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 2010 ANNUAL REPORT

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EXECUTIVE SUMMARY

This annual summary report presents a synopsis of methodology used and an account of sampling activities conducted during two Comprehensive Monitoring sampling efforts on the San Marcos Springs/River ecosystem in 2010. For ease of comparison, the data are reported in an annual report format similar to previous reports (BIO-WEST 2001a,b-2010a,b).

Unlike 2009, discharge in the San Marcos River was above the historical average to begin 2010. This was a considerable departure from the drought central Texas experienced over the previous couple of years. Discharge remained above the historical average until rainfall began to decrease in fall, and flows ended the year slightly below average. Unlike the Comal River (BIO-WEST 2011), there were no flood events that triggered Critical Period monitoring on the San Marcos system in 2010. The minimum discharge in 2010 was almost twice that of 2009, and was the second highest minimum discharge since the inception of the study. Near or above average flow conditions in 2010 resulted in stable water temperatures and water quality conditions. Fluctuations in water temperatures increased at sites farther downstream in 2010, but no temperature measurements eclipsed 26 ºCelsius (C).

Above and near average flows after the extended period of low-flows during 2009 afforded an opportunity to assess how the aquatic vegetation community responded. The community in the City Park Reach was at its most fragmented in fall 2009, but the increased flows and depressed recreation pressure allowed the vegetation to rebound by spring 2010. *Hygrophila*, *Potamogeton*, and *Hydrilla* reoccupied areas where they had previously been established; however, by fall 2010 many of these plants were again fragmented due to typical summer recreation pressure. Unlike 2009, *Hydrilla* seemed to be the only vegetation considerably affected by recreation in 2010. Recreation exhibits far less influence on aquatic vegetation in the I-35 Reach because access points are limited. Total aquatic vegetation area in the I-35 Reach was lower in both sampling efforts in 2010 than 2009 when flows were lower. This is typical for this reach as higher discharge conditions create higher velocities in the channel and limit the areas of habitat suitable for several of the plants that inhabit this section of the river. Additionally, higher velocities increase the sediment passing through Rio Vista Rapids (the previous dam held much of the sediment back) which may contribute to shifting banks and islands resulting in fragmentation of aquatic vegetation patches in this reach. Like the City Park Reach, the Spring Lake Dam Reach experiences heavy recreation due to multiple access points and its location on campus. Total aquatic vegetation area in this reach increased overwinter, but decreased again by fall due to fragmenting from recreation pressure. Like City Park, paths developed in the shallow middle section of the reach making aquatic vegetation patchier in distribution. This had the greatest impact on stands of *Potamogeton* and *Vallisneria*.

Coverage of Texas wild-rice (*Zizania texana*) increased from fall 2009 to summer 2010 with an increase of nearly 500 meters squared (m^2) in the uppermost section of the San Marcos River. The island created by sedimentation at Sewell Park was inundated more in 2010, but Texas wild-rice only expanded slightly in this area. Sediment washed out of Sessom’s Creek has created BobDog Island at the terminus, which has restricted flow to the river right section of Sewell Park where these plants used to flourish. Areal coverage of Texas wild-rice changed little in the lower reaches, except in the reach where it had been planted in 2003 by United States Fish and Wildlife Service (USFWS) scientists. Within lesser quality habitat areas, the higher flows in 2010 uprooted many plants leaving fewer, smaller plants behind. Flow conditions and activities in the river over the last couple of years contributed to the loss of Texas wild-rice plants in “vulnerable” areas at the Thompson’s Island Reach. As a result, a couple of new “vulnerable” plants were identified in the I-35 Reach, and used in the “Texas Wild-rice Physical Observations” portion of the study. Higher flows in 2010 inundated many Texas wild-rice plants leading to vegetation mats being less prevalent and declines in the amount of herbivory. Emergence of these plants throughout the San Marcos River was also lower due the increased depths. Unlike 2009, not a single "vulnerable" plant was observed in water less than 0.5 m in depth.

Flow conditions and recreational pressure in 2009 led to drastic changes in aquatic vegetation resulting in the lowest fountain darter (*Etheostoma fonticola*) population estimate (normalized estimate calculated based on average fountain darter density per vegetation type over the study period multiplied by aquatic vegetation coverage) of the study in fall 2009. A return to above average flow conditions provided a great opportunity to evaluate how the fountain darter population would recover from the extended low-flow period witnessed in 2009. As summarized above, the aquatic vegetation made a strong recovery which translated into a positive recovery for the fountain darter population as well. In fact, using the same methodology for calculating normalized population estimates, the 2010 fountain darter population estimate was the highest since the study's inception. Although flow data are variable, they do appear to be related to fountain darter abundance. A linear trendline suggests that as discharge increases, the number of fountain darters captured in each drop net event decreases. This is likely related to darters becoming concentrated into more limited habitat under lower flow conditions. *Cabomba* continues to be an important aquatic vegetation species in the San Marcos River, as fountain darter densities are highest within this vegetation. *Hydrilla* and *Potamogeton* also provide large areas of habitat for fountain darters. Overall, there is little variation in the average density of fountain darters found among vegetation types in the San Marcos River. As a result, shifts in aquatic vegetation don't result in dramatic changes in fountain darter densities. Dip-netting and SCUBA surveys in Spring Lake continue to confirm the importance of filamentous algae and bryophytes to fountain darters, but these vegetation types are not found in large numbers in the San Marcos River. Size class distributions indicate that reproduction occurs year-round (most pronounced in Spring Lake), with reproductive peaks in the spring.

San Marcos Salamander (*Eurycea nana*) densities increased at each site from fall 2009 to spring 2010 as flow increased above the historical average. Fall densities decreased at all sites with the largest drop at the site in the eastern arm of the San Marcos River immediately downstream of Spring Lake. As in previous years, a large rock structure was erected below Spring Lake Dam using rocks that are typically good habitat for salamanders, and causing shifts in flow patterns away from quality habitat. In addition, the extreme velocities encountered in this reach during higher than average total discharge conditions limited the effectiveness of snorkel counts in this reach.

The recent drought in central Texas provided a unique opportunity to observe the biota and associated habitat in the San Marcos River over an extended period of lower than average flows. Above average flows in 2010 yielded a chance to observe how the biota and associated habitat recovered in areas that had experienced impacts during the drought. Continued 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 provide insight into the life histories of these rare and endangered species and provide the knowledge to assist in guidance of future management decisions.

METHODS

Study Location

The upper San Marcos River is part of the Edwards Aquifer system, and extends approximately 6.1 kilometers (km) from it's origin as a series of springs welling in Spring Lake to the confluence with the Blanco River in Hays County (Figure 1). The upper portion of the river is characterized by near constant water temperatures and relatively constant flow. This portion of the river also includes several endemic organisms that are federally listed as threatened or endangered, including: Texas wild-rice, San Marcos salamander, San Marcos gambusia (*Gambusia georgei* [likely extinct]), Comal Springs riffle beetle (*Heterelmis comalensis*), and fountain darter. This section of the river is located within an urban area and is subject to a substantial amount of recreational 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 use of this unique ecosystem (Figure 1).

During 2010, two comprehensive sampling efforts (spring and fall) were conducted in the San Marcos River system. The sampling schedule included the following components during each sampling effort unless otherwise noted:

<u>Aquatic Vegetation Mapping</u>
- Texas wild-rice survey (summer only)

<u>Water Quality</u>
- Thermistor Placement
- Thermistor Retrieval
- Fixed Station Photography
- Point Water Quality Measurements

<u>San Marcos Salamander Observations</u>

<u>Texas Wild-Rice Physical Observations</u>
- Cross-section data
- Physical measurements

<u>Fountain Darter Sampling</u>
- Drop Nets
- Dip Nets
- Visual Observations

Low-Flow Sampling

There were no low-flow sampling events on the San Marcos River in 2010.

High-Flow Sampling

There were no high-flow sampling events on the San Marcos River in 2010.

San Marcos Springflow

All San Marcos River 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 2010). 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 SonTek® FlowTracker with handheld unit.

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. Due to the consistency in water quality conditions measured over the first several years of sampling, 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 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, mid-depth, and near the bottom (when applicable) in all drop-net sampling sites using a Hydrolab Quanta. No grab samples were collected in 2010 because no Critical Period Events were triggered.

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; taken at all water quality sampling locations depicted in Figure 1.

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). In addition, annual Texas wild-rice monitoring was performed in summer for the San Marcos River (to the most downstream Texas wild-rice plant). 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 (or similar 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 foot (ft) Perception Swifty kayak with the GPS antenna mounted on the bow. The aquatic vegetation was identified and mapped by gathering coordinates (creating polygons) 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.

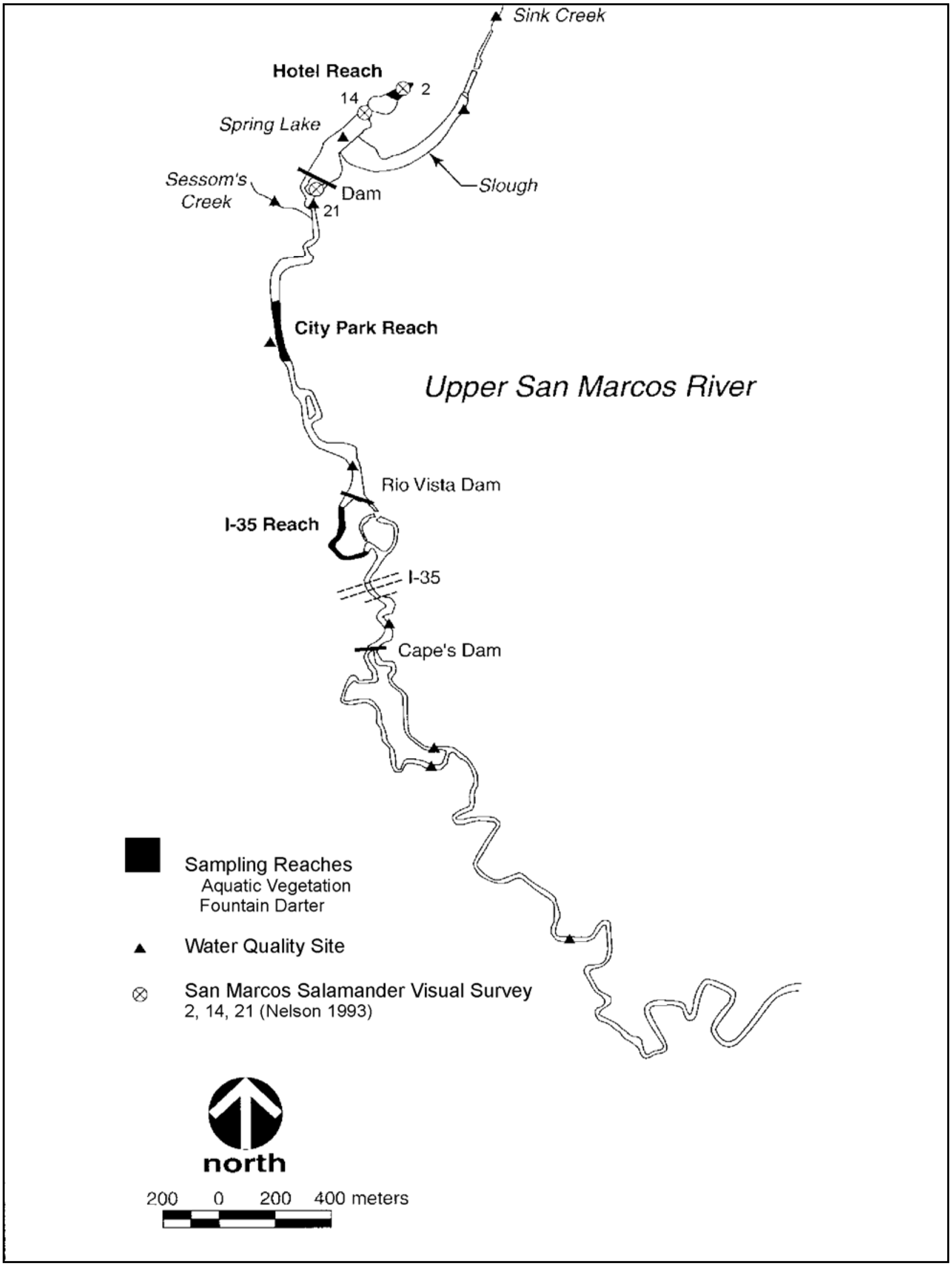


Figure 1. Upper San Marcos River water quality and biological sampling areas.


