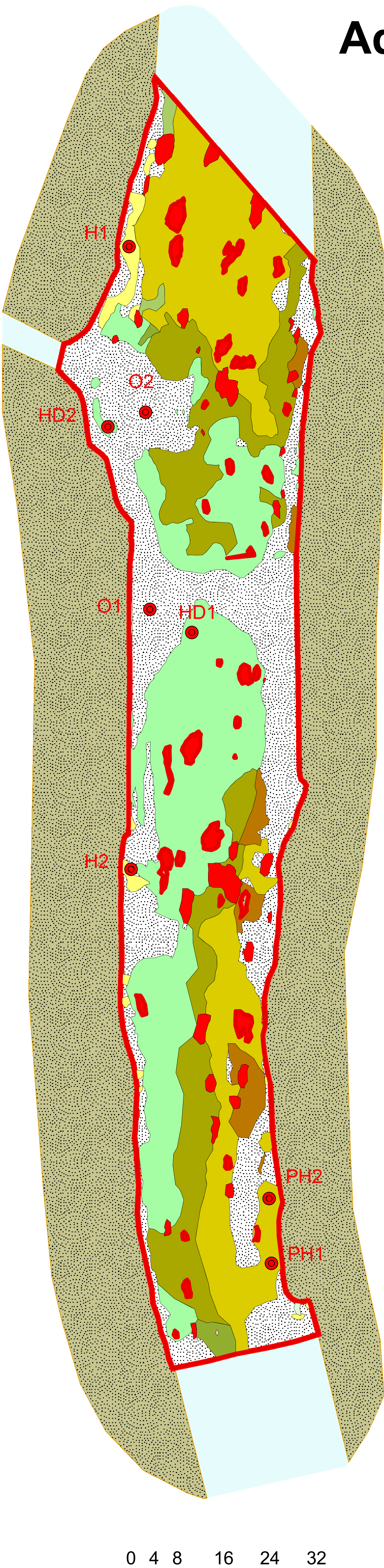
Upper San Marcos River



San Marcos River Aquatic Vegetation

City Park - Fall

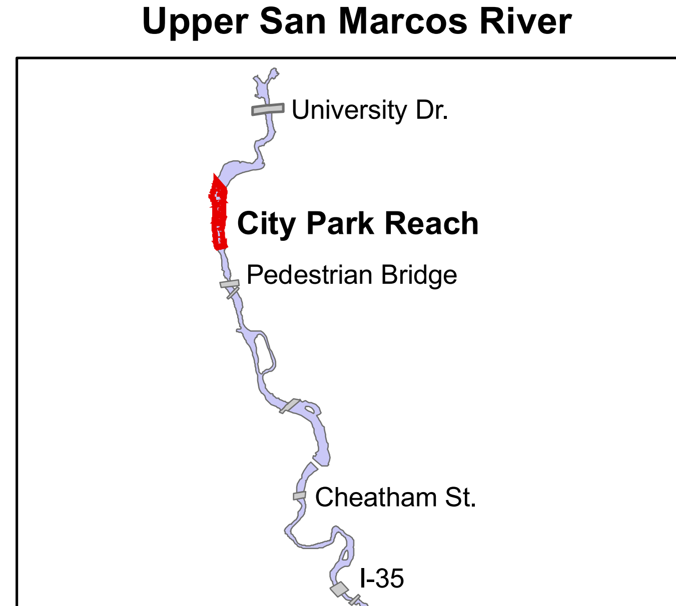
October 8, 2007



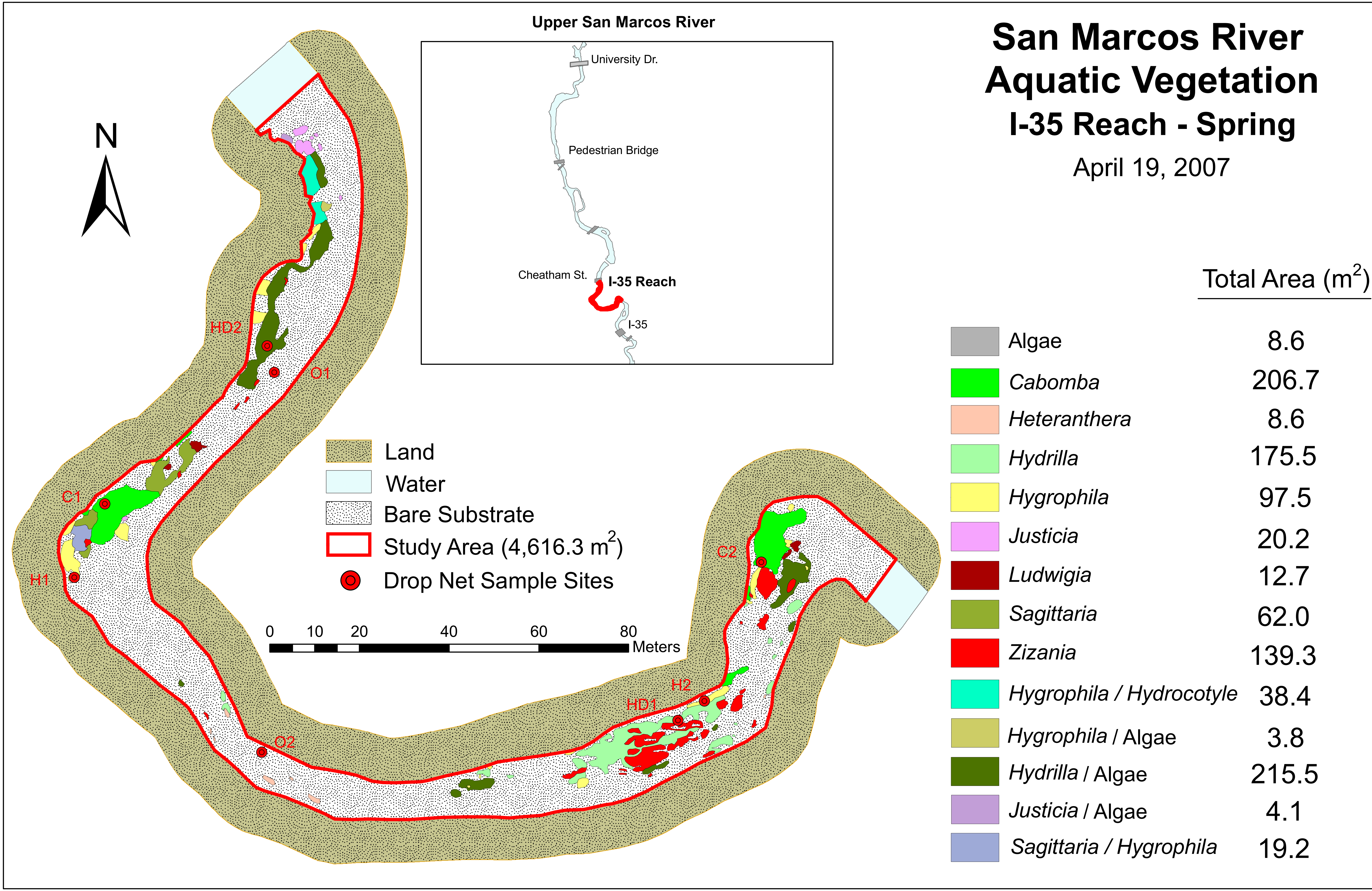
- Land
- Water
- Bare Substrate
- Study Area (4,616.3 m^2)
- Drop Net Sample Sites

	Total Area (m^2)
Hydrilla	1,520.5
Hygrophila	91.4
Potamogeton	145.5
Sagittaria	36.1
Vallisneria	2.1
Zizania	272.6
Heteranthera	0.3
Potamogeton / Hydrilla	836.3
Potamogeton / Hygrophila	1,240.0
Potamogeton / Hygrophila / Sagittaria	24.1

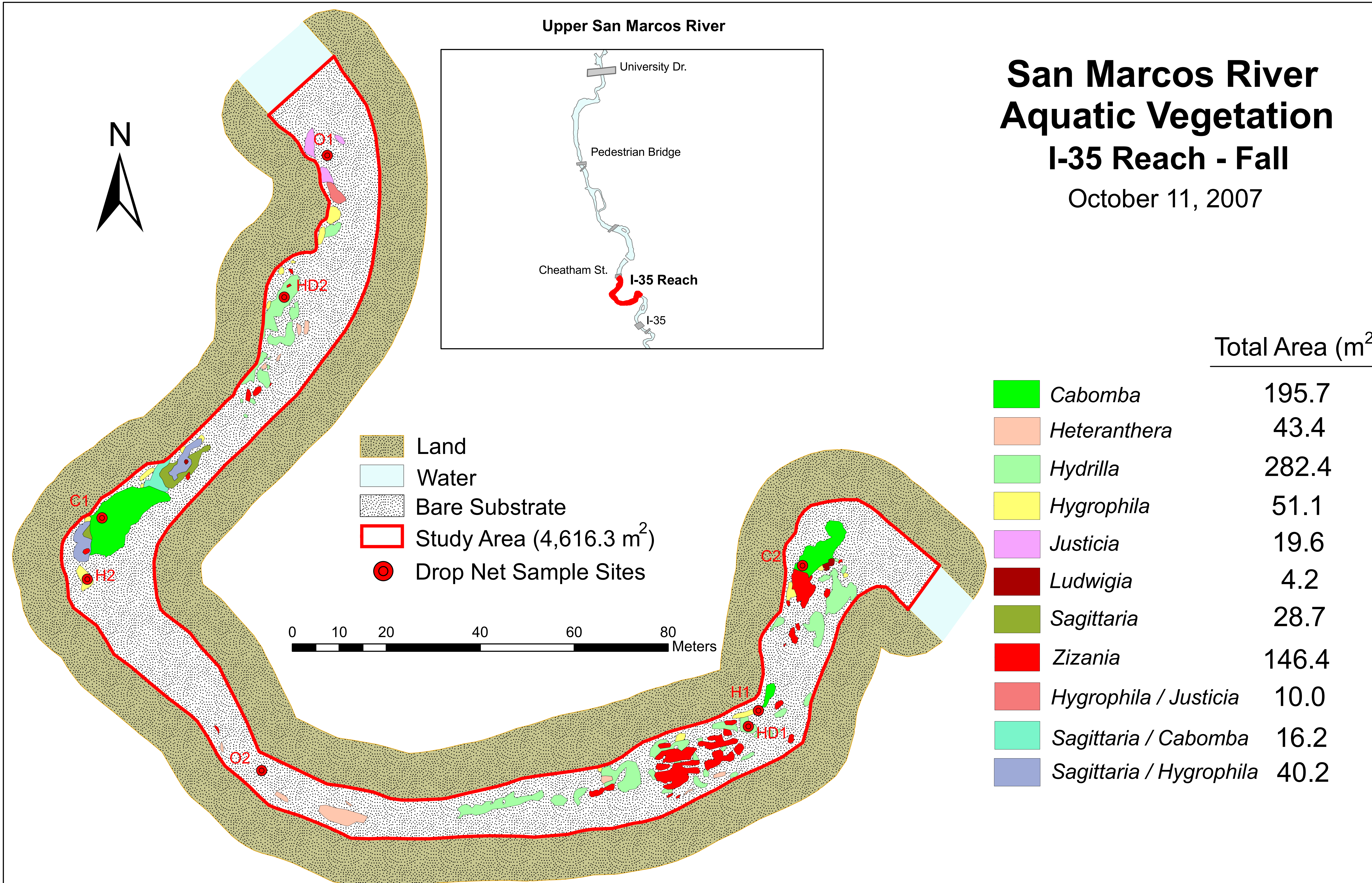
Upper San Marcos River



IH-35 Reach



San Marcos River
Aquatic Vegetation
I-35 Reach - Spring
April 19, 2007
Upper San Marcos River
University Dr.
Pedestrian Bridge
Cheatham St.
I-35 Reach
I-35
N
HD2
O1
C1
H1
C2
H2
HD1
O2
Land
Water
Bare Substrate
Study Area (4,616.3 m2)
Drop Net Sample Sites
0
10
20
40
60
80
Meters
Total Area (m2)
Algae 8.6
Cabomba 206.7
Heteranthera 8.6
Hydrilla 175.5
Hygrophila 97.5
Justicia 20.2
Ludwigia 12.7
Sagittaria 62.0
Zizania 139.3
Hygrophila / Hydrocotyle 38.4
Hygrophila / Algae 3.8
Hydrilla / Algae 215.5
Justicia / Algae 4.1
Sagittaria / Hygrophila 19.2

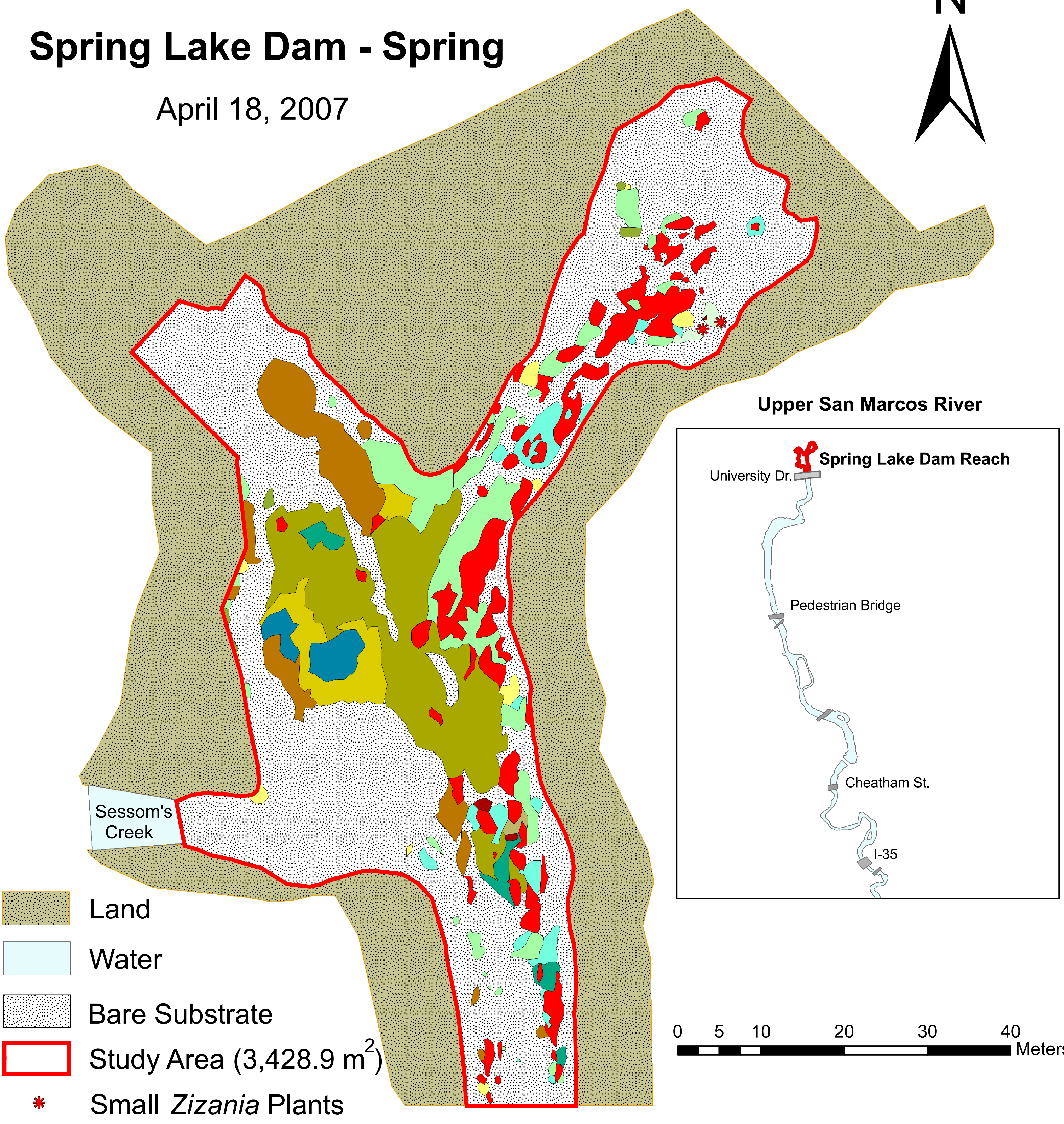

San Marcos River
Aquatic Vegetation
I-35 Reach - Fall
October 11, 2007
Upper San Marcos River
University Dr.
Pedestrian Bridge
Cheatham St.
I-35 Reach
I-35
N
Land
Water
Bare Substrate
Study Area (4,616.3 m2)
Drop Net Sample Sites
0 10 20 40 60 80 Meters
O1
HD2
C1
H2
O2
C2
H1
HD1
Total Area (m2)
Cabomba 195.7
Heteranthera 43.4
Hydrilla 282.4
Hygrophila 51.1
Justicia 19.6
Ludwigia 4.2
Sagittaria 28.7
Zizania 146.4
Hygrophila / Justicia 10.0
Sagittaria / Cabomba 16.2
Sagittaria / Hygrophila 40.2