Measuring standard water quality parameters


Fixed station photo facing upstream (City Park)


Fixed station photo facing across channel (City Park)


Fixed station photo facing downstream (City Park)

GPS and kayak equipment used during aquatic vegetation mapping

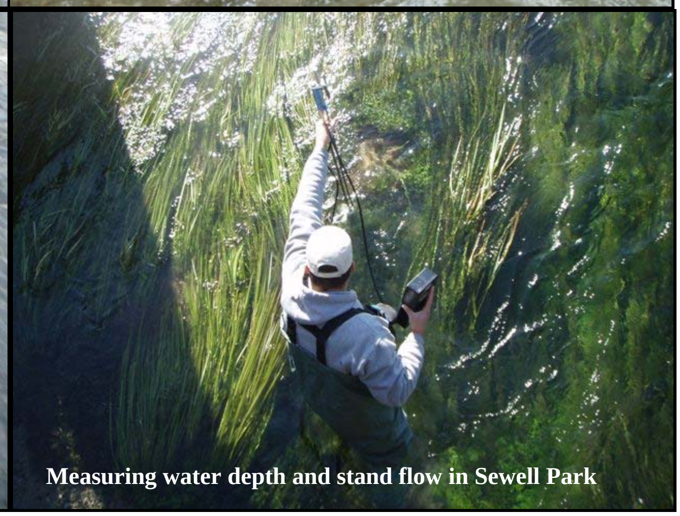
Texas Wild-Rice Physical Observations

At the beginning of the initial sampling activities for this project (Fall 2000), Texas wild-rice stands throughout the San Marcos River were assessed and documented as being in "vulnerable" areas if they possessed one or more of the following characteristics: (1) occurred in shallow water (< 1.0 ft. depth during average flows), (2) revealed extreme root exposure because of substrate scouring, or (3) generally appeared to be in poor condition. Monitoring activities associated with "vulnerable" stands were designed following discussions with Dr. Robert Doyle, currently with Baylor University, and Ms. Paula Power, formerly with the USFWS National Fish Hatchery and Technology Center, San Marcos. The areal coverage of Texas wild-rice stands in vulnerable locations were determined in 2010 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 ([TPWD] J. Poole, pers. comm.) in which percent cover was estimated for the imaginary rectangle created from the maximum length and maximum width measurements.


Recording GPS positions of Texas wild-rice in I-35 Reach


Measuring area of Texas wild-rice at Thompson's Island


Partially emergent stand of Texas wild-rice


Measuring water depth and stand flow in 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/flowering), the percent covered with vegetation mats or algae buildup, any evidence of foliage predation (herbivory), 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 were monitored. To complement all of the measurements made during each survey, photo sets were made for each of the sampling events in 2010.

Fountain Darter Sampling

Drop Nets

A drop net is a type of sampling device previously used by 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 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 from a grid overlain on the most recent map (created using GPS-collected data during the previous week) of that reach.

Drop netting on the San Marcos River.

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. First, fountain darter densities in the various vegetation types were calculated using the complete San Marcos River dataset (2000-2010). Comparing density values between vegetation types provides valuable information on species/habitat relationships. These average density values were then used with aquatic vegetation mapping data on total coverage of each vegetation type 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 a given reach). Because there were generally only two drop net samples in each vegetation type within each reach, density estimates between sampling efforts can have 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 uncertainty associated with it. 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).

In addition to density and abundance calculations, drop net data were also used to generate length-frequency histograms for each season sampled. Analysis of these data, along with length-frequency data generated from dip netting, allows for inferences into reproductive seasonality.

Dip Nets

In addition to drop net sampling for fountain darters, a dip net of approximately 40 centimeters (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, Todd Island Reach – 1 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.

Presence/Absence Dipnetting

Presence/Absence dip netting was initiated on the San Marcos River during spring 2006. This method is designed to be a quick, efficient, and repetitive means of monitoring the fountain darter population. Also, since it is much less destructive than drop netting, it can be conducted during extremely low-flow periods without harming critical habitat.

Fifty sites were distributed among three sample reaches based on total area, diversity of vegetation, previous fountain darter abundance estimates, and overall biological importance of each reach. Fourteen sites were chosen in the Spring Lake Dam Reach, 22 sites were chosen in the City Park Reach, and 14 sites were chosen in the I-35 Reach. During each sampling event, several sites are chosen in each of the dominate vegetation types in each reach. However, since vegetation coverage changes often, the number of sites within each vegetation type fluctuates slightly between samples.

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 with river water to avoid recapturing organisms. After all dips were completed at a site, all organisms were released at the site of capture.

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 (known as Riverbed) 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 site was determined by physically measuring each 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 2010 Comprehensive sampling events on the dates shown in Table 1.

Table 1. Study components of the 2010 sampling events.

Event	Date(s)
Spring	
Vegetation mapping	April 20-22
Texas wild-rice physical observations	April 21
Fountain darter sampling	April 22, 27-30
San Marcos salamander observations	May 6
Summer	
Texas wild-rice mapping	July 28–August 3
Fall	
Vegetation mapping	October 19-21
Texas wild-rice physical observations	October 25
Fountain darter sampling	October 20-21, 27-28
San Marcos salamander observations	October 28

San Marcos Springflow

Springflows in the San Marcos River in 2009 were below 100 cubic feet per second (cfs) for 243 days and below 120 cfs for 384 consecutive days from 2008 to 2009. A minimum flow of 83 cfs occurred twice in 2009, whereas the minimum flow in 2010 was almost twice that (163 cfs, Table 2). With a maximum single daily average of 273 cfs, 2010 was a stable discharge year without any major rain events. The last time a single daily average exceeded 400 cfs was in 2007 (Figure 2) reflecting the drought in the region from 2007-2009. Near the conclusion of 2009 several rain events contributed to increasing flow that continued through early summer 2010. During the latter half of 2010, precipitation events were few and discharge declined through the end of the year. While average daily flow remained above the historic average for most of the year, by October declining rainfall resulted in lower discharge leading to the minimum daily average flow occurring on December 22 and 23 (Figure 3). Near or above average flow conditions in 2010 resulted in stable water temperatures and water quality conditions in the San Marcos River.

Table 2. Minimum and maximum discharges (cfs) in the San Marcos River since the beginning of the study in 2000.

Year	Minimum Discharge	Maximum Discharge
2000	108	397
2001	167	1,019
2002	157	668
2003	156	332
2004	146	1,280
2005	136	361
2006	90	145
2007	101	971
2008	97	217
2009	83	206
2010	163	273

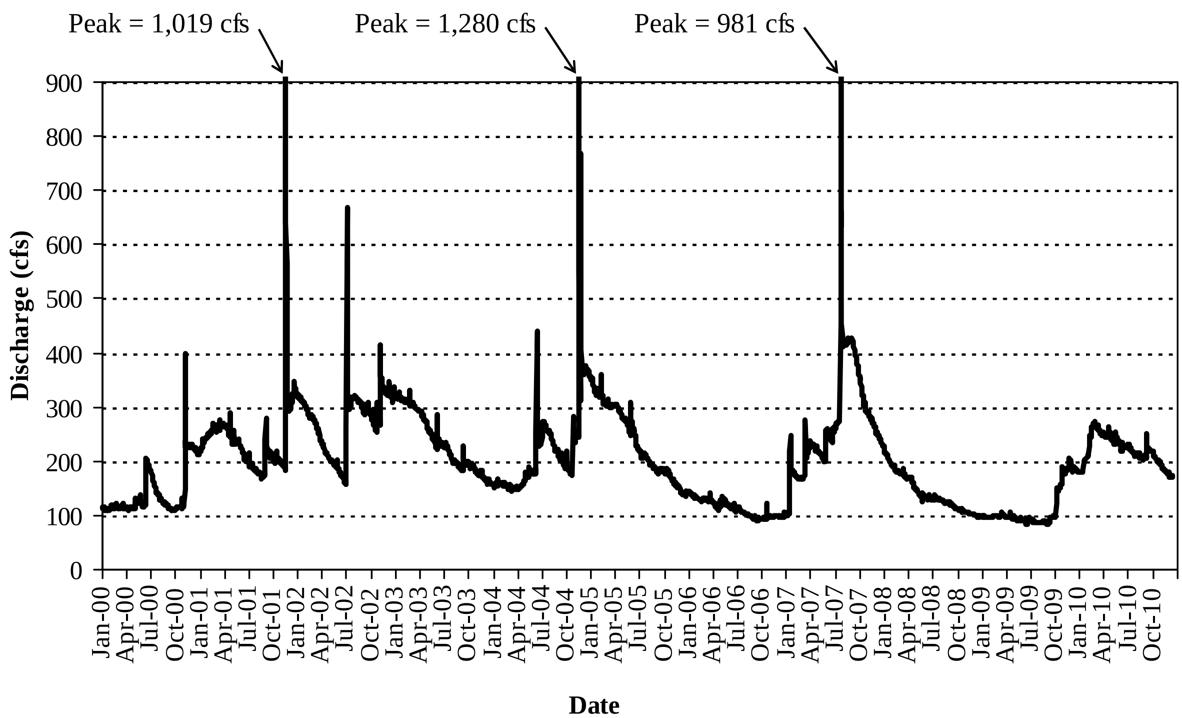


Figure 2. Daily average discharge (cfs) for the San Marcos River since the beginning of the study in 2000.