Spring Lake Dam Reach

San Marcos River Aquatic Vegetation

Spring Lake Dam - Spring

April 18, 2007



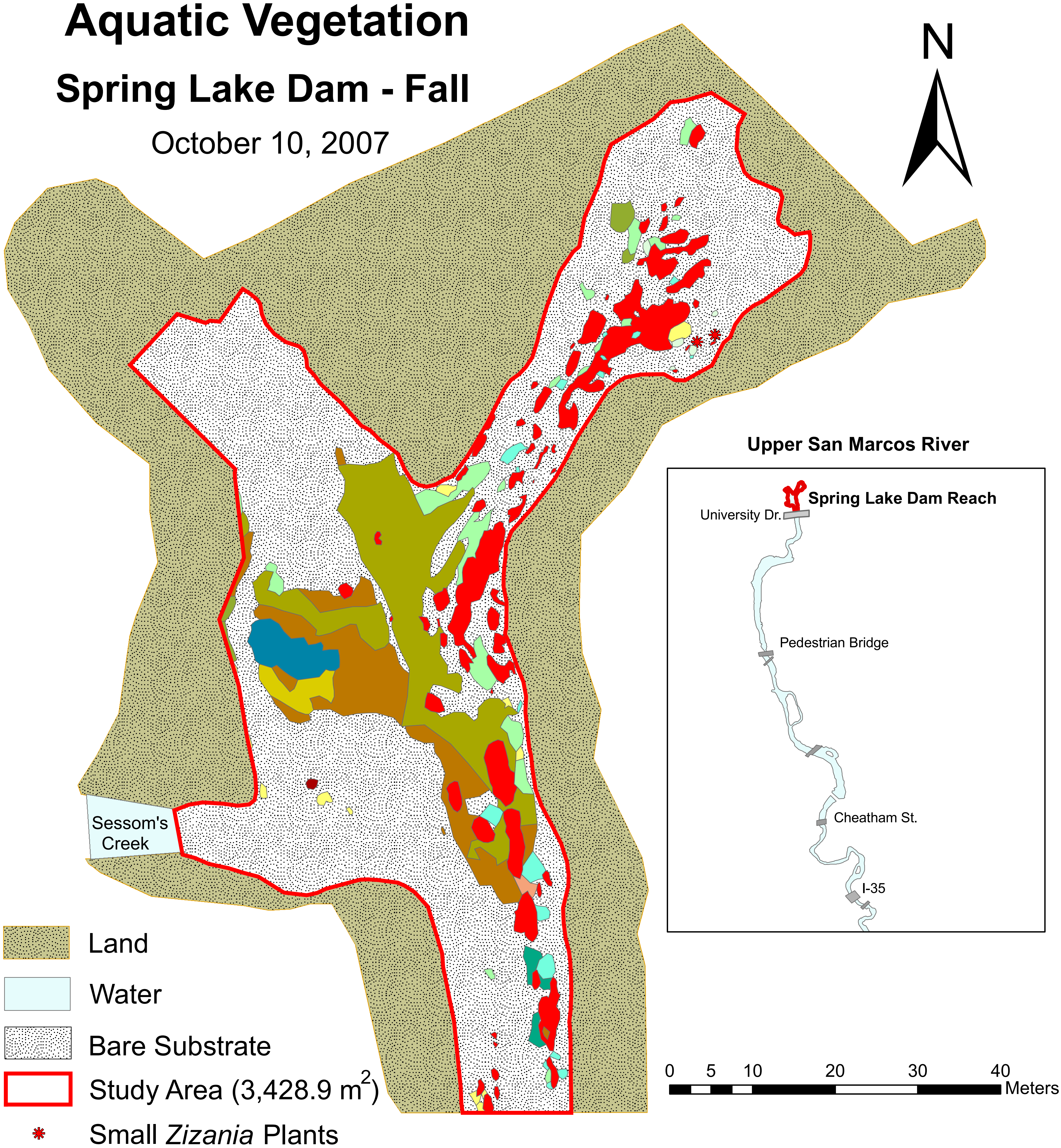
	Total Area (m^2)
Hydrilla	227.9
Hydrocotyle	71.7
Hygrophila	25.0
Ludwigia	3.74
Potamogeton	174.4
Sagittaria	8.5
Zizania	283.2

	Total Area (m^2)
Vallisneria	8.1
Hydrilla / Hydrocotyle	4.2
Potamogeton / Hydrilla	410.7
Potamogeton / Hydrocotyle	32.6
Potamogeton / Hygrophila	90.3
Potamogeton / Vallisneria	44.1

San Marcos River Aquatic Vegetation

Spring Lake Dam - Fall

October 10, 2007



	Total Area (m^2)
Hydrilla	80.0
Hydrocotyle	29.6
Hygrophila	16.6
Ludwigia	1.4
Potamogeton	209.1
Sagittaria	17.2

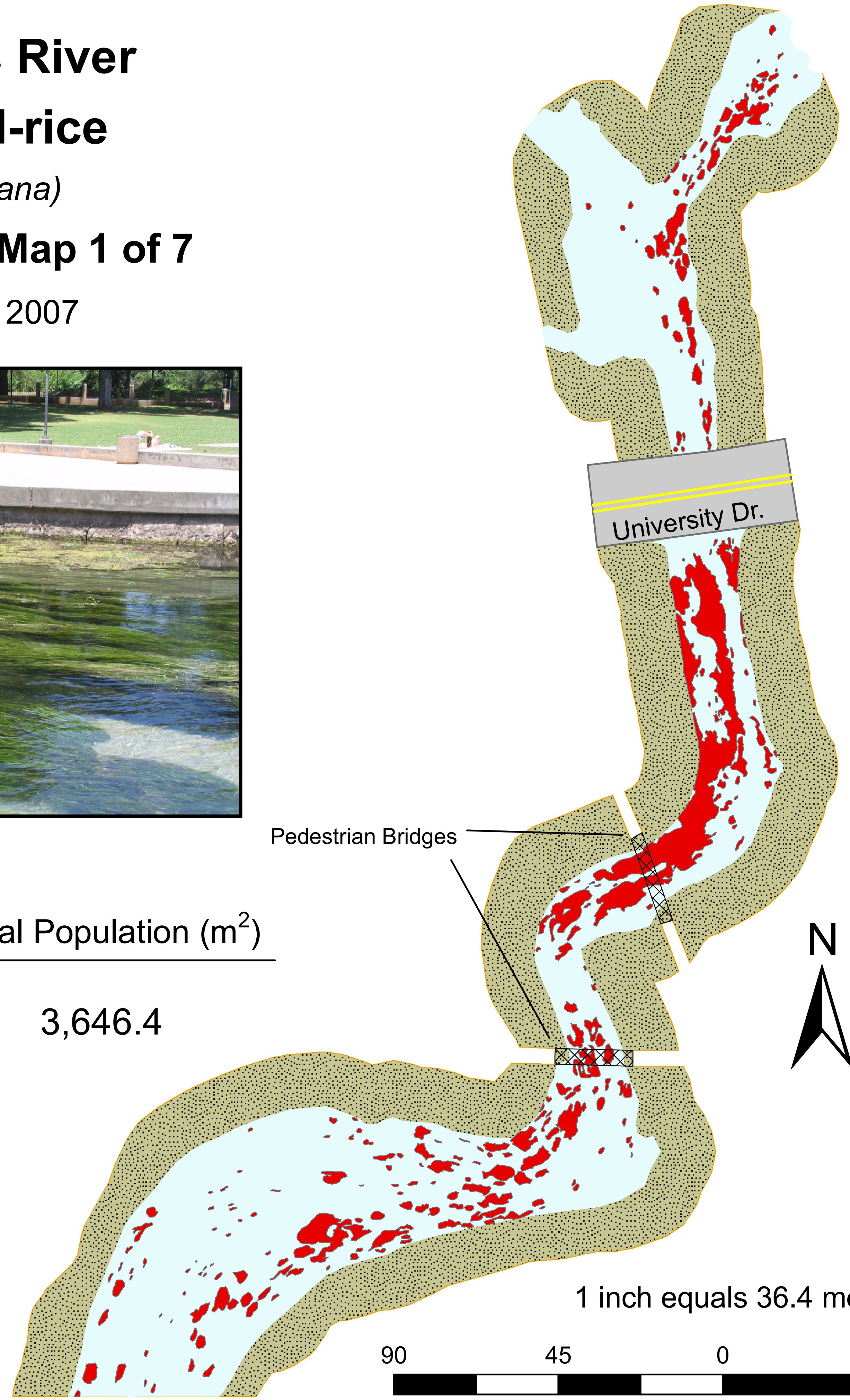
	Total Area (m^2)
Vallisneria	4.0
Zizania	298.4
Hydrilla / Hydrocotyle	3.9
Potamogeton / Hydrilla	351.1
Potamogeton / Hydrocotyle	15.7
Potamogeton / Hygrophila	27.2
Potamogeton / Vallisneria	47.2

Texas Wild-Rice

San Marcos River
Texas wild-rice
(Zizania texana)

Summer 2007 - Map 1 of 7

August 1 - 8, 2007

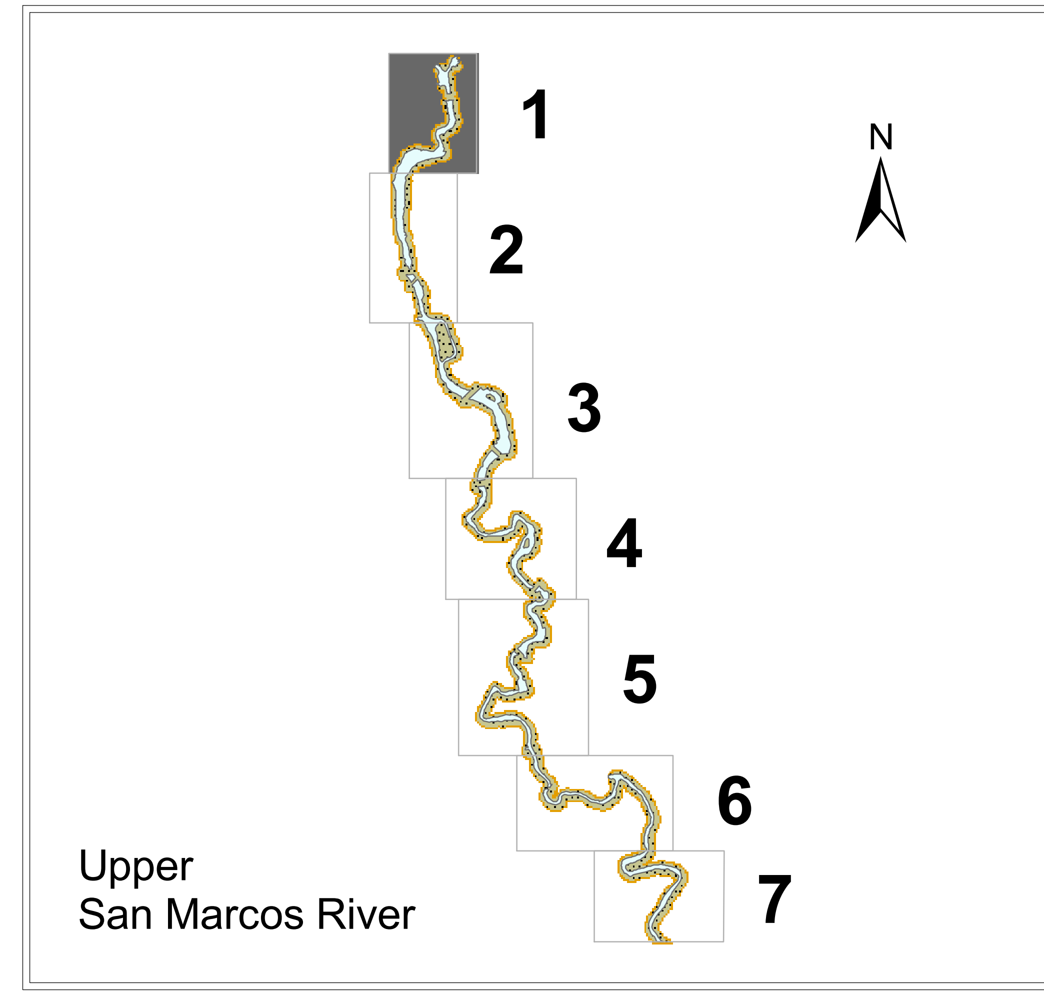


	Map 1 (m^2)	Total Population (m^2)
Zizania	2,222.9	3,646.4

1 inch equals 36.4 meters

90 45 0 90 Meters

Project Location



BIO-WEST, Inc.