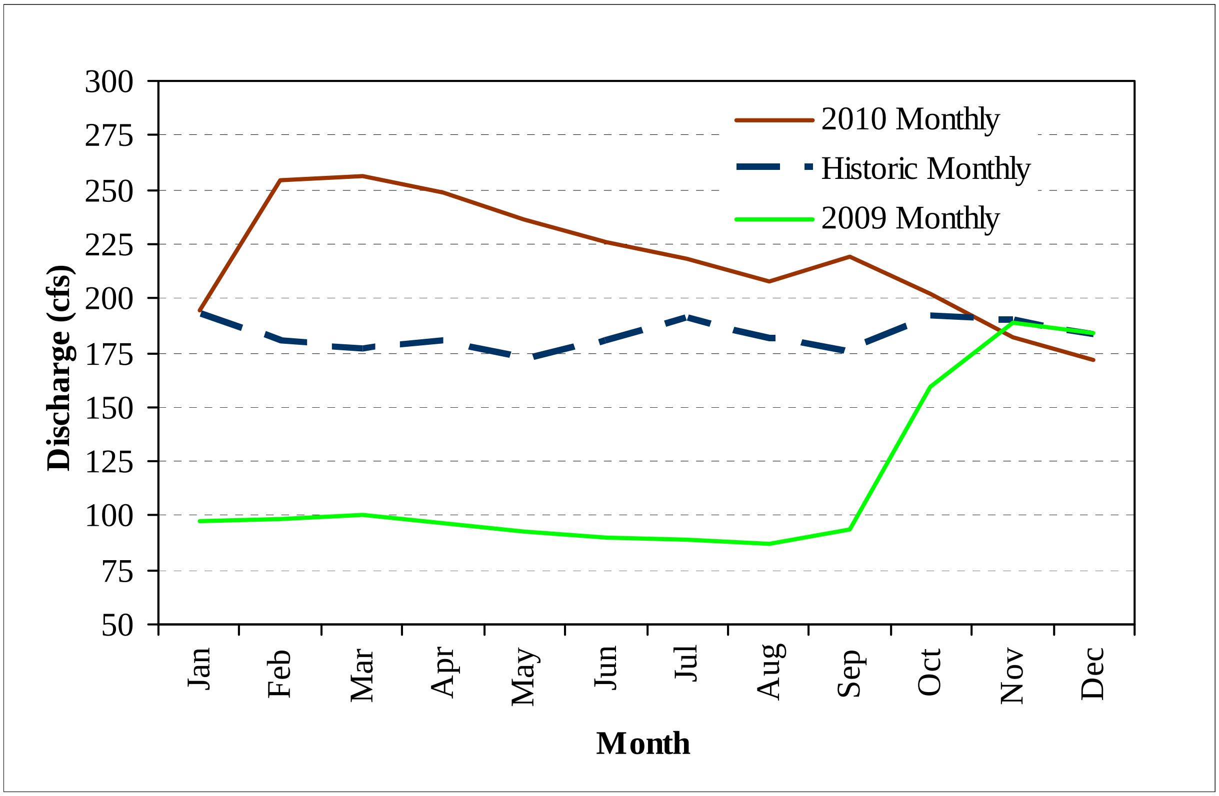


Figure 3. Mean monthly discharge (cfs) in the San Marcos River during the 1956-2010 period of record.

Water Quality Results

The thermistor temperature data for the City Park and I-35 reaches are presented in Figure 4, and additional graphs for all reaches can be found in Appendix B. The continuously sampled water temperature data provides information regarding fluctuations due to atmospheric conditions, and springflow influences in the San Marcos River from 2000-2010. 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 causing a spike in temperature, 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).

Higher than average flows in 2010 kept water temperatures in the San Marcos River from eclipsing the Texas Commission on Environmental Quality's (TCEQ) water quality standards value of 26.67 ºC at any of the sites. However, it is important to note that the thermistor at the Sessom's Creek site was lost in late 2009, and was not replaced in 2010. Under typical summer conditions, this site is often the only one to exceed the 26.67 ºC standard. To prevent tampering and stranding during low-water conditions, a more suitable location for this thermistor in the lower portion of Sessom's Creek is being investigated. The lowest water temperature recorded in 2010 (13.72 ºC) occurred at the Thompson's Island site within the main channel of the San Marcos River on January 16.

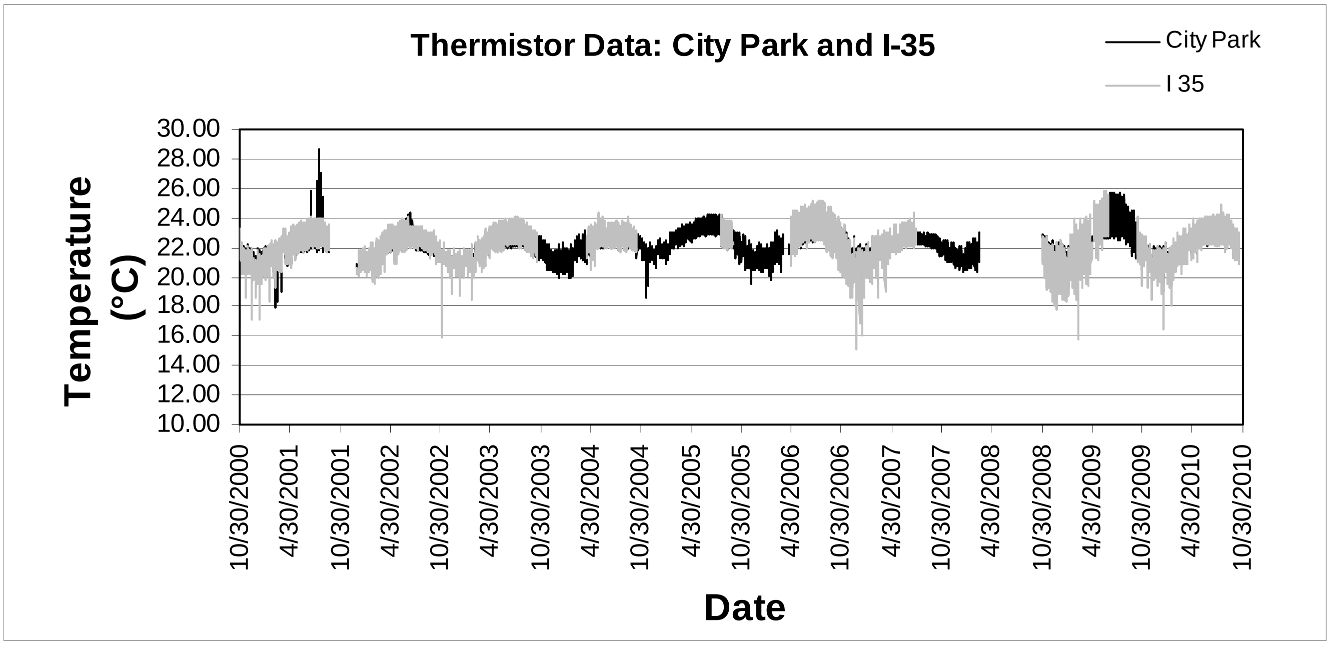


Figure 4. Thermistor data from the City Park and I-35 sites.

Although temperatures did not exceed the TCEQ standard in 2010, under lower flows in 2009 temperatures exceeded the standard at three sites (Sessom's Creek, the artificial channel at Thompson's Island [TI-art], and Rio Vista Dam) (BIO-WEST 2010b). To further investigate the relationship between springflow and temperature, temperature data from the Rio Vista Dam site were compared between 2009 and 2010 (Figure 5). While four-hour average temperatures at this site exceeded the 26.67 ºC standard several times during the low-flow hot summer months of 2009 (average flow May – Sept. = 91 cfs, range: 83 – 101 cfs), they rarely exceeded 24.0 ºC under higher flow conditions in 2010 (average flow May – Sept. = 222 cfs, range: 204 - 253). These water temperatures highlight the effects of low-flows prevalent in 2009 compared to 2010.

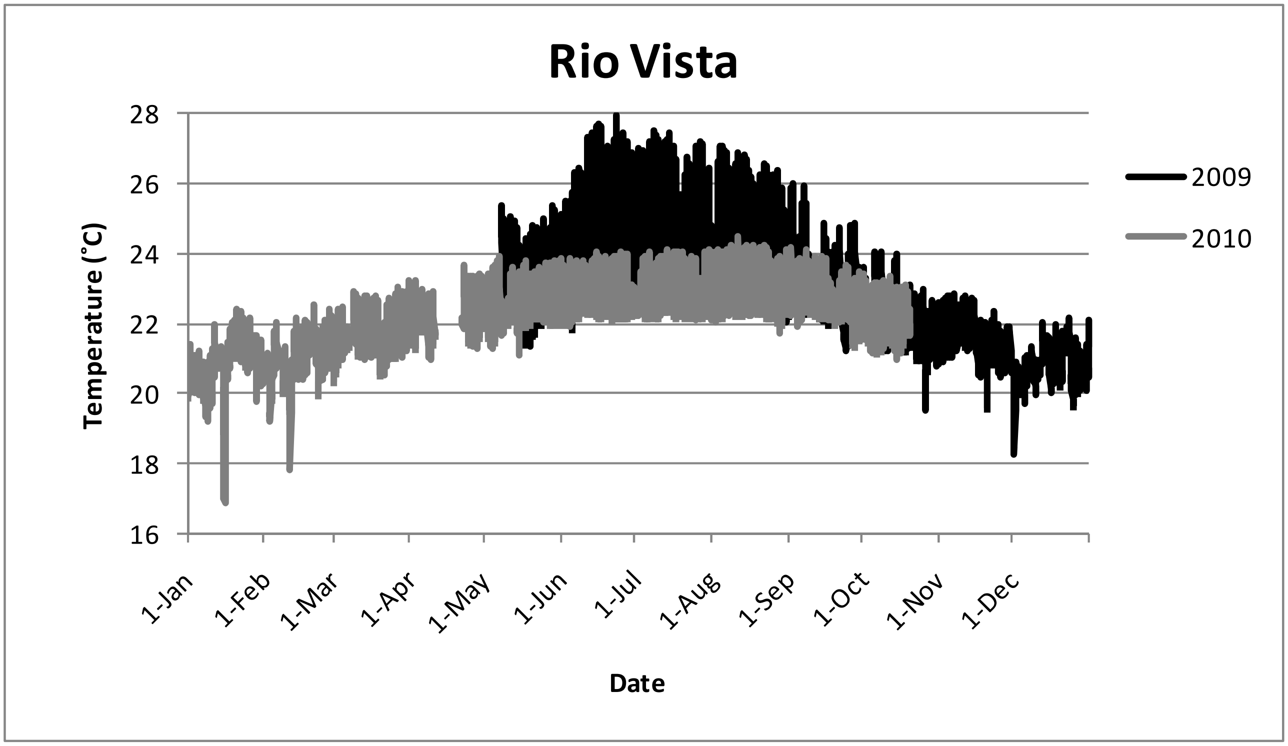


Figure 5. Thermistor data (ºC) at the Rio Vista Dam site in 2009 and 2010.

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 ordered by date of occurrence. It is difficult to make broad 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.

City Park Reach

The fall 2009 aquatic vegetation mapping effort marked the culmination of several years of drought in central Texas. As such the total amount of vegetation in the City Park Reach (2,690 m^2) was the lowest observed since the inception of the study (Figure 6). Higher flows and decreased recreation pressure over winter contributed to an increase in overall vegetative growth (4,545 m^2) by spring 2010. *Hydrilla* re-established in the middle section of the reach where recreation pressure is greatest due to shallower depths. *Hygrophila* and *Potamogeton* re-established in the upper section of the reach where there had been large open areas of bare substrate (silt) due to lower flows and increased recreation pressure caused by the long, hot summer in 2009. Texas wild-rice also began to recover establishing new plants in the upper section and expanding established plants in the lower section of the reach where depths are greater. However, plants uprooted in the middle section of the reach in 2009 failed to re-colonize in 2010.

As part of the cyclical nature of plant growth and recreation pressure during the year in this reach, total vegetation area decreased by fall 2010 (3,856 m^2). Unlike the Comal River there was not a major flood event in the summer, therefore recreation pressure was high continually during the summer months. As in previous years, *Hydrilla* exhibited a large decline (759 m^2) in the middle section of the reach where depths are shallow and allow more access for people. The usual summer path was observed where large stands of *Hydrilla* had established in spring. Unlike 2009, *Hydrilla* appeared to be the only type of aquatic vegetation substantially impacted by recreation pressure in the City Park Reach in 2010. Texas wild-rice continued to expand (increased by 11 m^2) along with *Potamogeton* and *Hygrophila*. Although total vegetation area rebounded from 2009, it was still below the long-term average (for each respective season) in both spring and fall 2010 (Figure 6). However, unlike 2009, fall coverage was near the long-term fall average (Figure 6). This area will be closely monitored in the future to assess changes in vegetation coverage as flows change and recreation pressure cycles seasonally.

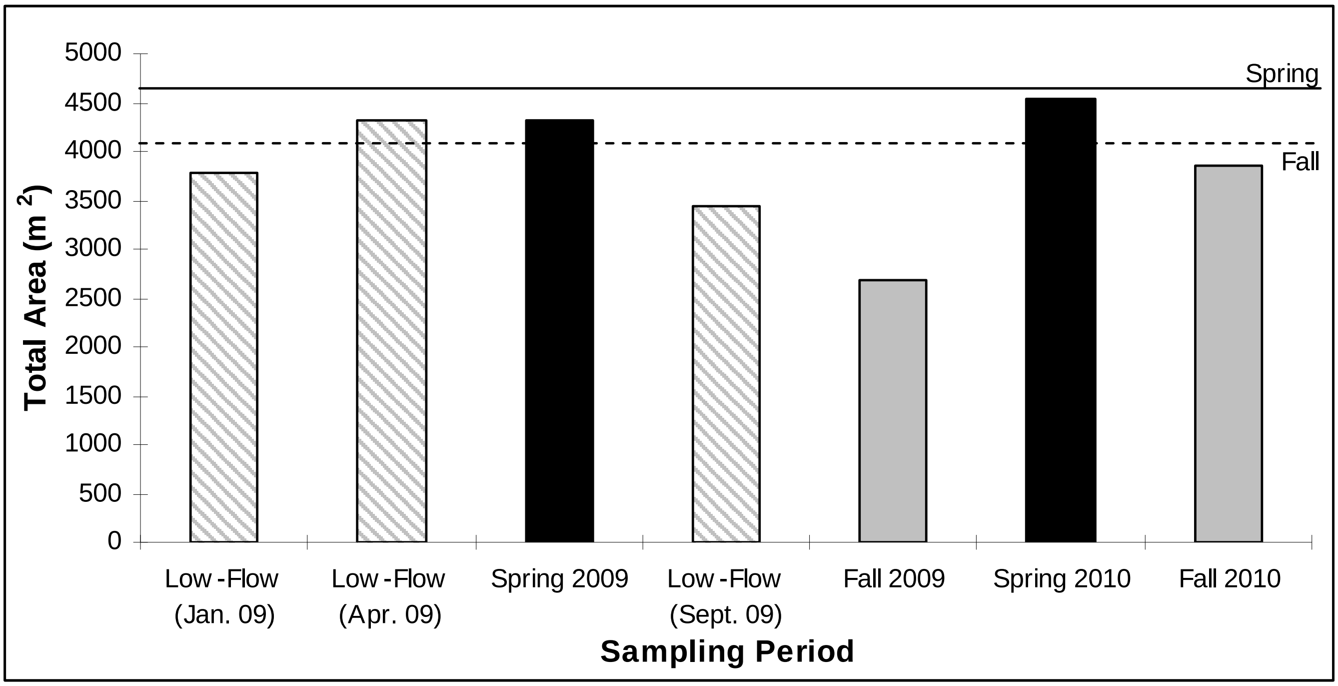


Figure 6. Total coverage of aquatic vegetation (m^2) in the City Park Reach in 2009 and 2010. Solid line (spring) and dashed line (fall) represent average total area (m^2) of respective seasons from 2000 – 2010 (does not include sampling periods when flows were <100 cfs).

I-35 Reach

Unlike the City Park Reach, the I-35 Reach experiences substantially less direct recreation pressure because it is downstream of a major tuber take out point (Rio Vista Rapids) and has limited access to the river. As a result, vegetation is less likely to be uprooted from mechanical disturbance; however, velocities in this reach are higher because the river is narrower and shallower than areas upstream. The channel morphology continues to change each year as a result of the Rio Vista Rapids construction in 2006, which has allowed more sediment to pass downstream. Increased flows in 2010 inundated gravel bars that were dry in 2009 allowing more surface area for aquatic vegetation to grow, but by spring 2010 this was not the case. Aquatic vegetation decreased by 112 m^2 in the I-35 Reach (Figure 7). *Cabomba* decreased the most because of a large plant fragmenting near the bottom of the reach. This coincides with slight channel changes here where the bank appeared to slough off increasing the amount of silt.

This vegetation type is important because it provides the highest-quality fountain darter habitat (of those sampled quantitatively) in the San Marcos River. Texas wild-rice that began to fragment in the middle section of the reach in 2009 grew together forming two large plants. This coincided with an increase of 25 m^2 of Texas wild-rice

By fall 2010 total vegetation area increased slightly (33 m^2) as flows were decreasing in the river. This continues a trend of increasing vegetation coverage with decreasing flows in this reach. This is in contradiction to the City Park and Spring Lake Dam reaches where vegetation typically fragments in decreasing flows because of recreational pressure. Again, this underscores the difference recreation pressure can make in these reaches. In the upper section of the river where access is less limited, shallower depths allow more people to disturb vegetation. With less access to the river in the I-35 Reach leading to less recreation pressure, aquatic vegetation is allowed to flourish even as flows decrease. Only *Sagittaria* and *Cabomba* decreased from spring to fall in 2010. Texas wild-rice grew by 17 m^2 with a large plant expanding its coverage near the bottom of the reach.

Of the three reaches studied in the San Marcos River, the I-35 Reach is the most "natural" one because it has comparably less recreation pressure. This results in an effect that is the opposite of the City Park and Spring Lake Dam reaches. As flows decrease, vegetation flourishes because lower velocities are less likely to displace plants (as in 2009) and total area is nearer the long term average (both spring and fall) (Figure 7). However, when flows are above average like in 2010, aquatic vegetation decreases possibly being displaced because of higher velocities present in the reach (Figure 7). Close observation of the aquatic vegetation dynamics in this reach under variable flow conditions will continue to be an important contribution to this study.

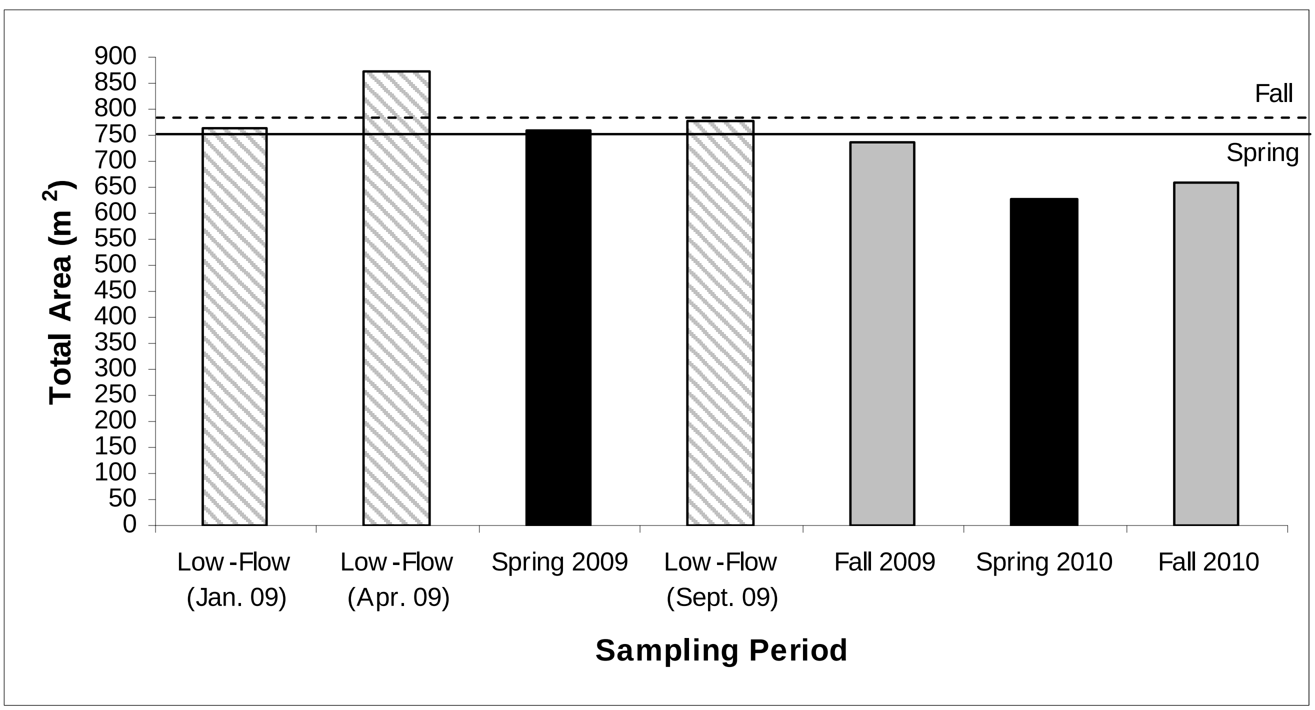


Figure 7. Total coverage of aquatic vegetation (m^2) in the I-35 Reach in 2009 and 2010. Solid line (spring) and dashed line (fall) represent average total area (m^2) of respective seasons from 2000 – 2010 (does not include sampling periods when flows were <100 cfs).

Spring Lake Dam Reach

Like the City Park Reach, the Spring Lake Dam Reach experiences heavy recreation pressure due to multiple access points and its location on campus next to a high-density apartment complex. During an extended period of lower than average discharge (2007 – 2009), aquatic vegetation was severely fragmented. This occurred to a large area of Texas wild-rice in 2006 (BIO-WEST 2007b) and to a lesser degree in 2009 (BIO-WEST 2010b). However, like City Park, during the winter months vegetation tends to grow back as recreation pressure lessens. This was the case again in 2010 (Figure 8). Total aquatic vegetation areal coverage was similar to that in spring 2009, which also reflected over winter vegetation growth. In 2010, much of the increase could be attributed to expansion of *Hydrilla* and Texas wild-rice. *Hydrilla* plants grew larger in the middle of the reach likely benefitting from velocity breaks created by large Texas wild-rice plants. Texas wild-rice also expanded in this section of the reach as well as in the upper section nearer the dam. Although areal coverage of aquatic vegetation rebounded in spring 2010, it was still well below the long-term spring average continuing the trend from 2009.