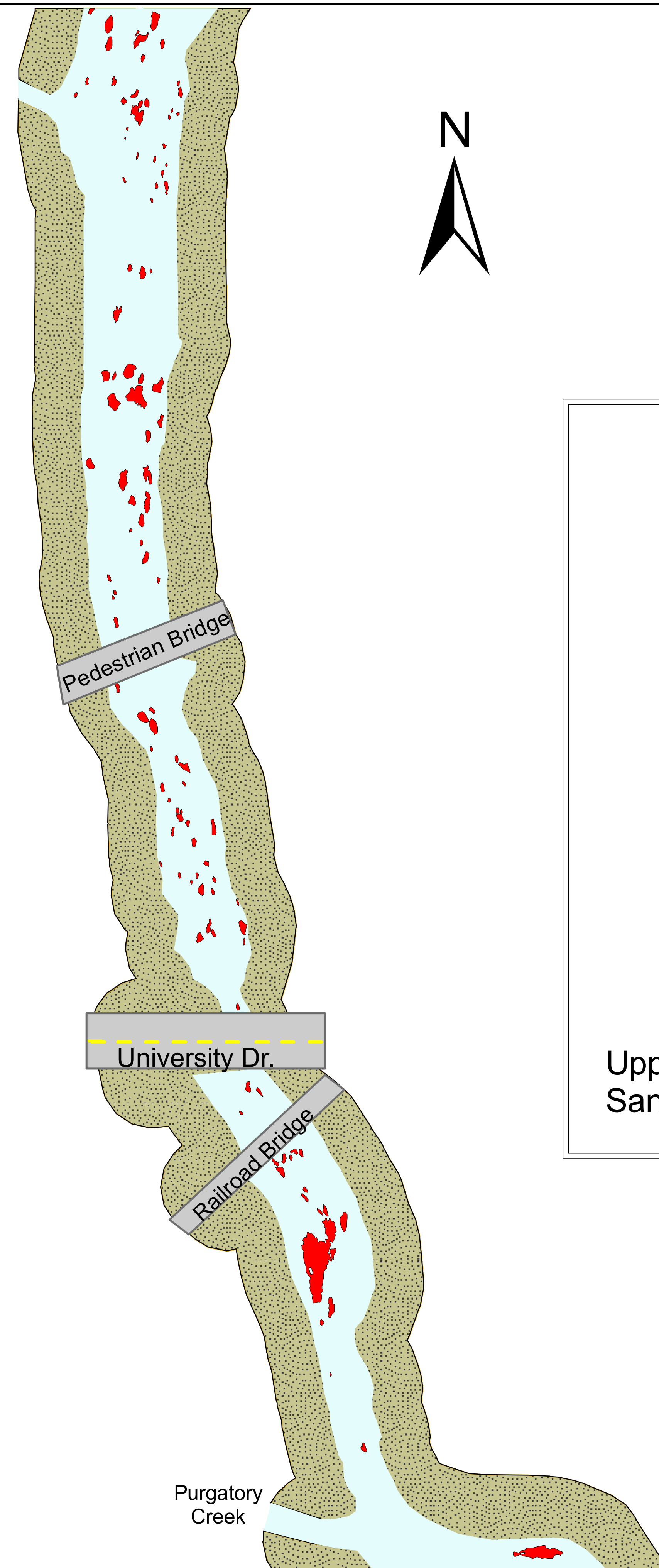
EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2007 - Map 2 of 7
August 1 - 8, 2007

		Map 2 (m^2)	Total Population (m^2)
(red)	*Zizania*	573.5	3,646.4

1 inch equals 45.8 meters

120 60 0 120 Meters



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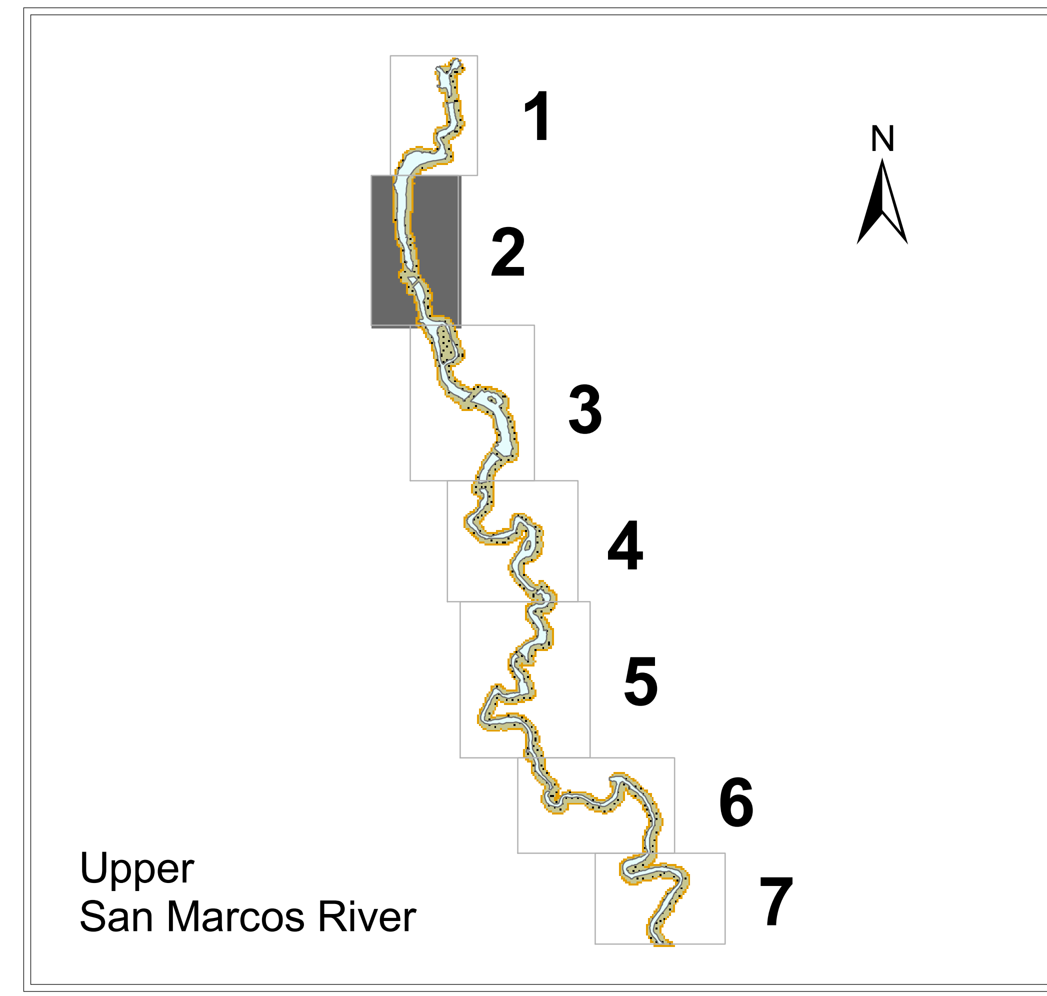
Project Location



BIO-WEST, Inc.

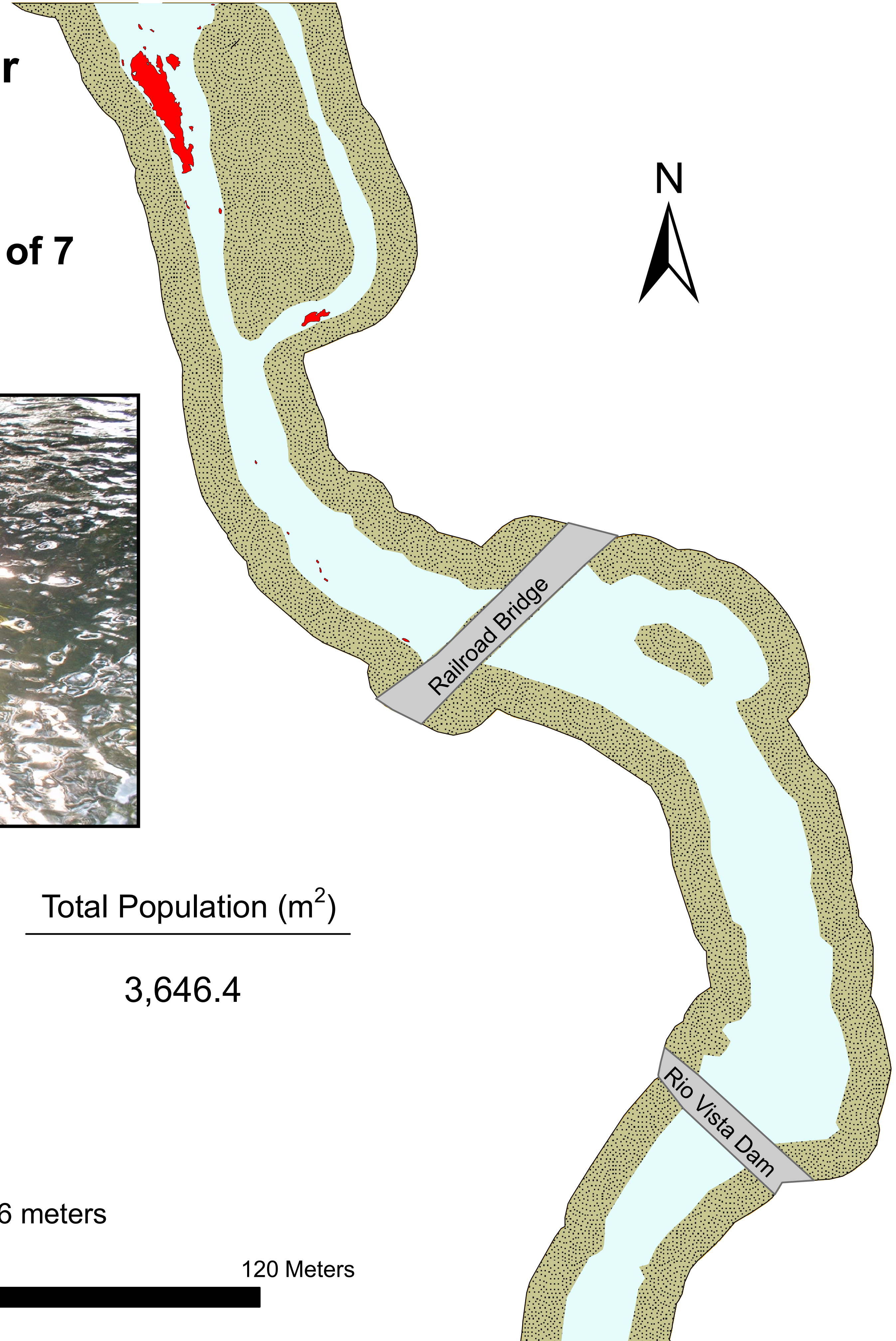
EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2007 - Map 3 of 7
August 1 - 8, 2007

	Map 3 (m^2)	Total Population (m^2)
Zizania	396.6	3,646.4

1 inch equals 47.6 meters

120 60 0 120 Meters



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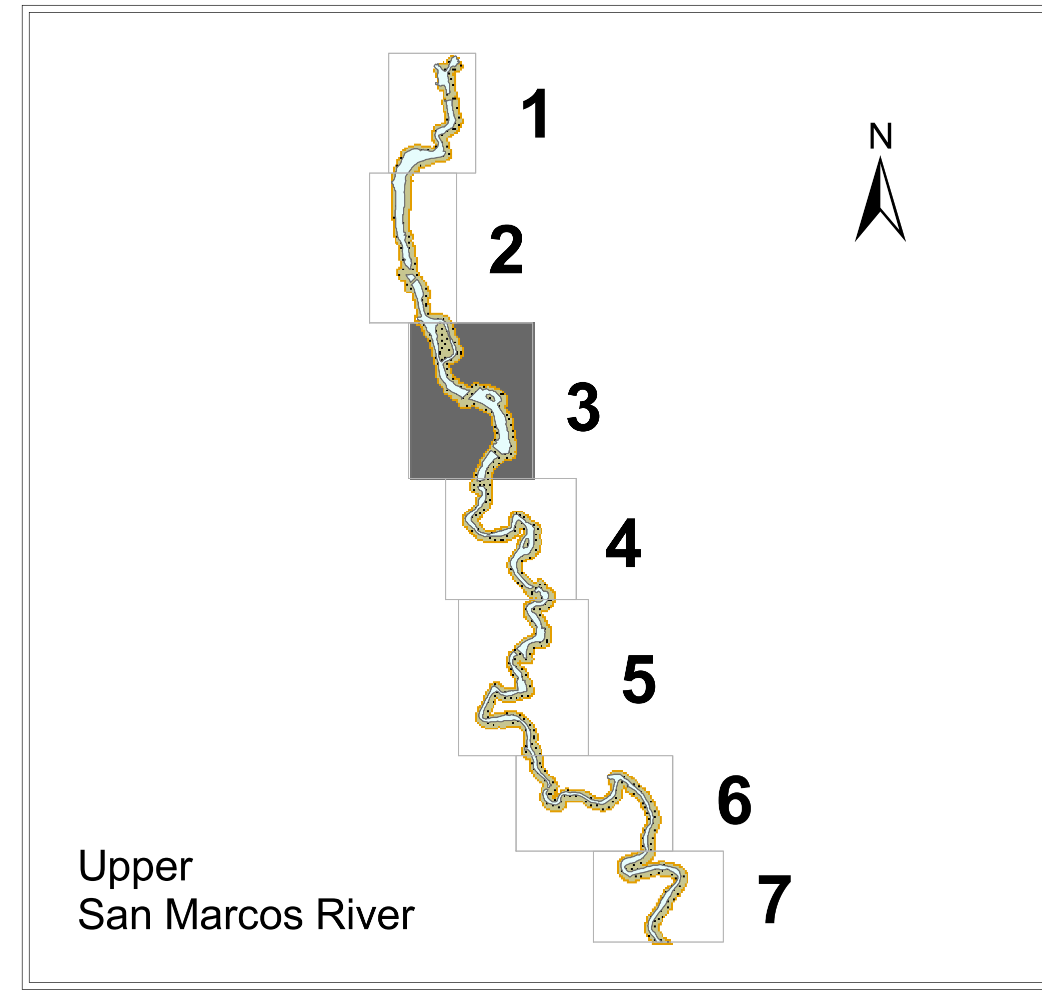


BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

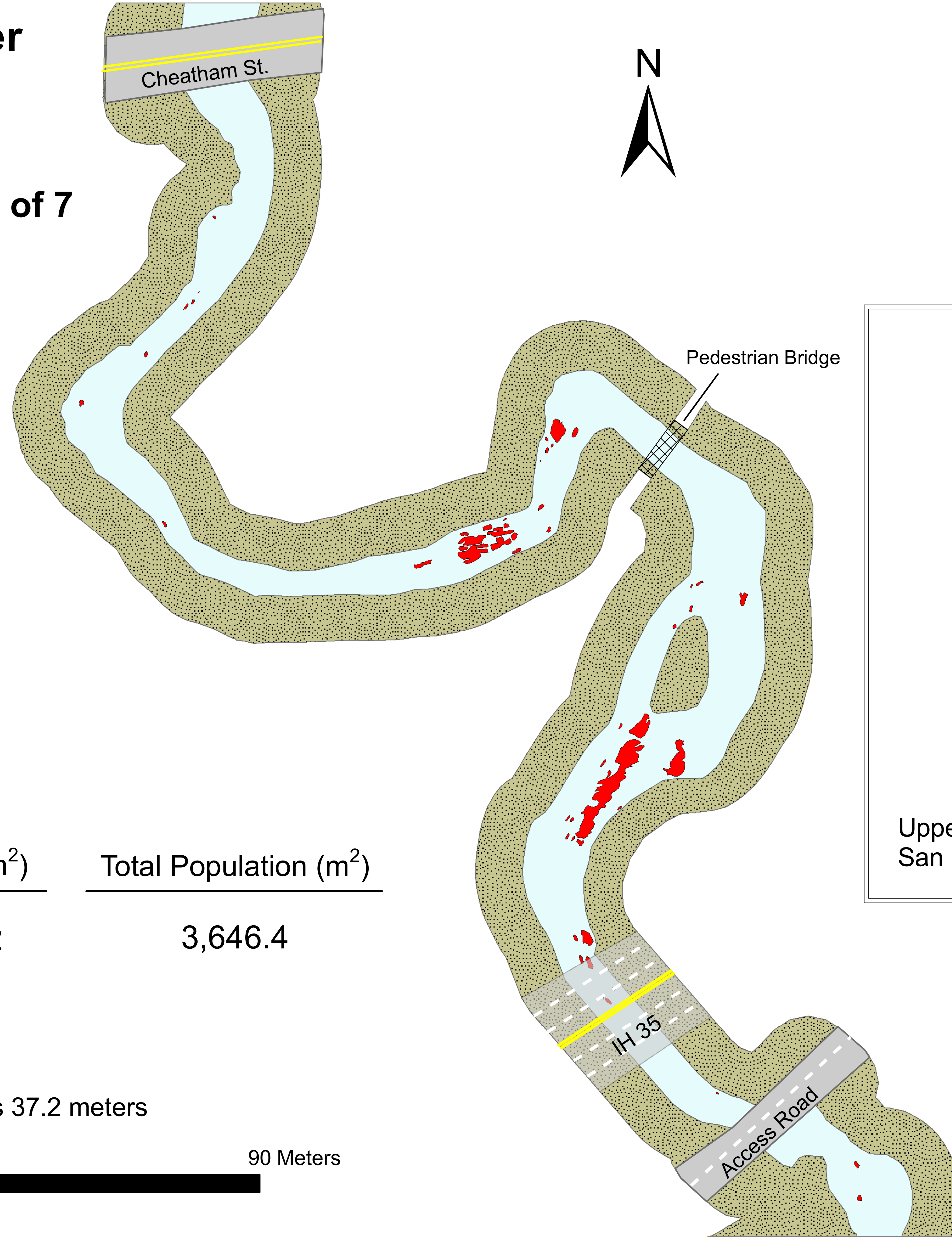
San Marcos River

Texas wild-rice

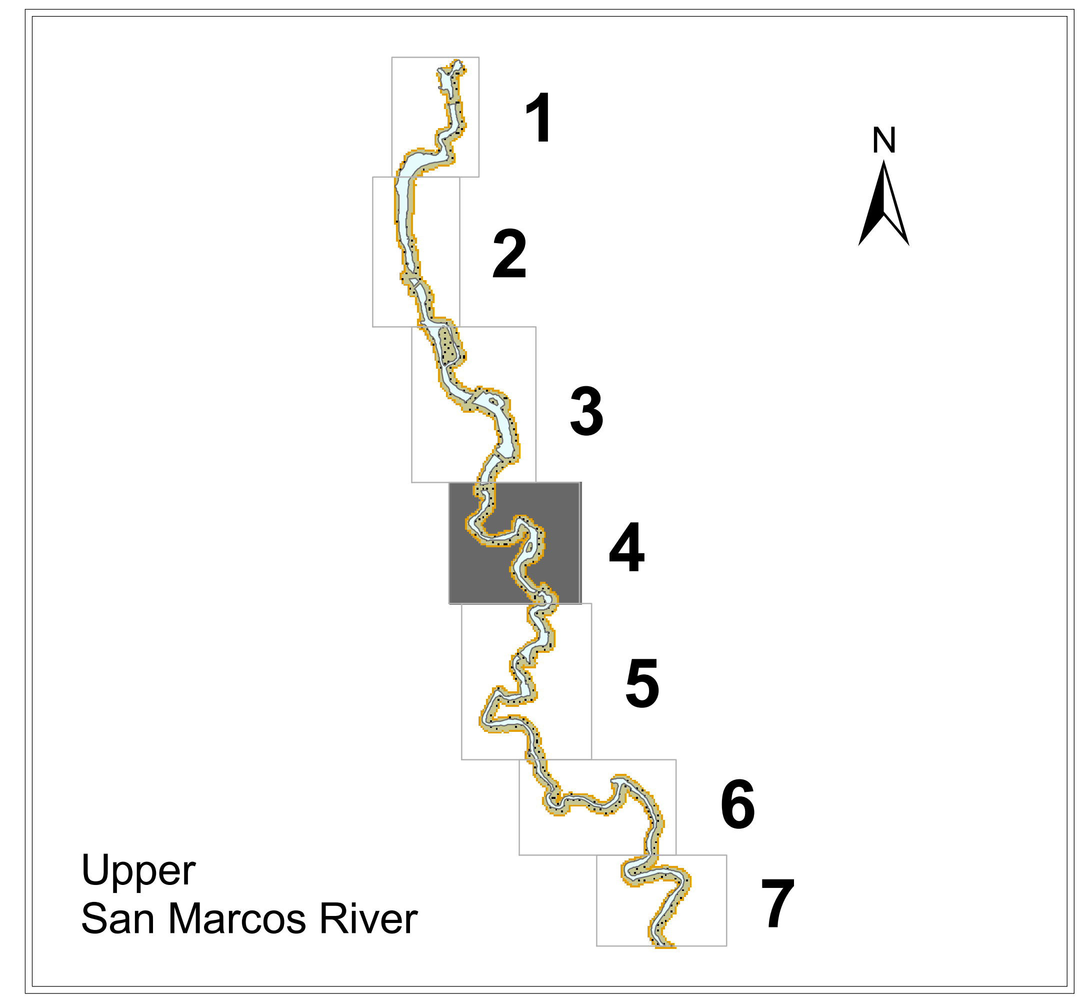
(Zizania texana)

Summer 2007 - Map 4 of 7

August 1 - 8, 2007



Project Location



	Map 4 (m^2)	Total Population (m^2)
Zizania	404.2	3,646.4

1 inch equals 37.2 meters

90 45 0 90 Meters

BIO-WEST, Inc.

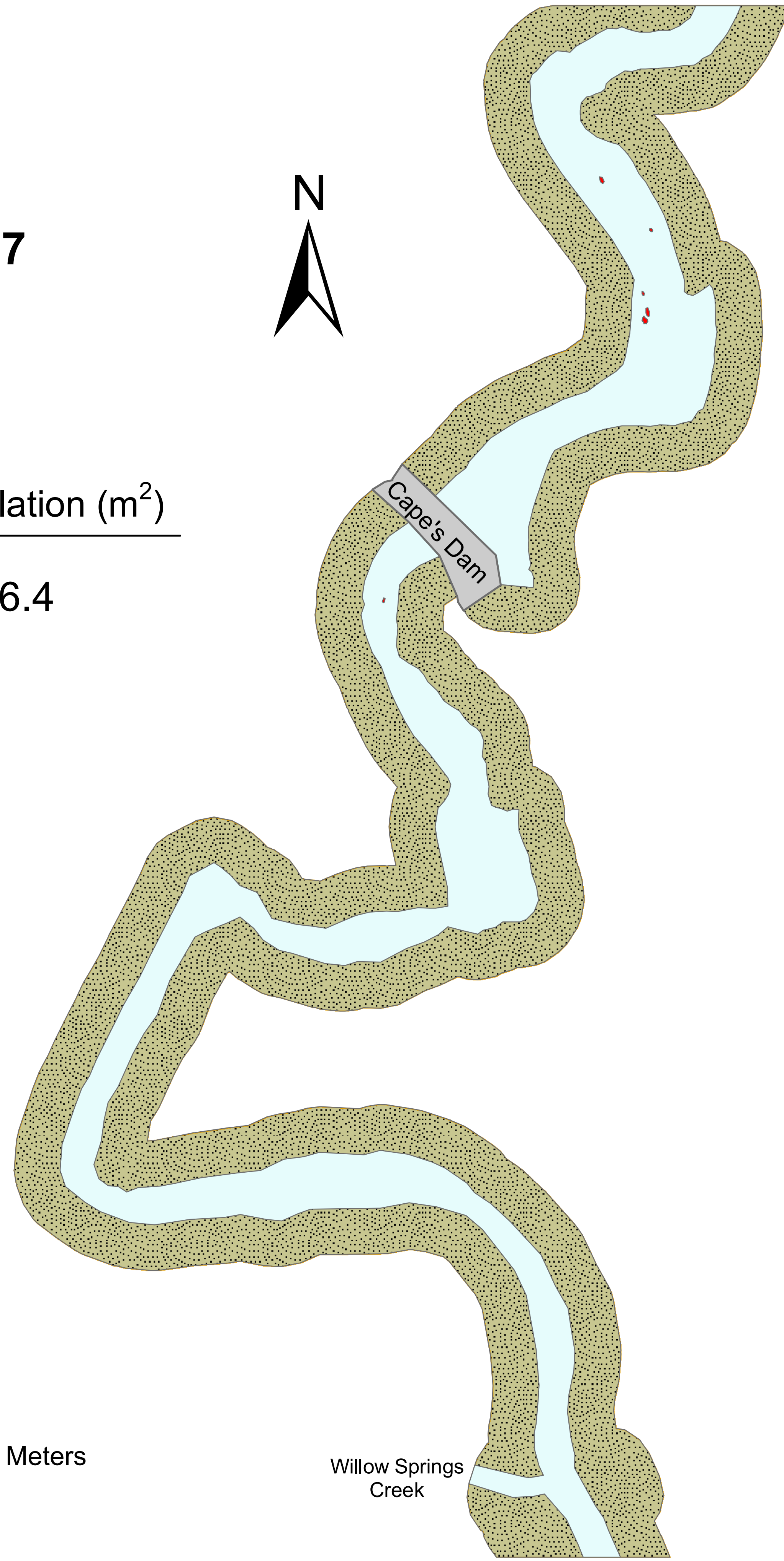
EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2007 - Map 5 of 7
August 1 - 8, 2007

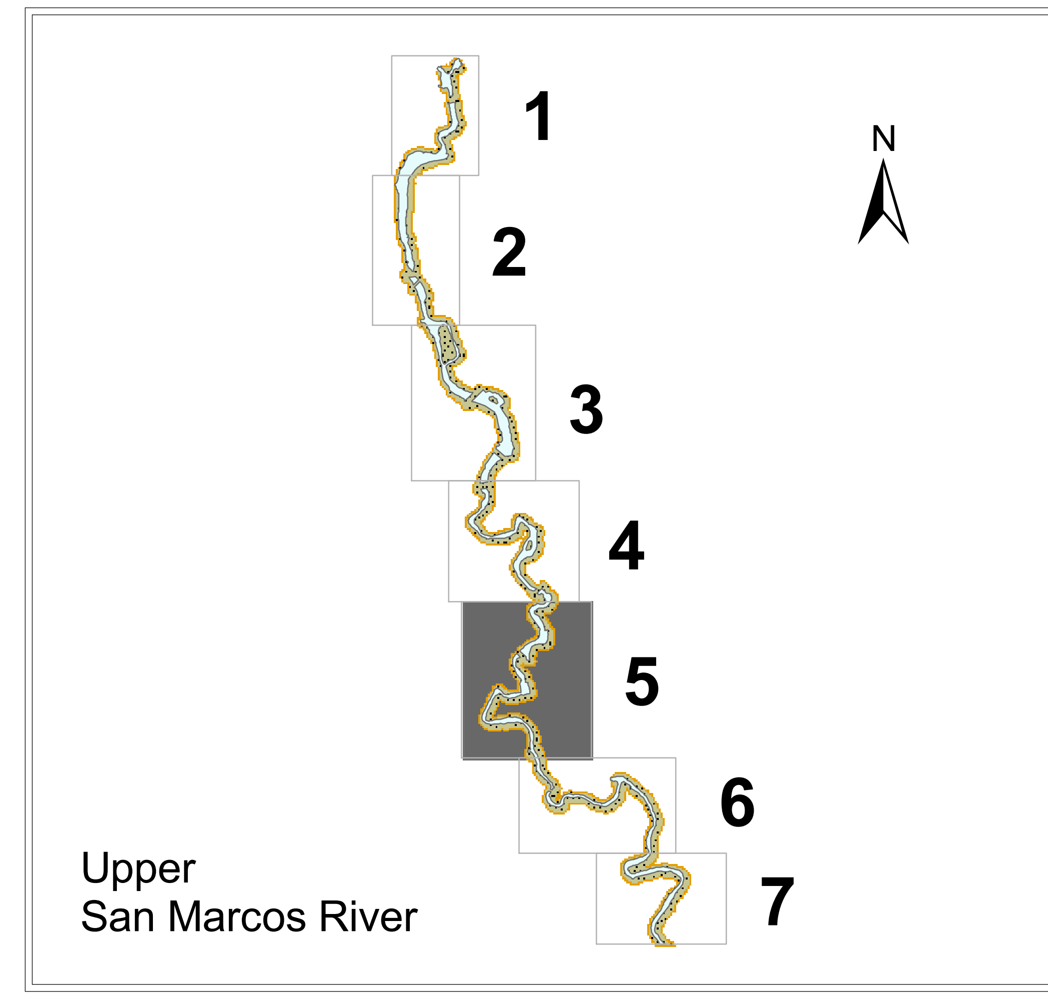
	Map 5 (m^2)	Total Population (m^2)
Zizania	10.1	3,646.4