As in previous years, total aquatic vegetation area decreased by fall due to mechanical damage from people using this area in greater numbers over the summer months. Total aquatic vegetation coverage of 1,008 m^2 in fall 2010 was the second lowest total amount since the study began (fall 2009 was the lowest) and over 200 m^2 below the fall long term average (Figure 8). Similar to the City Park Reach, two paths were created through vegetation in the western arm adjacent to deeper water where people gather to swim. This had the greatest impact on *Potamogeton* and *Vallisneria* stands. In addition, several small Texas wild-rice plants were reduced in areal coverage. Another effect of recreation in the Spring Lake Dam Reach is the creation of man-made dams in the eastern spillway. An abundance of large rocks in this area makes it easy for large flow-altering dams to be created as shown in Figure 9. Nearly every year rocks that are important habitat for many organisms (including the San Marcos salamander) are displaced in the creation of rock structures in the Spring Lake Dam Reach. As in Figure 9, these structures can restrict flow to aquatic vegetation and damage it from the mechanical disturbance of their creation.

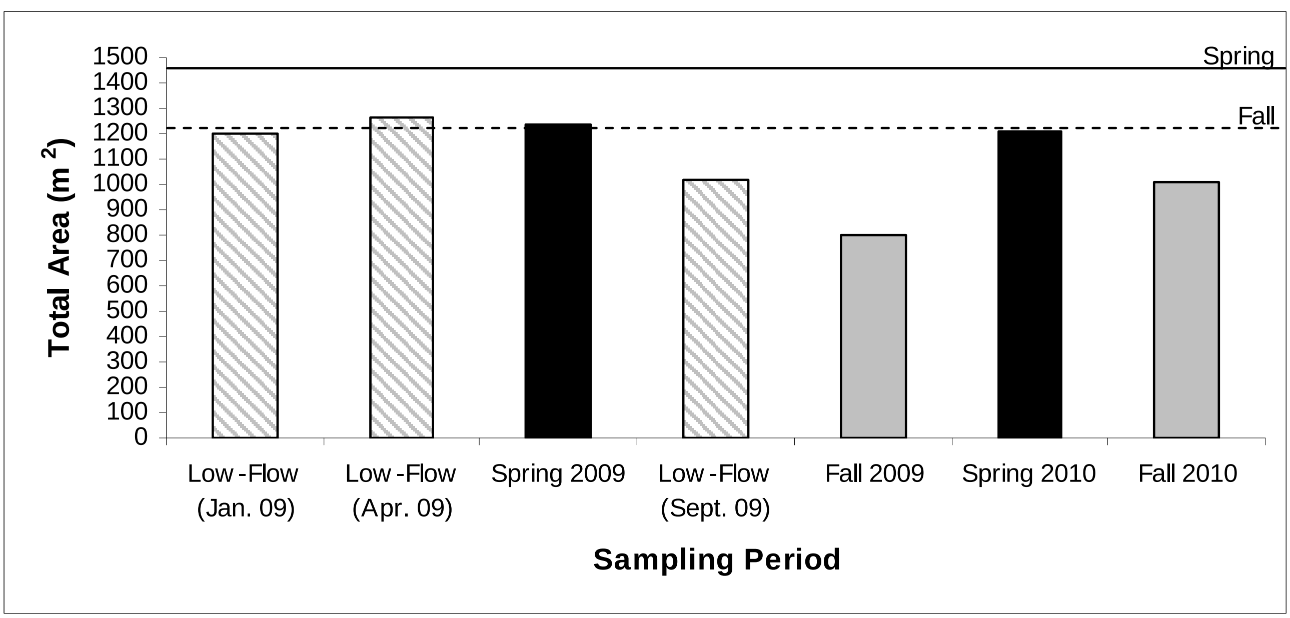


Figure 8. Total coverage of aquatic vegetation (m^2) in the Spring Lake Dam Reach in 2009 and 2010. Solid line (spring) and dashed line (fall) represent average total area (m^2) of respective seasons from 2000 – 2010 (does not include sampling periods when flows were <100 cfs).

Figure 9. Flow-altering dams created by people in the eastern arm of the Spring Lake Dam Reach, fall 2010.

Texas Wild-Rice Annual Mapping

Texas wild-rice maps for the entire San Marcos River broken out by map segment for each sampling period can be found in the map pockets in Appendix A. After several years of drought in central Texas, flows in the San Marcos increased and were relatively constant in 2010. Unlike 2009, flows did not drop below 100 cfs in 2010. As a result, only one Texas wild-rice mapping event took place during the usual summer sampling effort (July 28 – August 3). Overall, total coverage of Texas wild-rice increased from fall 2009, and was similar to totals mapped in summer of 2009 (Table 3). Areal coverage of plants increased by nearly 500 m^2 in the uppermost section of the San Marcos River (Map 1, Appendix A). Although recreation pressure is high in this section, many of the plants are found in deep areas preventing them from being tampered with. In addition, floating vegetation mats tend to accumulate on several of these larger stands which discourages disturbance from people. However, this is not an optimal solution, as these mats can block sunlight creating achloric (yellowed) leaves inhibiting growth and can also prevent flower shoots from pushing out of the water restricting reproduction. The large Texas wild-rice plant within Sewell Park increased in width slightly (likely with the inundation due to higher flows of the island that has formed here), but remained much smaller than before the island was formed. The increased rate of sedimentation coming out of Sessom's Creek has contributed to the expansion of BobDog Island just upstream of University Drive (in the Spring Lake Dam Reach). As a result, BobDog Island directs most of the flow along the river-left bank in Sewell Park. This has left many plants along river-right in very shallow water that receives little flow, in turn leading to increased sedimentation along this side of the river. Close monitoring of this stand will continue as it has been identified as a "vulnerable" plant, therefore additional measurements are taken to evaluate how physical habitat affects changes in Texas wild-rice (see Texas wild-rice Physical Observations section).

Total areal coverage in the Map 2 (Appendix A) section increased by 174.6 m^2 from October 2009 to summer 2010. Much of this increase was due to growth of plants within the City Park Reach. Most plants in this reach are found in deeper water (at 2010 flows) and are less vulnerable to recreation disturbance. Total Texas wild-rice coverage increased over 20 m^2 in the Map 3 (Appendix A) section. As in the previous section, growth of individual plants was responsible for the increase in coverage. Maps 4 – 7 (Appendix A) represent sections of the river that see much lower recreation pressure, but habitat is less optimal for Texas wild-rice because much of the river here is shallow and swift. As a result, plants here are more vulnerable to rapid increases in discharge, and stranding from longer periods of low discharge (as seen at Thompson's Island in 2009). Texas wild-rice plants immediately upstream of I-35 were in extremely shallow water throughout much of 2009 making them more vulnerable to herbivory and covering from vegetation mats. The increased flows of 2010 created better habitat for these plants by keeping many of the leaves below the surface of the water, and resulted in growth throughout much of the reach. A few new Texas wild-rice plants were found just downstream of I-35 within the Map 5 section leading to an increase of 9.1 m^2 from October 2009 to summer 2010. Several Texas wild-rice plants disappeared from the Map 7 reach probably due to higher flows as many of them were in shallow areas with higher velocities making them more vulnerable to displacement. Overall, areal coverage of Texas wild-rice increased to over 4,000 m^2 in 2010 (Table 3).

Table 3. Total areal coverage (m^2) of Texas wild-rice (*Zizania texana*) within each study reach in 2009 – 2010 (total includes plants in Spring Lake).

Sampling Period	Map 1	Map 2	Map 3	Map 4	Map 5	Map 6	Map 7	Total Area (m^2)
Critical Period 1 2009	2,599.50	663.2	452.6	492.8	15.9	5.7	47.5	**4,277.2**
Critical Period 3 2009	2,516.60	609.7	433.3	412.7	13.6	2.2	46.3	**4,034.4**
Fall 2009	2,070.80	522.0	362.5	340.6	10.2	3.2	41.6	**3,350.9**
Summer 2010	2,518.6	696.6	383.8	372.7	19.3	3.1	14.0	**4,030.1**

Texas Wild-Rice Physical Observations

Texas wild-rice observations were conducted twice during 2010 because unlike 2009, there were no Critical Period events. These observations were made during comprehensive sampling events (spring and fall). Observations were made on vulnerable stands within the Sewell Park reach (Figure 10) and the I-35 reach (Figure 11), however the area downstream at Thompson's Island no longer contains any Texas wild-rice plants, and therefore is no longer included in the physical measurements. The total coverage of Texas wild-rice observed during 2010 in each "vulnerable" stand in the San Marcos River is presented in Table 4, and observations of trends in areal coverage within each study reach are discussed below. More detailed graphs on observations of root exposure, herbivory, emergence, etc. are found in Appendix B.

Several new vulnerable Texas wild-rice stands were identified in 2009, and monitoring of these stands began with the spring 2009 sampling event. One of these stands, "Sewell Park-1" was broken out as a fragment of the previously grouped stands "Sewell Park 1-3". It is located on river-right, in an area of deep silt substrate with very little downstream flow due to the upstream obstruction of BobDog Island and an island of terrestrial vegetation (within Sewell Park). The two other newly monitored Texas wild-rice stands, "I-35-9" and "I-35-10," are located on river-left in the I-35 reach at a bend in the river where a significant amount of sand and woody debris deposition has occurred over the past two years. This has left the area much shallower, with logs blocking flow to portions of the two stands. In 2010, these two stands have grown together, and are grouped under "I-35-9 and 10".

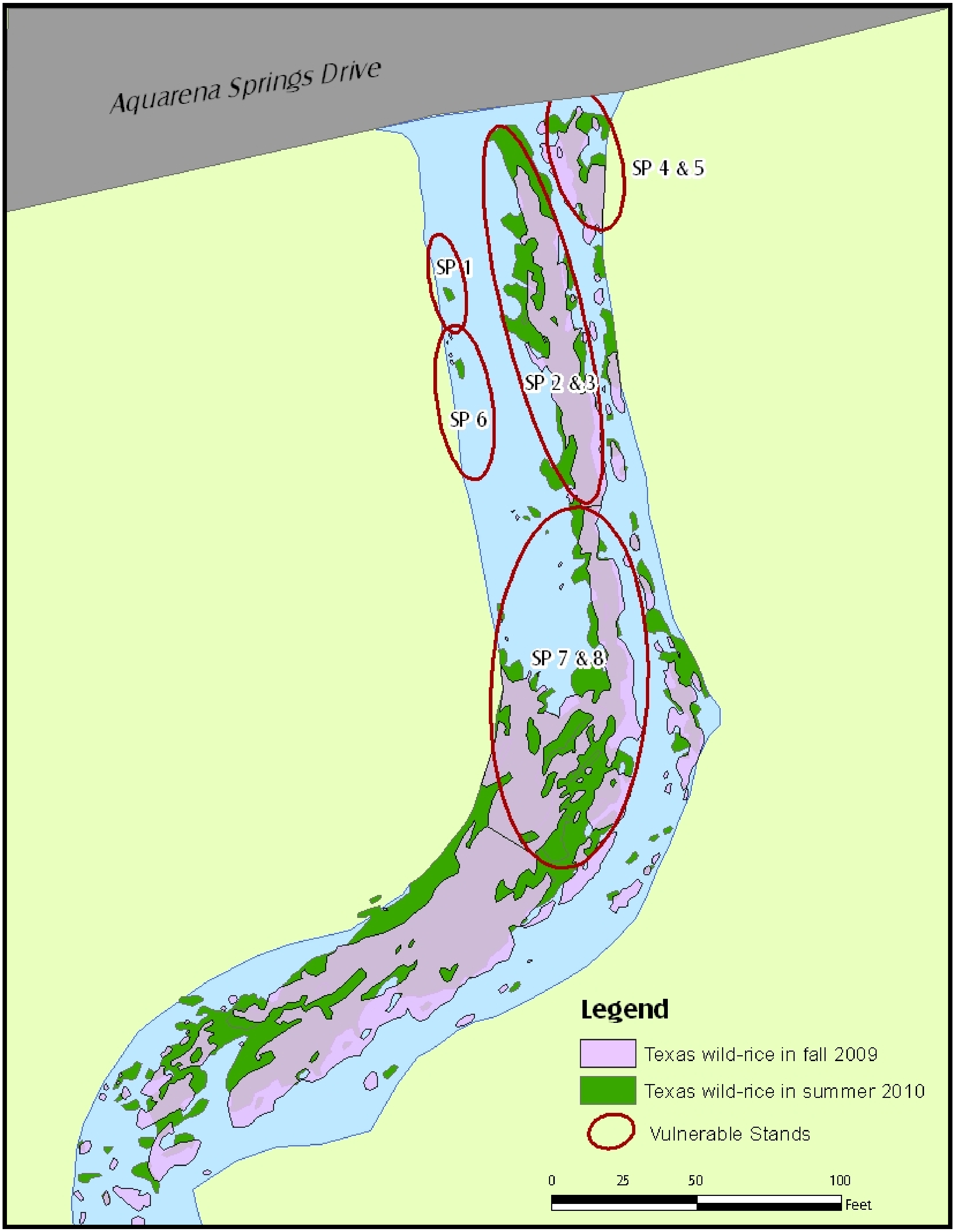


Figure 10. Map of vulnerable Texas wild-rice (*Zizania texana*) stands in the Sewell Park reach.

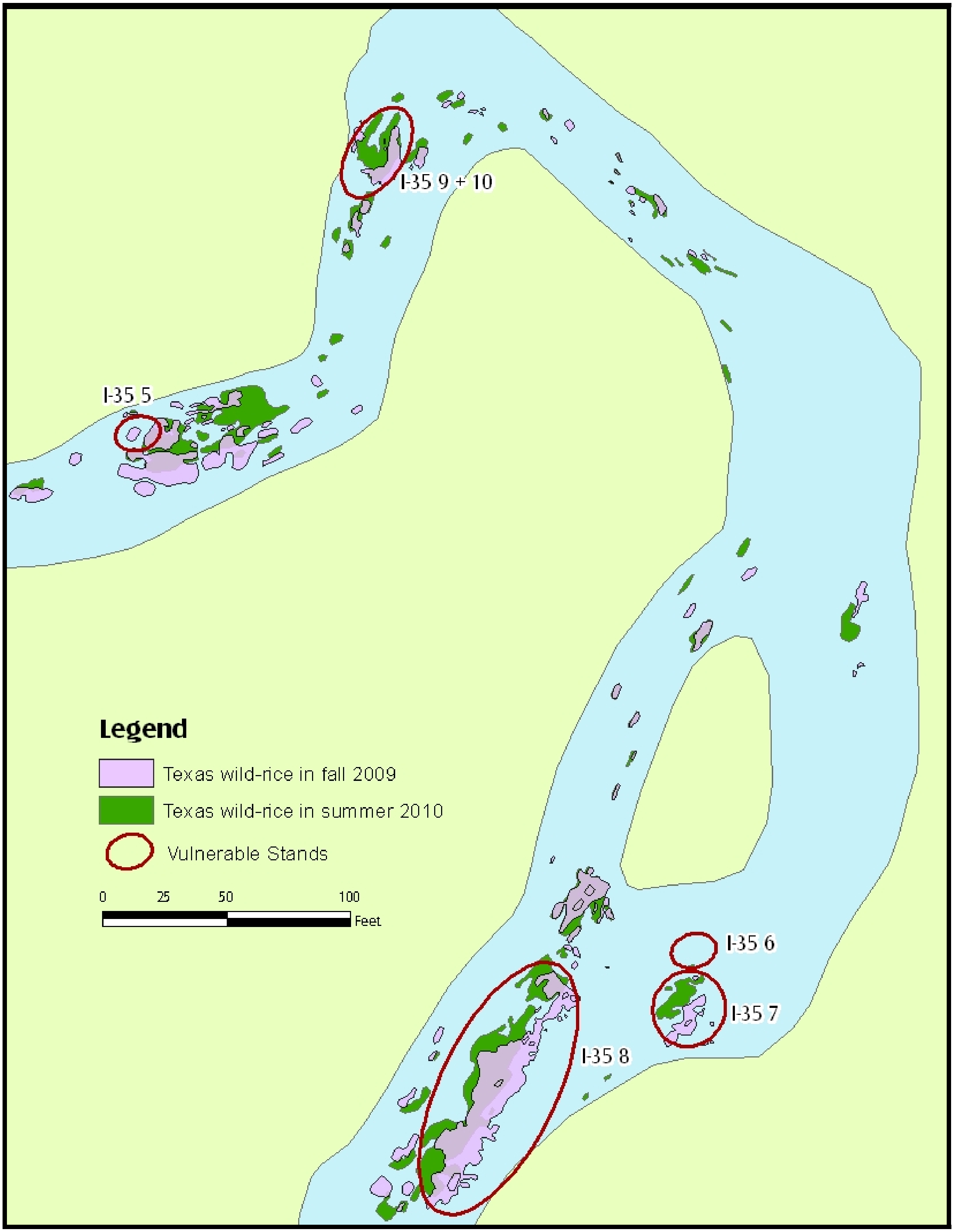


Figure 11. Map of vulnerable Texas wild-rice (*Zizania texana*) stands in the I-35 reach.

Table 4. Areal coverage (m^2) of Texas wild-rice vulnerable stands from summer 2009 to fall 2010.

REACH-STAND NO.[a]	August 2009	September 2009	Fall 2009	Spring 2010	Fall 2010
Sewell Park - 1	0.4	0	0	0.2	1.0
Sewell Park - 2 Sewell Park – 3	161.4	161.3	113.6	154.4	177.0
Sewell Park - 4 & 5	43.7	43.1	41.6	44.4	36.7
Sewell Park - 6	2.2	0.8	0.4	0.7	2.2
Sewell Park - 7 & 8	225.8	226.1	219.8	300.8	276.6
Total Area	**433.5**	**431.4**	**375.4**	**500.2**	**492.4**
I-35 - 5	0.6	0.7	0.5	0.1	0.8
I-35 - 6	0.8	0.8	0.3	0.3	0
I-35 - 7	17.4	17.4	11.0	11.6	13.4
I-35 - 8	153.6	156.5	134.6	111.2	109.7
I-35 – 9[b]	2.2	2.8	3.0	36.6	28.6
I-35 – 10[b]	15.4	14.8	12.2		
Total Area	**190.0**	**193.0**	**161.6**	**159.8**	**152.4**

[a] Many stands grew together to form individual stands after the first sampling period. [b] New stands measured beginning in spring 2009.

Sewell Park Reach

Of the three reaches sampled, Sewell Park has the highest mapped area of "vulnerable" Texas wild-rice stands (Table 4). Areal coverage of Texas wild-rice increased at all stands in Sewell Park from 2009 to 2010. This continues the trend observed throughout much of the river as flows increased above the historical average in early 2010. These vulnerable stands become inundated at greater depths creating better habitat protecting the plants from herbivory. Siltation from Sessom's Creek upstream continues to sustain the island present in the middle of what used to be a large Texas wild-rice plant. Several species of vegetation have established on this island and continued to flourish in 2010 even as water inundated parts of it causing it to shrink slightly. The total area of plants 7 and 8 decreased by almost 25 m^2 in Sewell Park in 2010. Plants 4 and 5 decreased in coverage along the river-right side of the river from spring to fall 2010. This section is often variable depending on how much recreation pressure it sees as it is adjacent to a highly used access point. The lowermost vulnerable stand at Sewell Park fragmented somewhat, but was still higher in areal coverage than early 2009.

Unlike 2009, not a single plant was located in water less than 0.5 feet in depth. Coincidentally, emergence of Texas wild-rice did not exceed 40% in 2010, whereas emergence was not below this level since early 2009. Again, higher flow and accompanying increased water depth is responsible for this difference. To our knowledge, no plants were relocated by USFWS due to stranding in 2010. Root exposure in Sewell Park was much lower in 2010, never exceeding 3.0 (see Appendix B). Another result of higher flows is that floating vegetation mats are less prevalent because they are pushed downstream. Percent coverage in 2010 of these mats did not exceed 7%, the lowest during an entire year since this study's inception. As mentioned earlier, herbivory was low in 2010 (below 3.0 all year) because higher flows result in less of the plant emerging or close enough to the surface for waterfowl to reach.

Unlike 2009, Texas wild-rice in vulnerable areas in Sewell Park started to thrive in 2010. The higher than average flows mitigated significant impacts from recreation, and created expanded areas of quality habitat for Texas wild-rice in vulnerable areas.

I-35 Reach

Unlike the Sewell Park reach, Texas wild-rice in I-35 vulnerable stands decreased in areal coverage from 2009 to 2010 (Table 4). However, this trend has been previously observed in this reach (BIO-WEST 2010b). These changes are likely related to the dynamic nature of this reach, and the fact that it does not experience much recreation pressure (in comparison to areas upstream). Since Rio Vista Dam was removed and replaced by a more flow through system in 2006, the flow dynamics in this reach have created shifting gravel bars and adjusting bank lines. This may be a factor in fragmentation of the large Texas wild-rice plant (I-35-8) in the lower part of the reach. Near the top of this plant a shallower sandbar has been created, and the Texas wild-rice plant has become more fragmented. However, this decrease may also be a result of the slow recovery from the effects (stranding, increased herbivory/root exposure) of low-flows over the last couple of years. Plant 6 in this reach was no longer present by fall 2010 which was not unexpected as this stand had been shrinking since spring 2009, and swifter currents in 2010 likely dislodged the remaining plant.