1 inch equals 48.1 meters

120 60 0 120 Meters



Project Location



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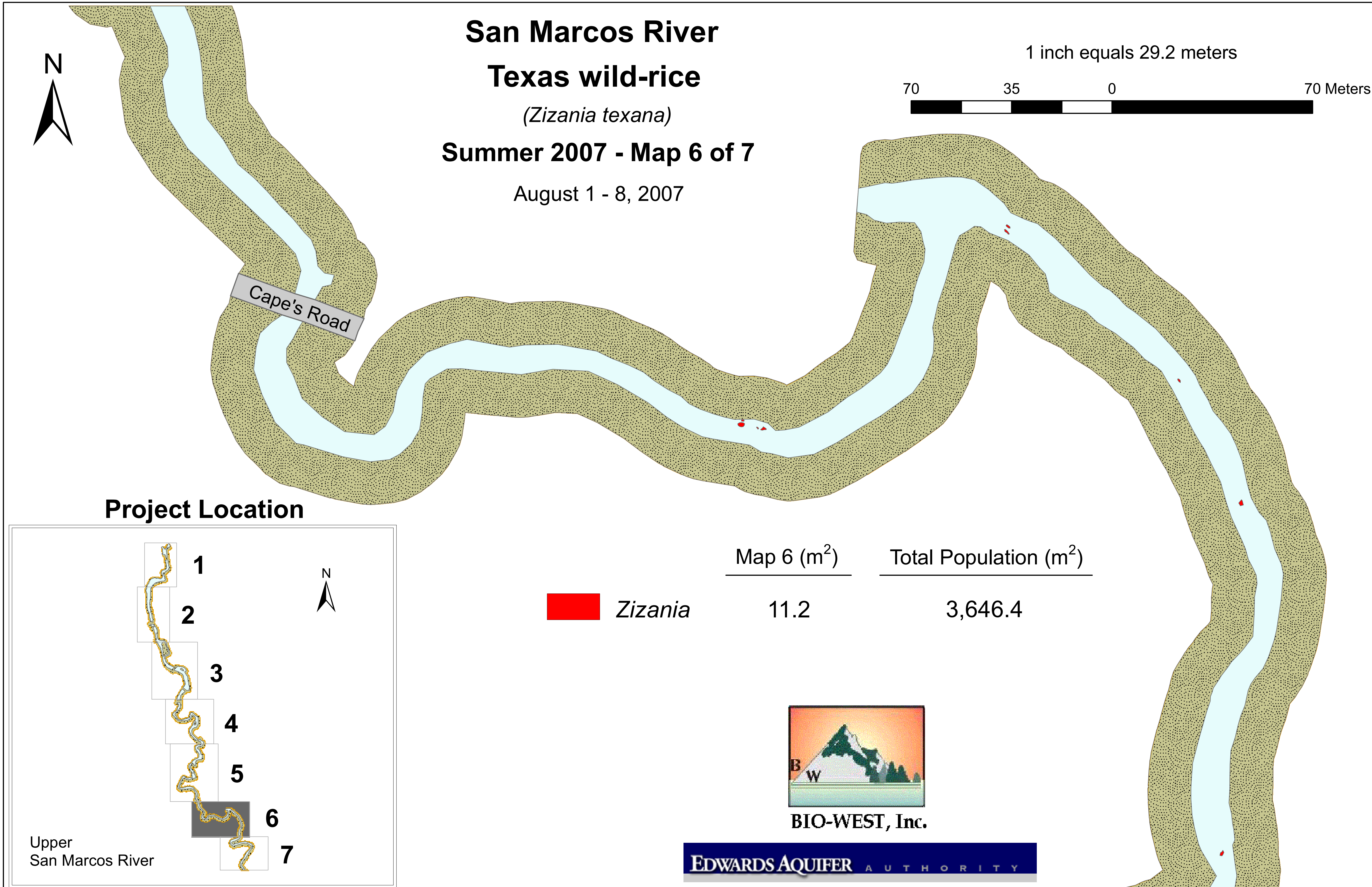
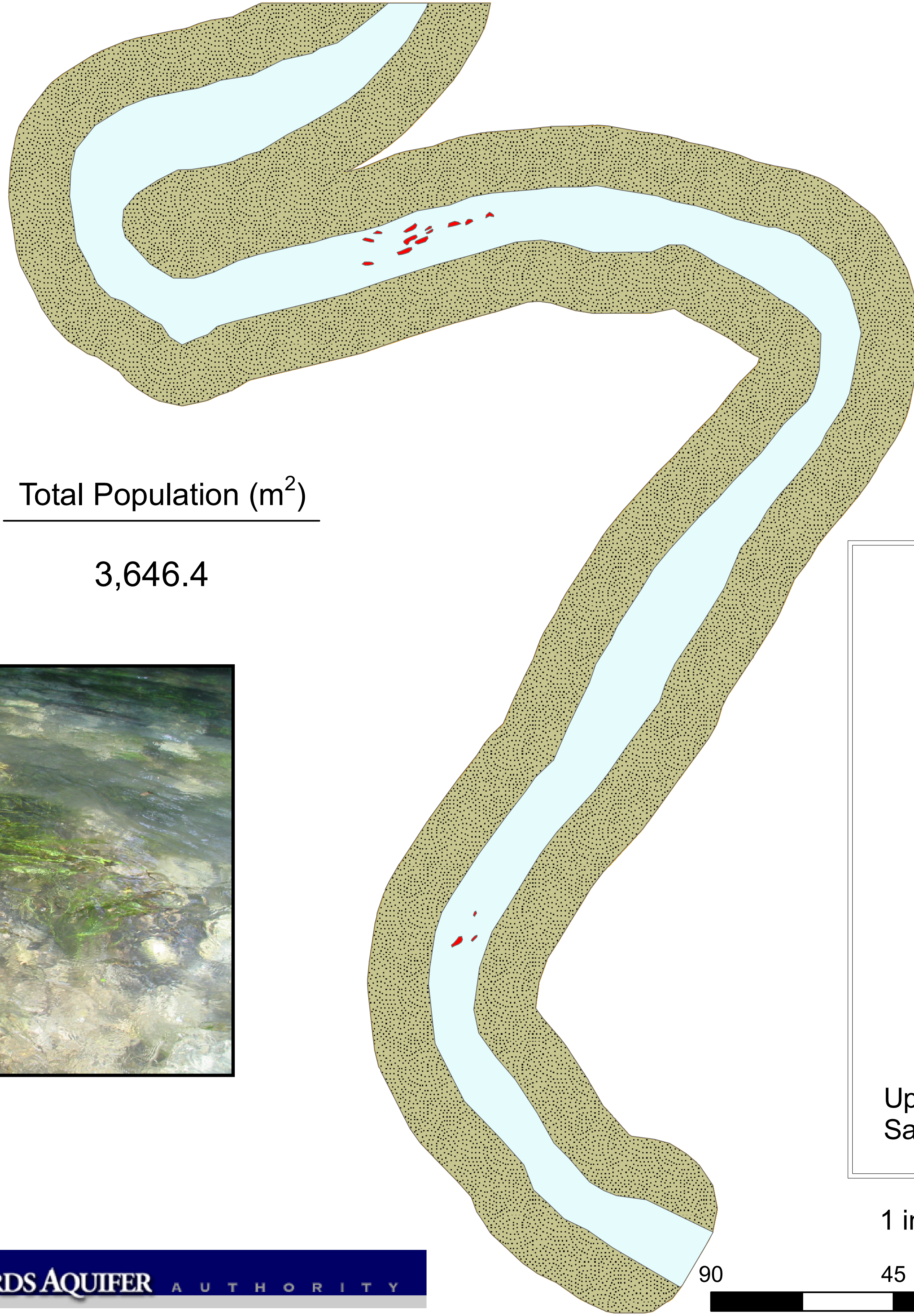
EDWARDS AQUIFER AUTHORITY


San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2007 - Map 6 of 7
August 1 - 8, 2007
1 inch equals 29.2 meters
70
35
0
70 Meters
N
Cape's Road
Project Location
1
2
3
4
5
6
7
N
Upper
San Marcos River
Map 6 (m2)
Total Population (m2)
Zizania
11.2
3,646.4
BIO-WEST, Inc.
EDWARDS AQUIFER AUTHORITY

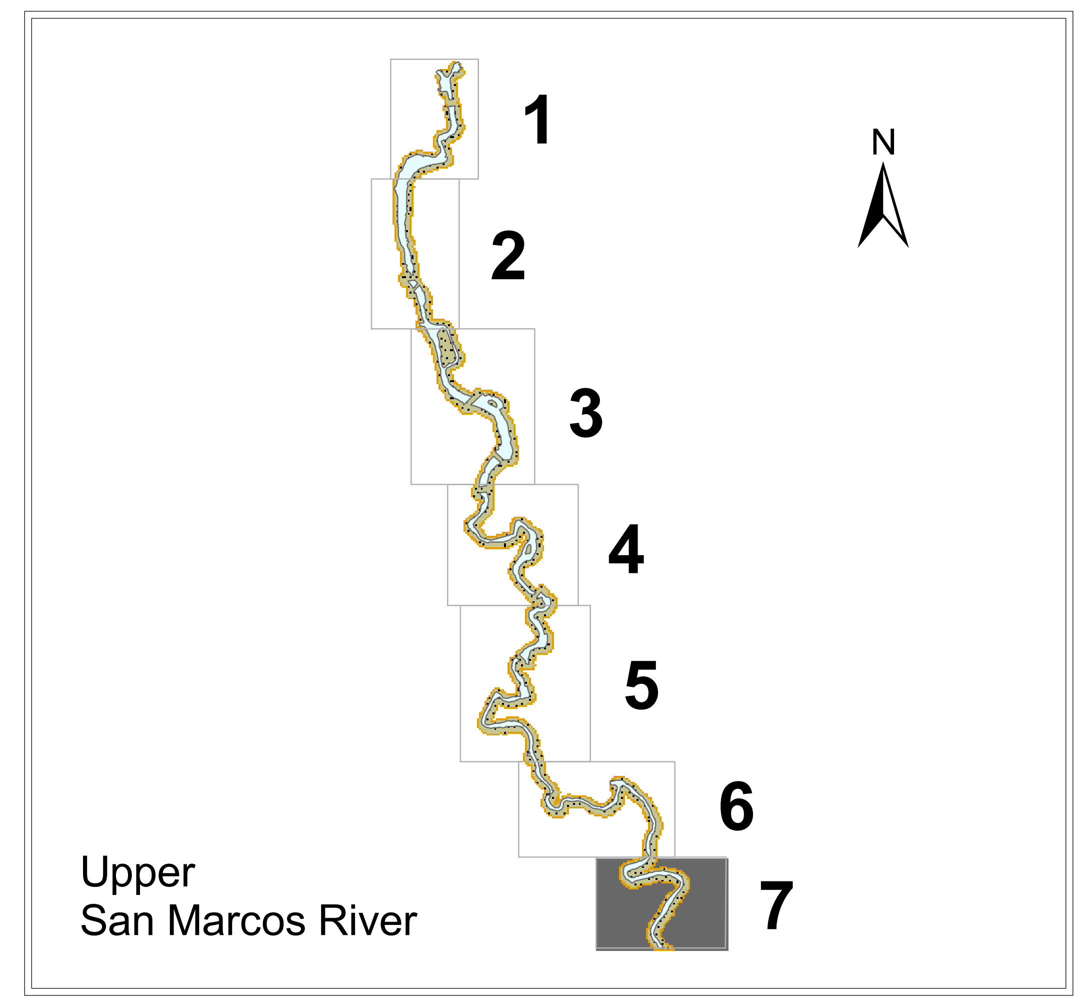
San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2007 - Map 7 of 7
August 1 - 8, 2007

	Map 7 (m^2)	Total Population (m^2)
Zizania	28.0	3,646.4



N

Project Location



1 inch equals 30.6 meters

90 45 0 90 Meters

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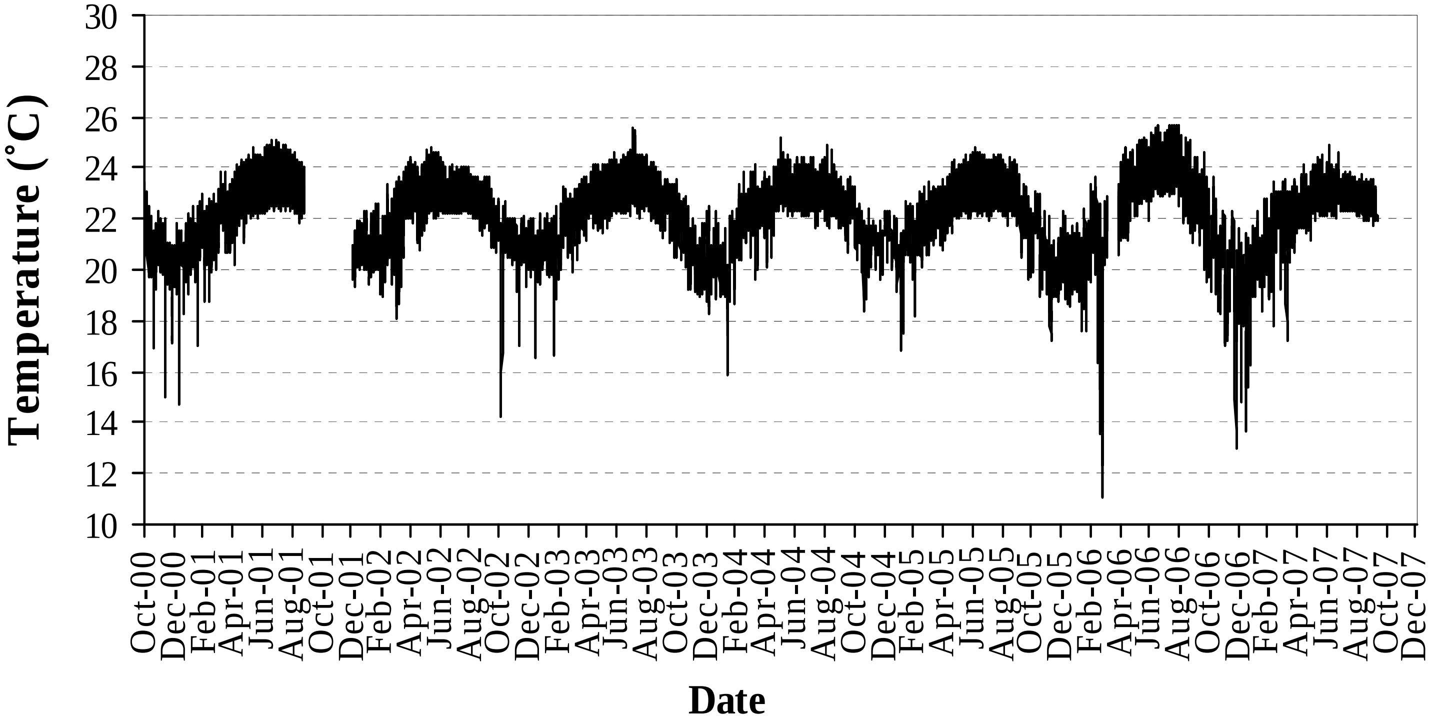
EDWARDS AQUIFER AUTHORITY

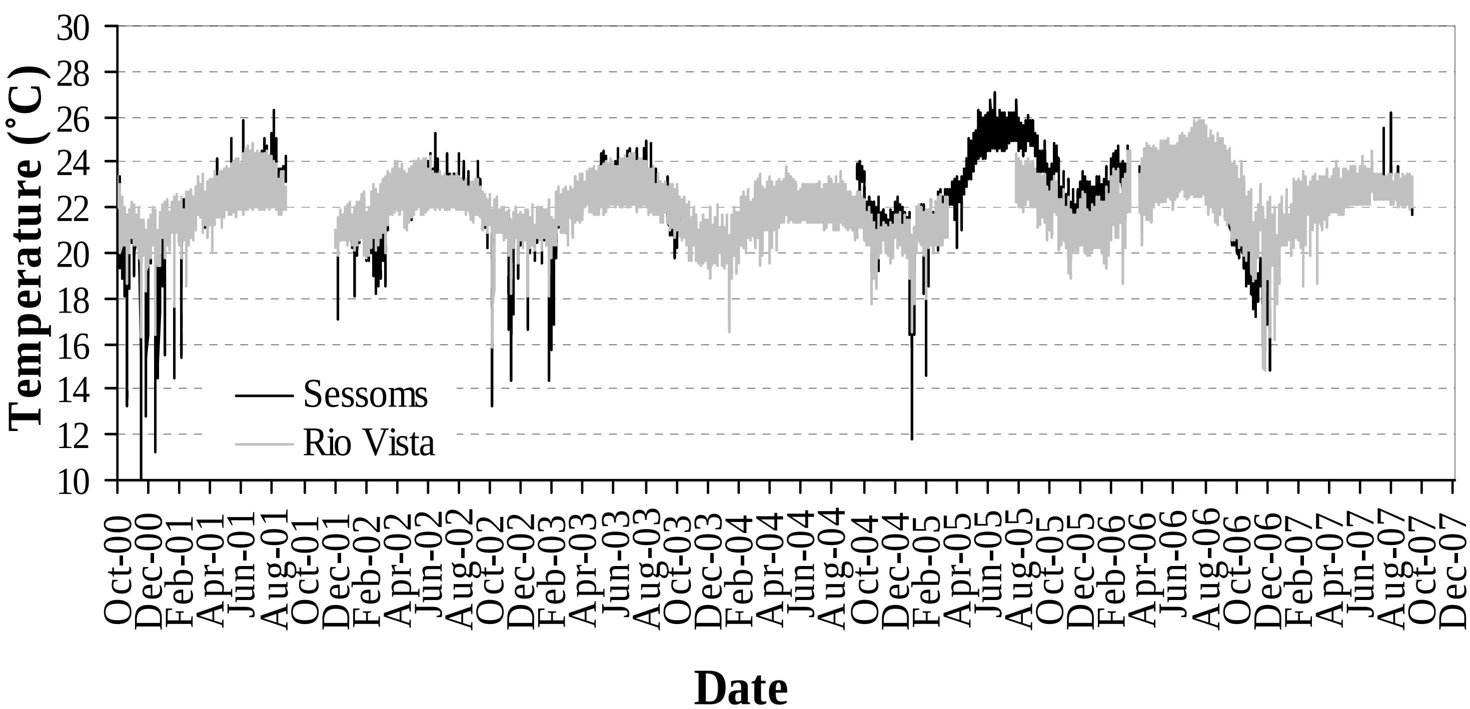
APPENDIX B:
DATA AND GRAPHS

Water Quality Data
and
Thermistor Graphs

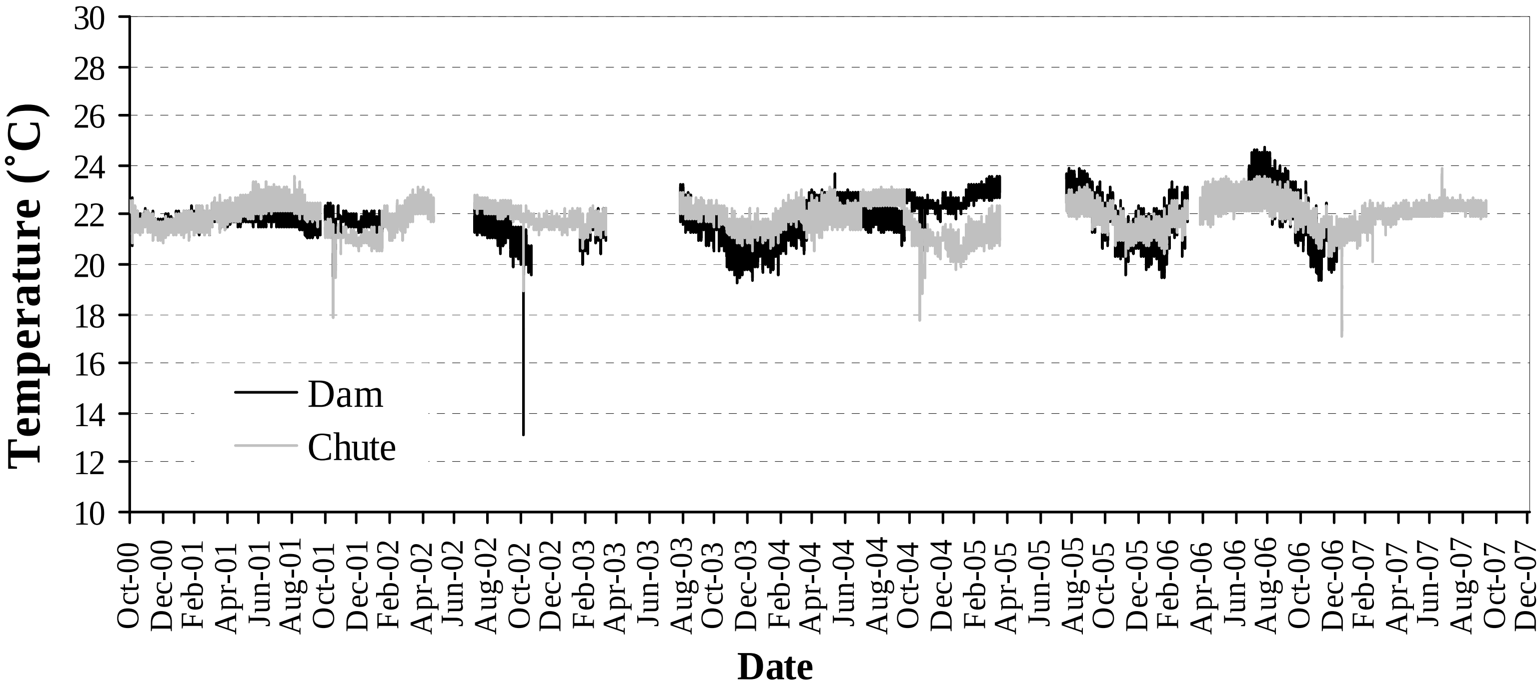
Thermistor Data: Animal Shelter



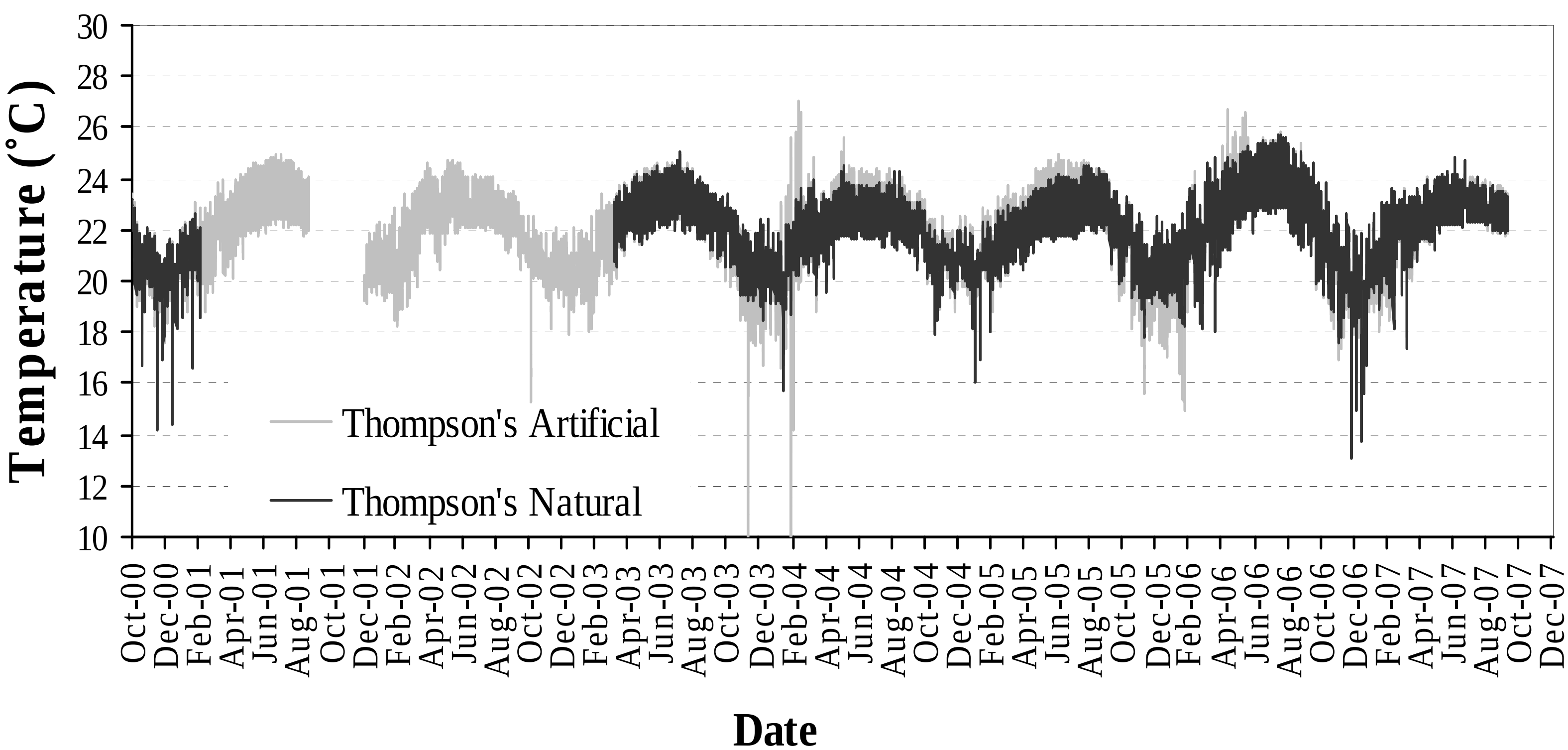
Thermistor Data: Sessoms Creek and Rio Vista Dam