As at Sewell Park, the higher flows in 2010 resulted in no plants found in water less than 0.5 ft. deep whereas nearly 70% of these plants (in vulnerable areas) were in water that shallow at some time during 2009. Consequently, percent emergence remained near 20% in 2010 less than half of the amount of emergence during much of 2009. As a result, herbivory was around 2.0 (see Appendix B) in the I-35 Reach in 2010. More flowering was observed in fall and likely a result of it being too early in the season by the time the spring sampling effort occurred. Root exposure was slightly less in 2010, and vegetation mats never covered more than 7% of any of the plants. In general, Texas wild-rice plants in vulnerable areas faired better in 2010 because higher flows result in better habitat (deeper water leaves plants less exposed to herbivory and stranding) conditions. The improved areal coverage of Texas wild-rice in vulnerable areas in 2010 is also likely facilitated by the lack of any significant high-flow events during the year. These high-flow events tend to rip the plants out, or shift sediment which either covers or exposes some or all of the plant. Continuous measurements across a range of flows (and flow events) will provide a better understanding of the habitat requirements of this endangered species, and will allow for informed management of Texas wild-rice in the future.

Thompson's Island Reach (Natural)

As stated earlier, these plants are no longer found in this reach.

Fountain Darter Sampling Results

Drop Nets

In 2010, drop netting was conducted on the San Marcos River in the comprehensive spring (April 29-30) and fall (Oct. 27-28) sampling events. No Critical Period monitoring was conducted on the San Marcos River in 2010. The number of drop net sites and vegetation types sampled in each reach per event is presented in Table 5. 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 5. Drop net sites and vegetation types sampled in each reach in the San Marcos River.

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)**

One hundred ninety-nine fountain darters were captured in the spring 2010 drop net sampling effort, whereas, 99 darters were captured in fall 2010. Over the course of the study, the number of darters captured per event has ranged from 24 in February 2002 to 616 in April 2007. To examine long-term trends in the fountain darter population relative to flow, abundance of fountain darters in each sample period were plotted over mean daily discharge throughout the study period (Figure 12). Due to the extremely variable daily discharge data no discharge-abundance relationships are obvious from this comparison. However, a linear trendline suggests the abundance of fountain darters in drop net samples has increased over the study period (Figure 12).

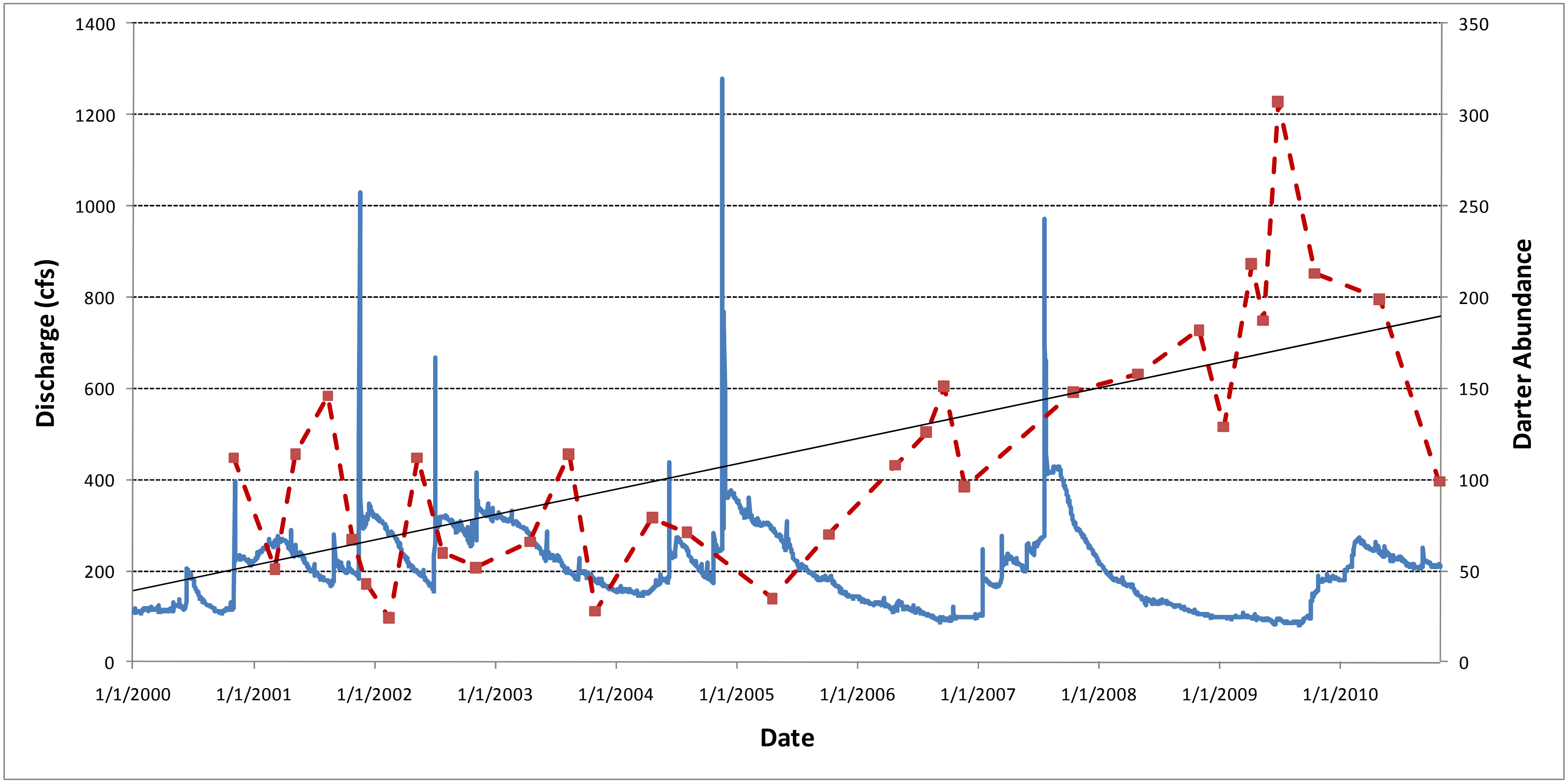


Figure 12. Mean daily discharge (blue line) and fountain darter abundance in drop net samples (red dotted line) over the study period.

To further explore the relationship between darter abundance and discharge, a scatterplot of daily mean discharge for each sample date and fountain darter abundance was developed (Figure 13). This figure demonstrates that as discharge increases, the number of fountain darters captured in each drop net event tends to decrease. This trend is likely influenced by clumping of darters into more limited habitat under lower flows making them more likely to be caught.

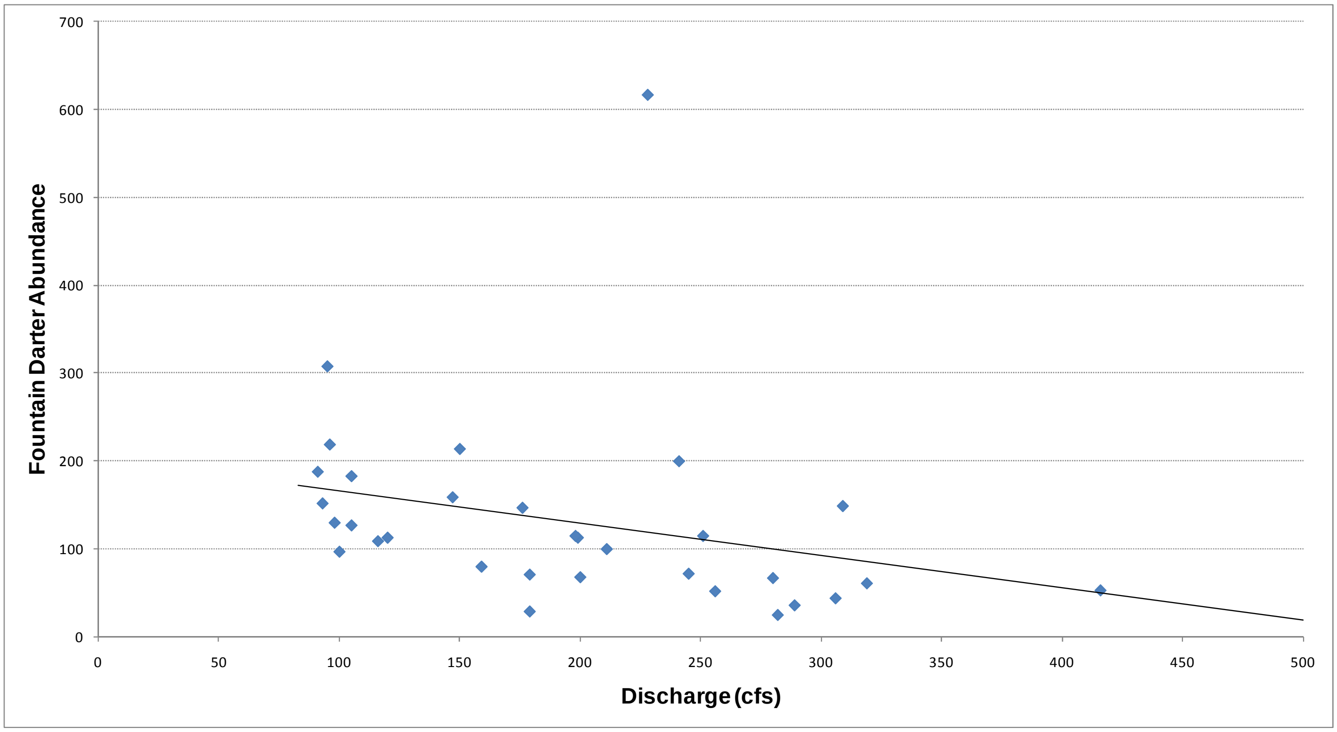


Figure 13. Scatterplot of fountain darter abundance in drop net samples versus daily mean discharge (cfs) on each sample date.

Submerged aquatic vegetation is a critical component of fountain darter habitat in the San Marcos River, as demonstrated by the density of darters in open habitats (zero) versus vegetated habitats (5.1-8.0/m^2, Figure 14). Fountain darter density varies between vegetation types, demonstrating that some vegetation types provide more suitable habitat than others. For example, fountain darter densities calculated from drop net data in the native vegetation type *Cabomba* (8.0/m^2) are higher than those observed in non-native *Hygrophila* (5.3/m^2, Figure 14). Fountain darter densities in native *Potamogeton* (5.6/ m^2) and non-native *Hydrilla* (6.1/m^2) are intermediate.

Although there is variation in densities between vegetation types in the San Marcos River drop net data, the magnitude of this variation is considerably smaller than in the Comal Springs/River ecosystem (BIO-WEST 2011). In the Comal system, certain vegetation types such as filamentous algae and bryophytes exhibit extremely high densities (24-26 fountain darters/m^2) resulting in an overall greater number of darters. In the San Marcos, filamentous algae and bryophytes are only found in Spring Lake. Although this area is not sampled by drop netting, dip net and SCUBA survey data confirms a high abundance of fountain darters in these vegetation types within Spring Lake.