Thermistor Data: Dam and Chute Tailraces

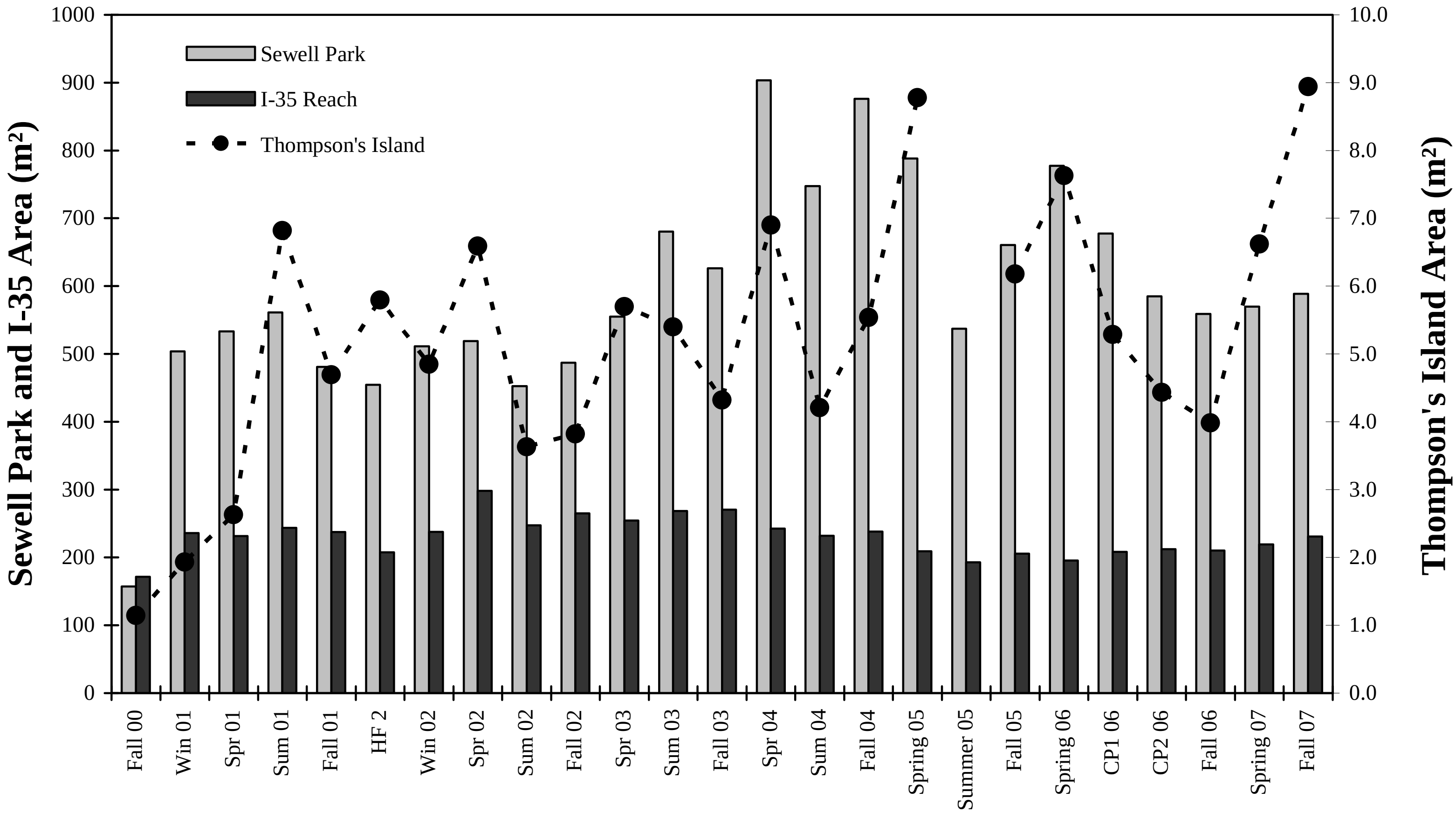


Thermistor Data: Thompson's Island Artificial and Natural Canal Sites

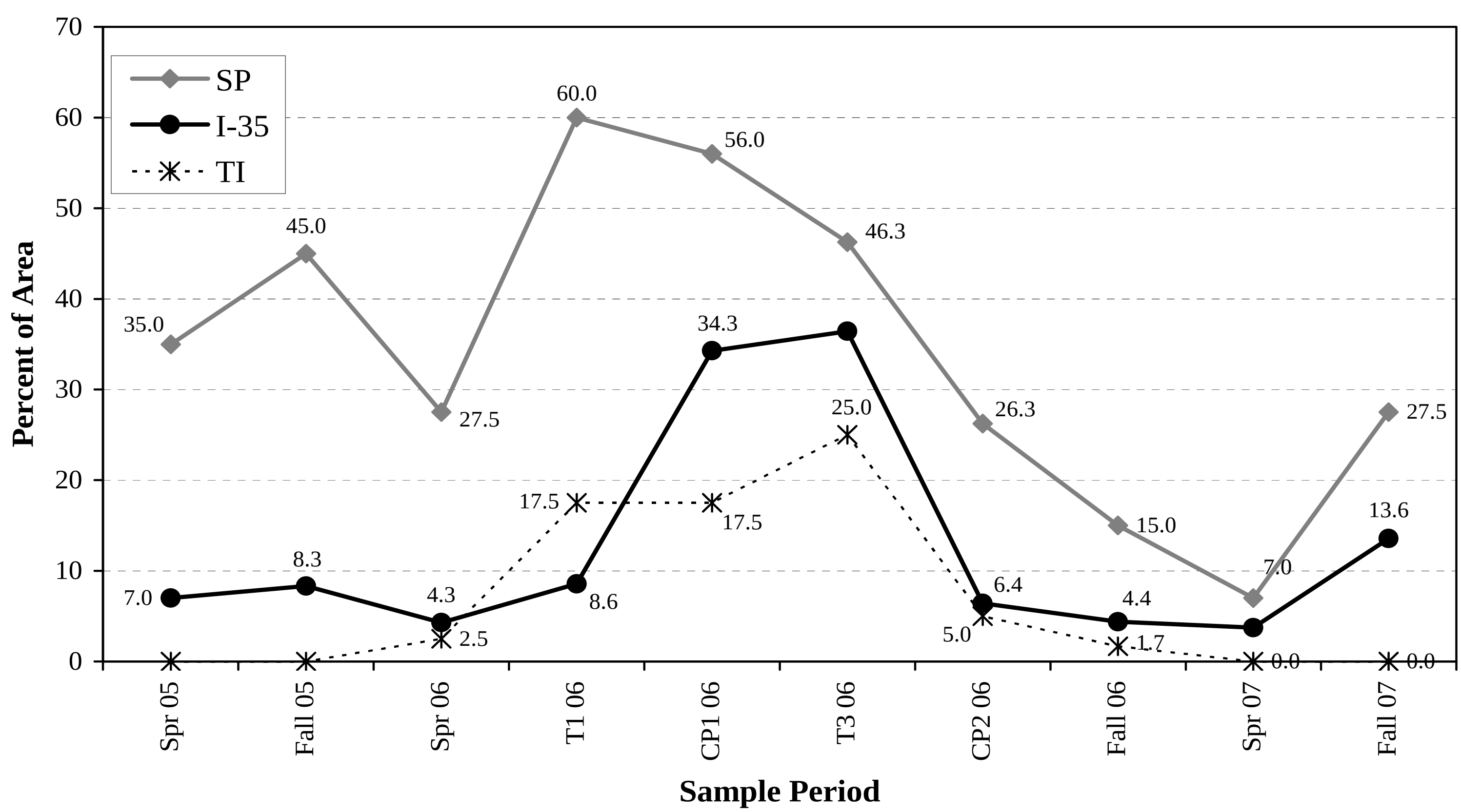


Texas Wild-Rice Observation Data

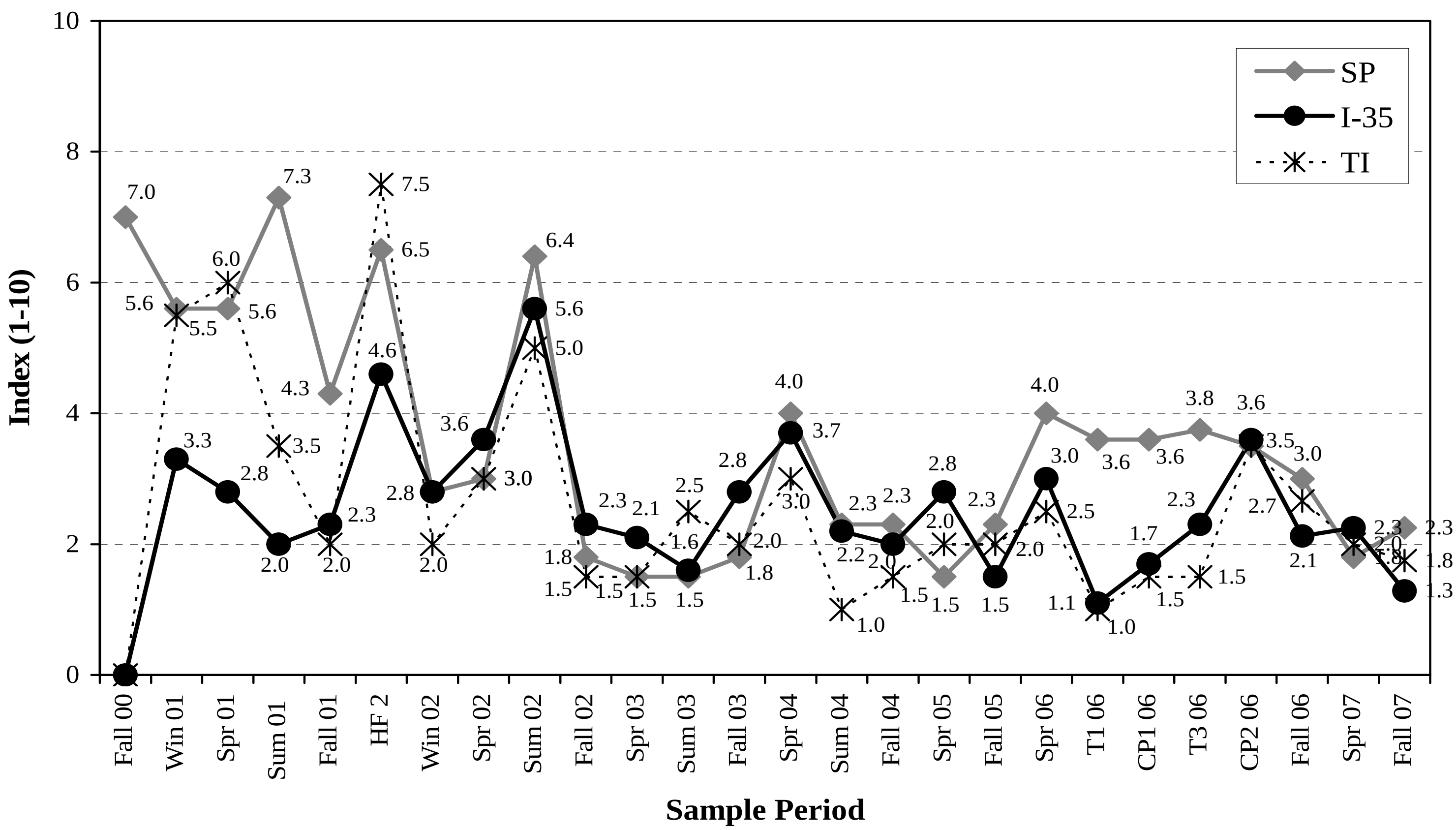
TWR Area by Season



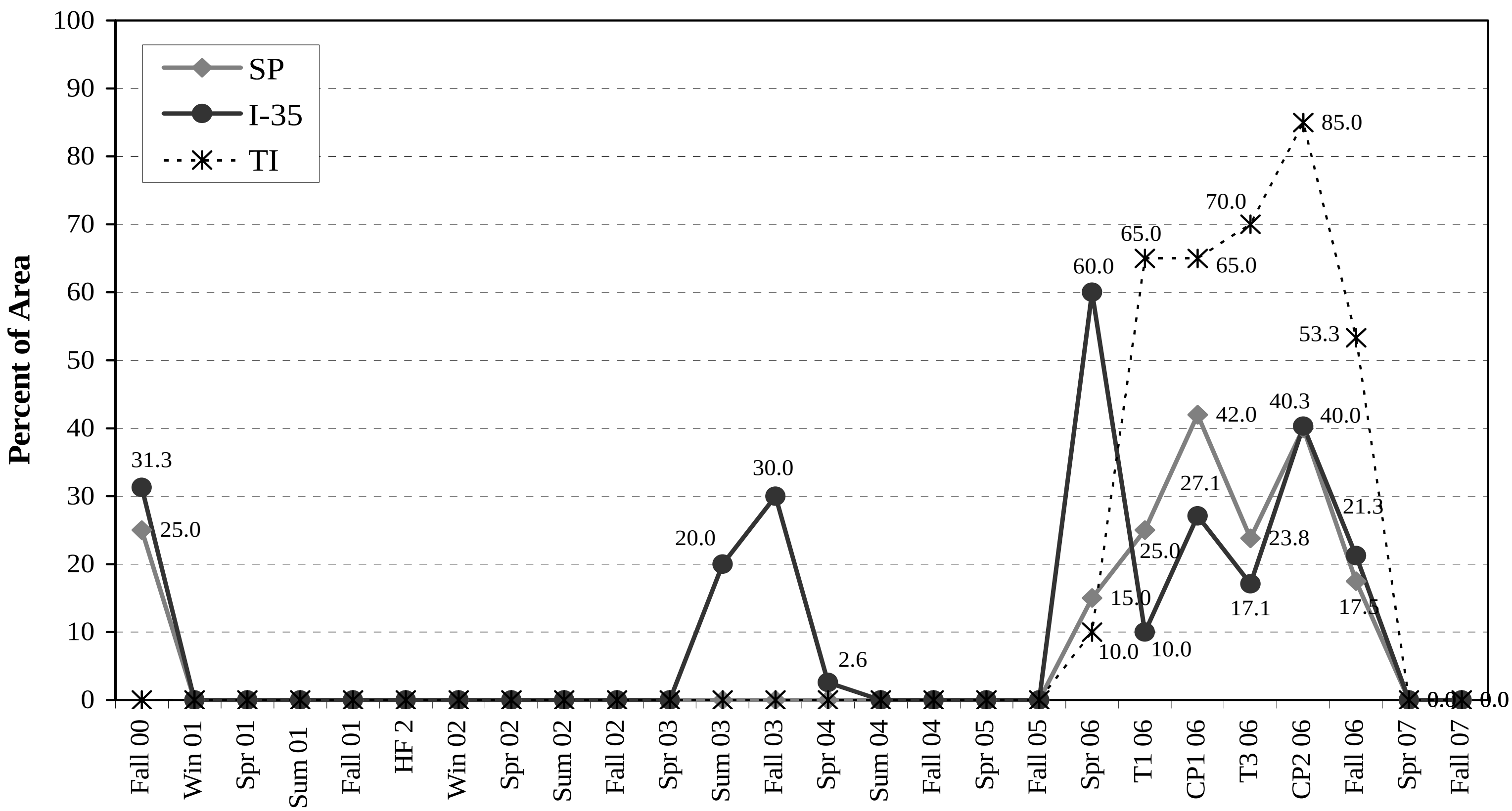
Percent of TWR Covered by Vegetation Mats



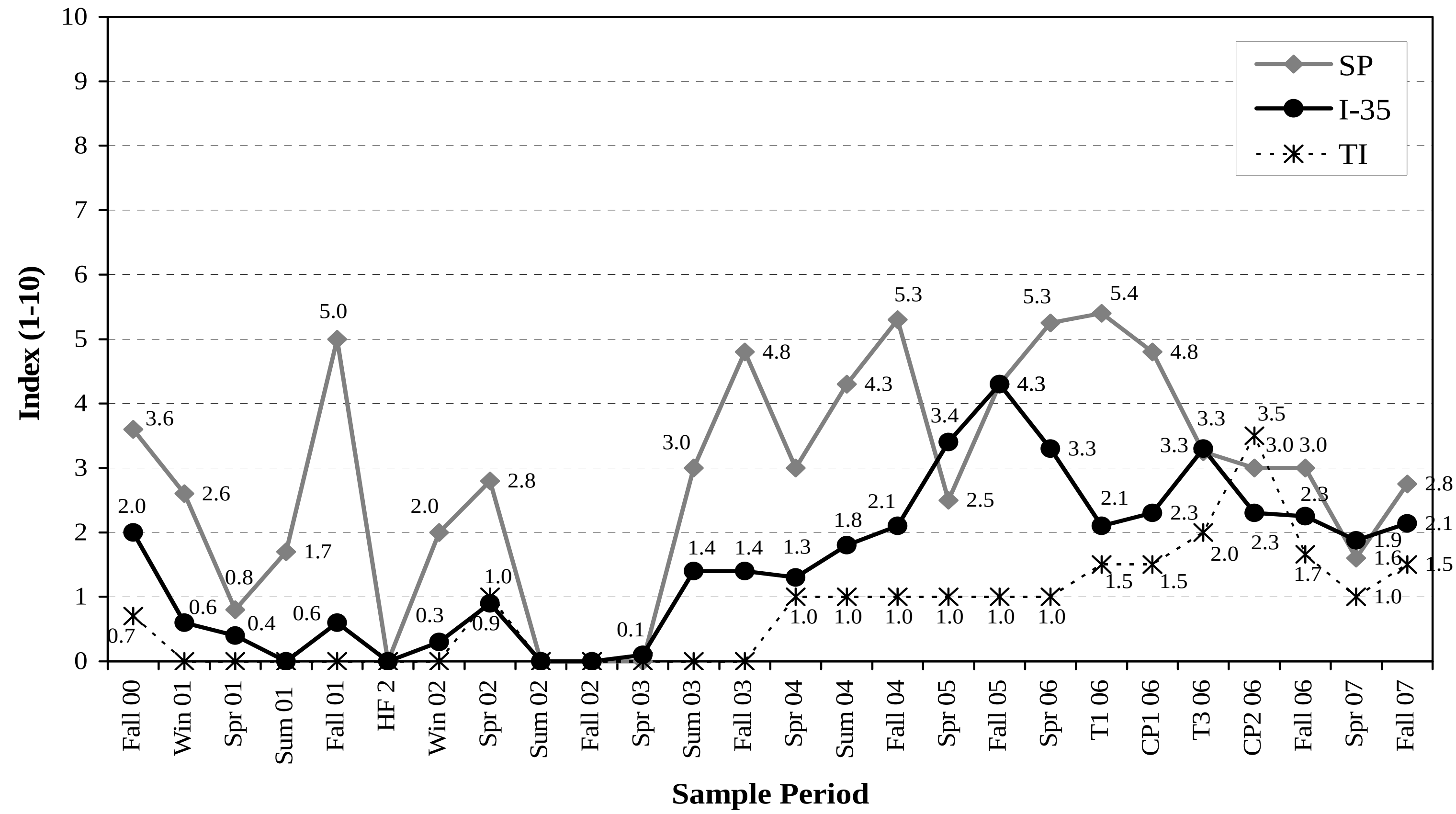
Index of Root Exposure for TWR Stands



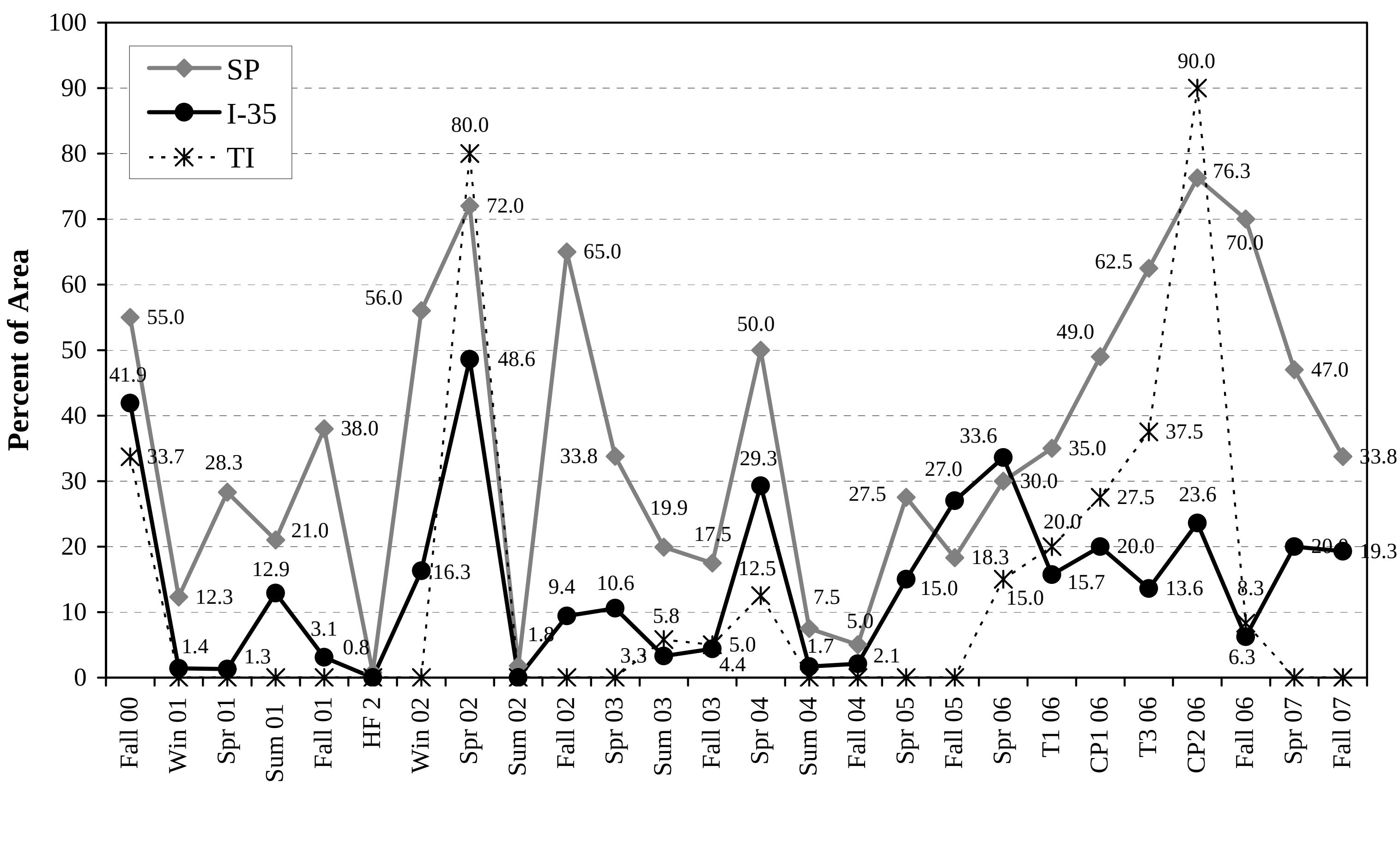
Percent of TWR Stands < 0.5 Feet



Index of Herbivory for TWR Stands

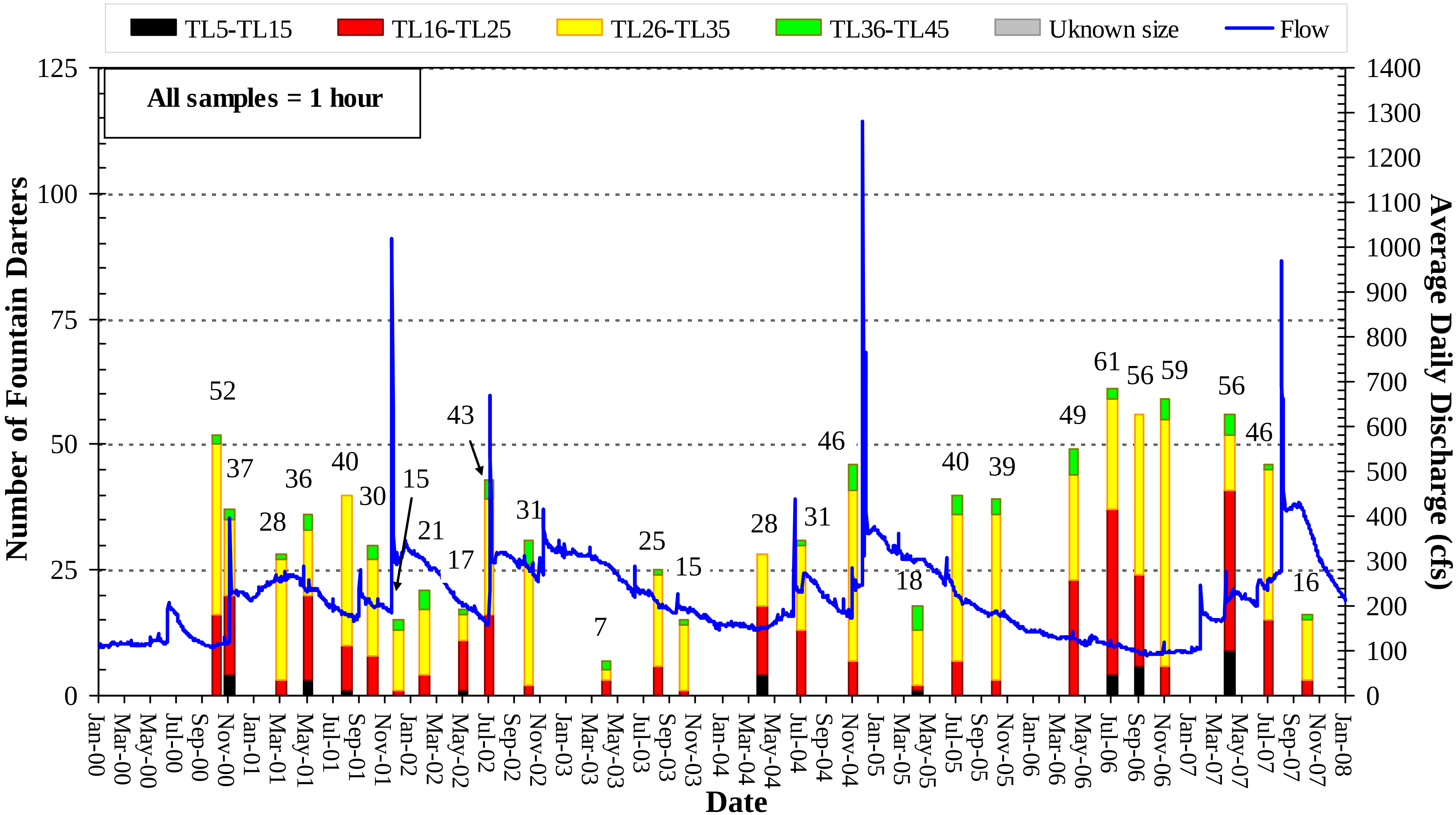


Percent Emergent TWR

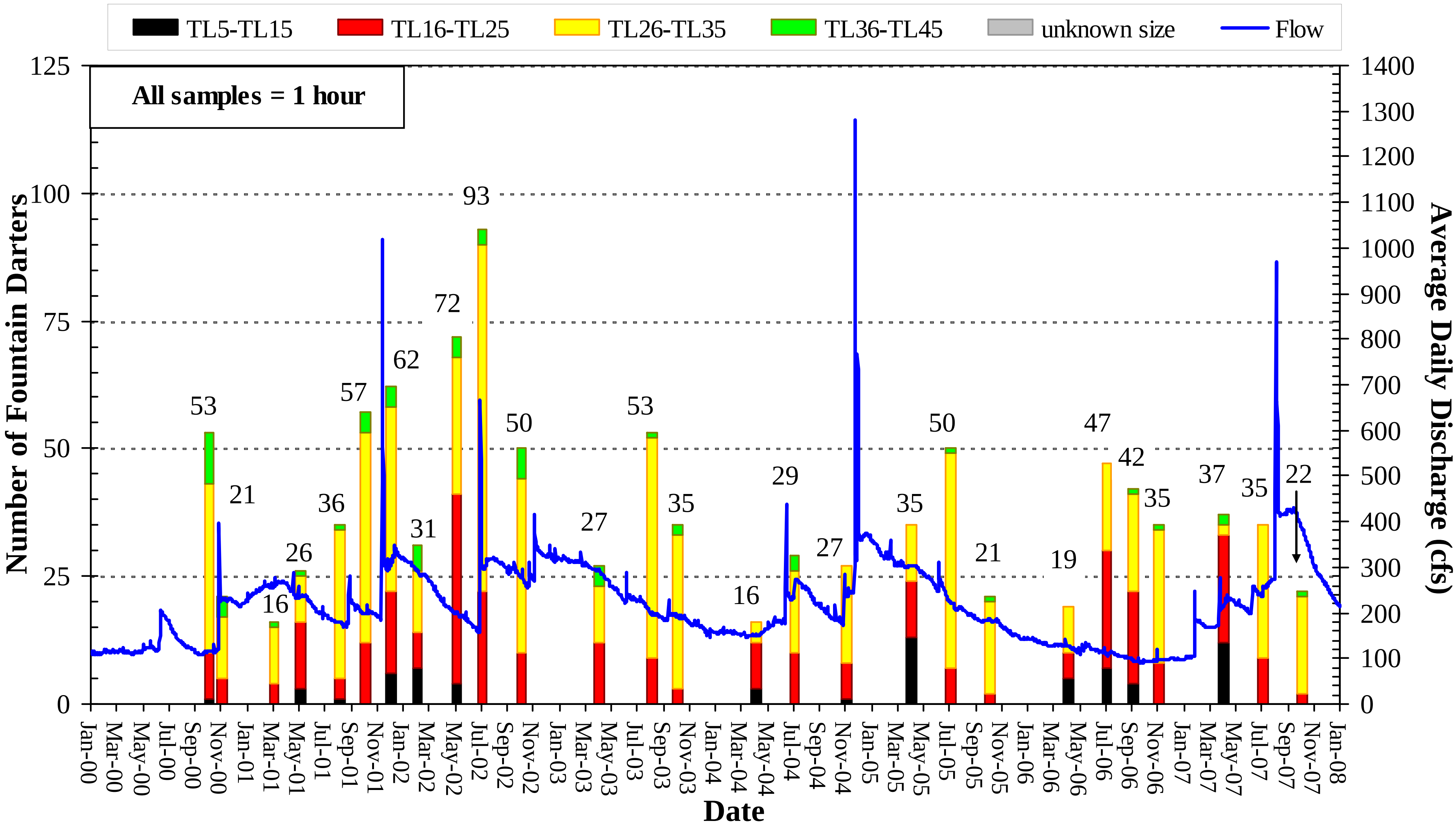


Dip Net Graphs

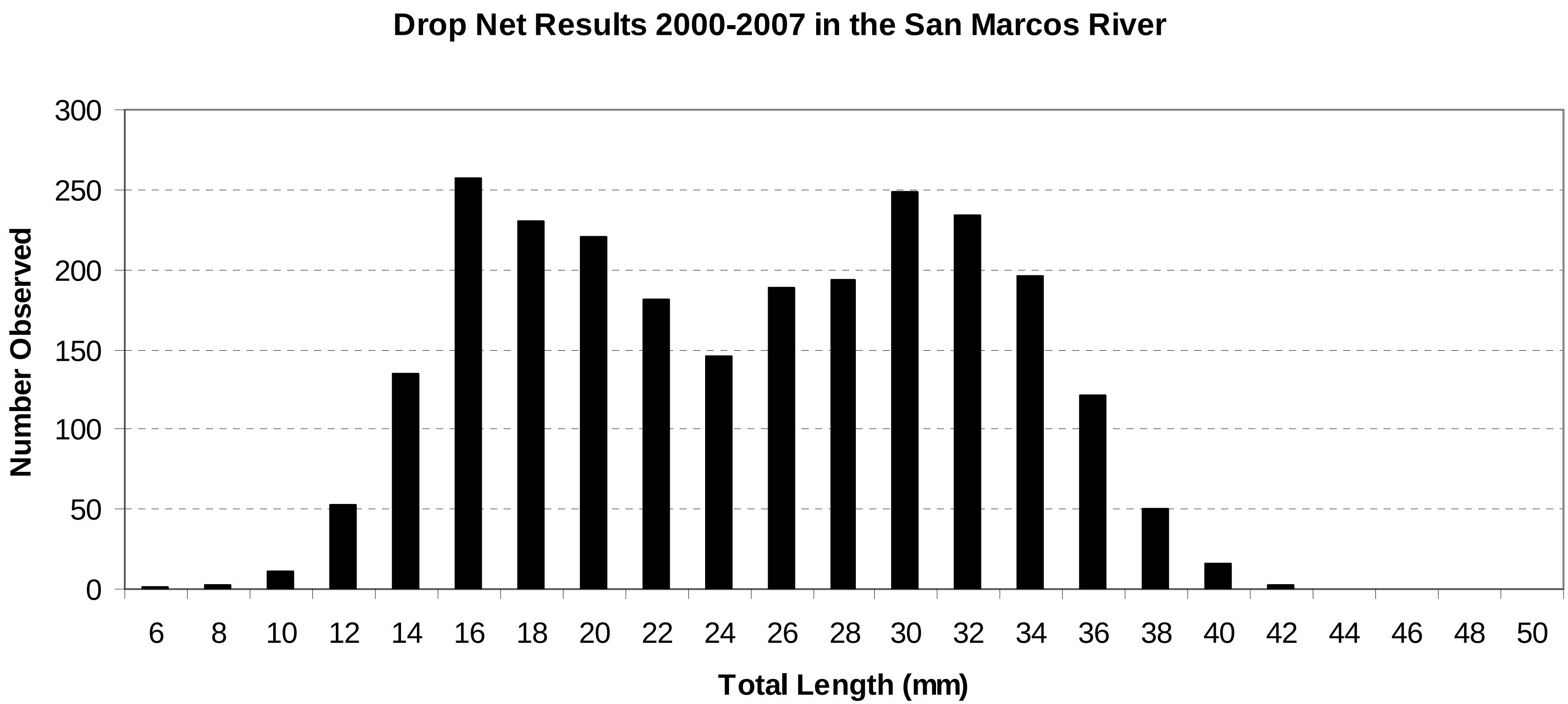
Fountain Darters Collected from the City Park Reach (Section 4L-M) Dip Net Results - San Marcos River



Fountain Darters Collected from the I-35 Reach (Section 7-M) Dip Net Results - San Marcos River



Drop Net Graph


Drop Net Results 2000-2007 in the San Marcos River
Number Observed
300
250
200
150
100
50
0
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
Total Length (mm)

APPENDIX C:
DROP NET RAW DATA

(not available online)