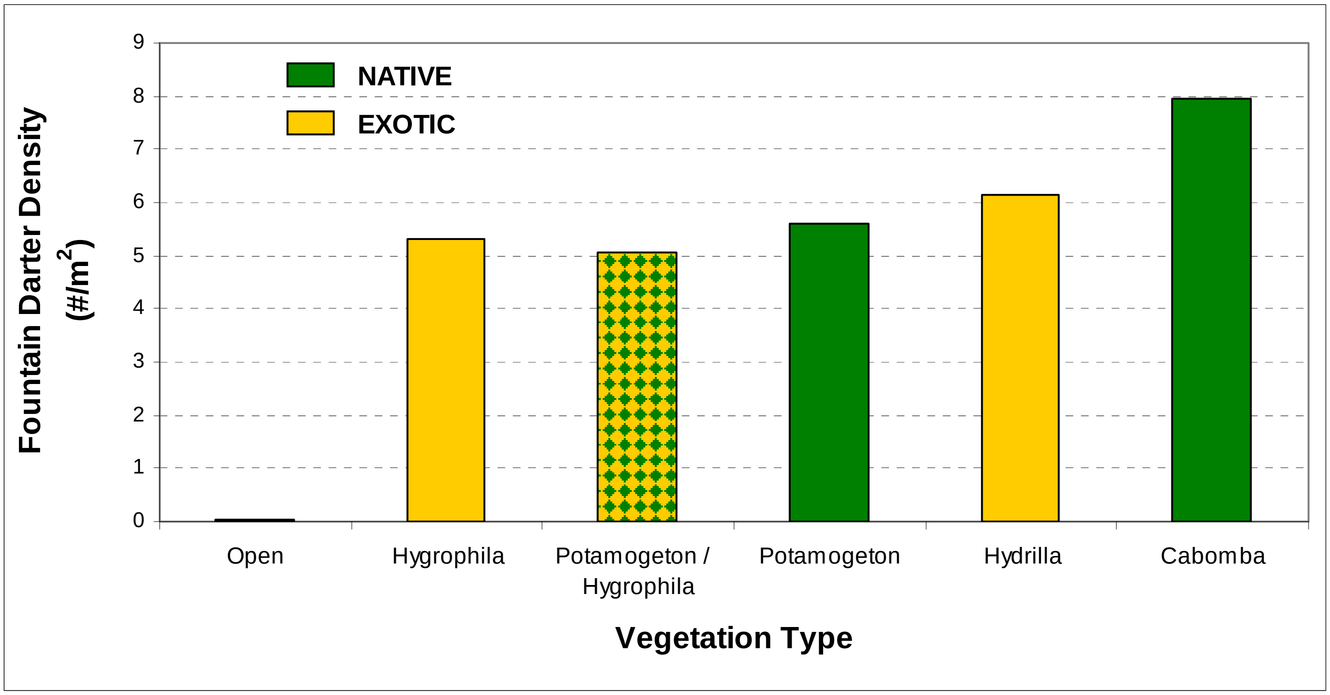


Figure 14. Density of fountain darters collected by vegetation type in the San Marcos River (2000-2010).

The size-class distribution for fountain darters collected by drop net from the San Marcos River during all sampling events combined in 2010 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 15 and 16) the size-class distributions reveal trends similar to those observed in the Comal Springs/River ecosystem. Fall samples from the I-35 Reach are dominated by larger individuals while juvenile fountain darters are most abundant in spring samples suggesting a spring reproductive peak. However, some limited reproduction seems to be occurring in the fall at the City Park Reach. Length frequency data from areas of high quality habitat in Spring Lake also suggests year-round reproduction (see dip net results).

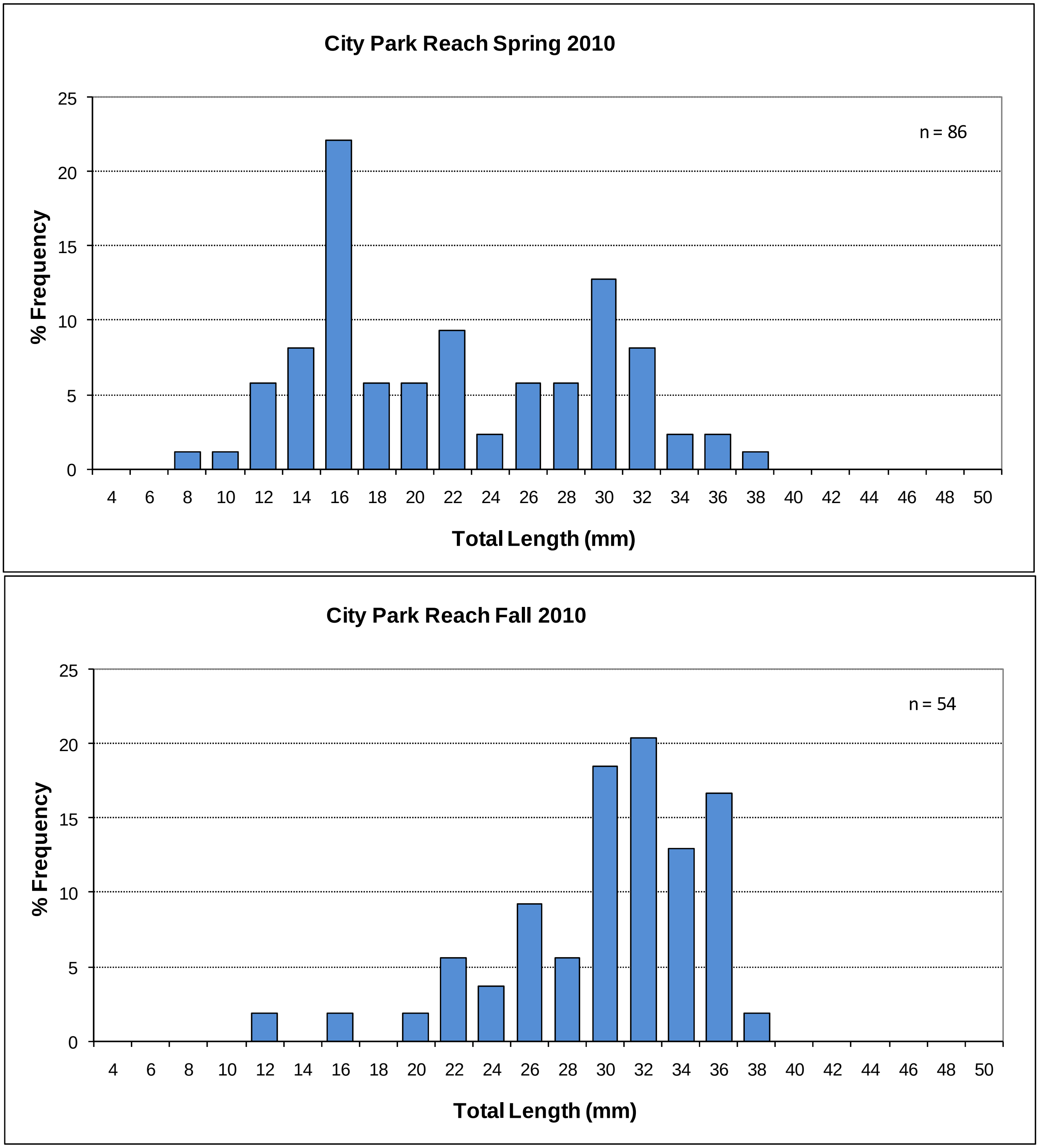


Figure 15. Length frequency distributions of fountain darters collected from the City Park Reach in spring and fall 2010.

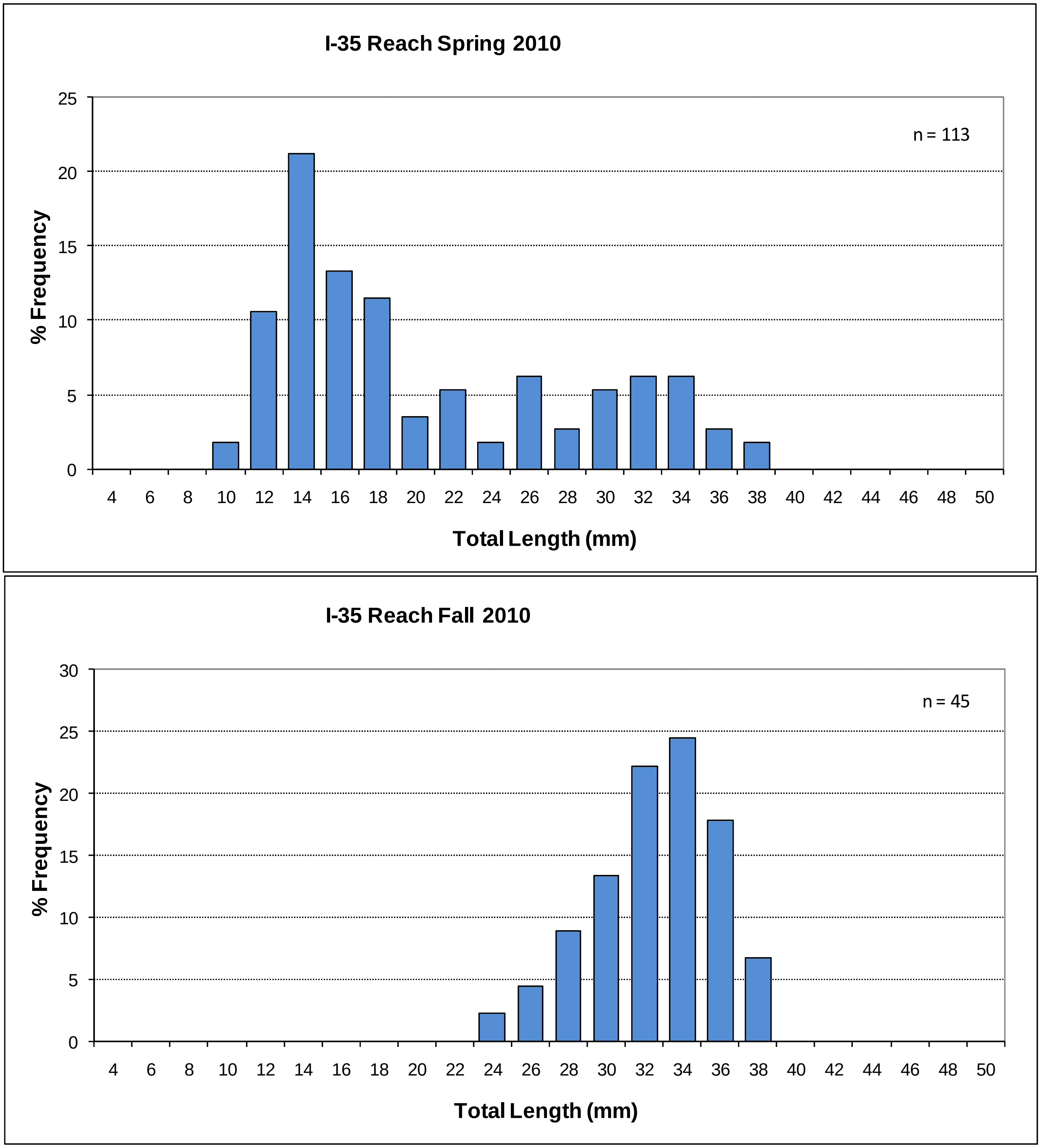


Figure 16. Length frequency distributions of fountain darters collected from the I-35 Reach in spring and fall 2010.

Estimates of fountain darter population abundance were based on changes in vegetation composition and abundance and average density of fountain darters found in each, as described in the methods section (Figure 17). Data from the Spring Lake Dam Reach were not included in these estimates because drop net sampling was not conducted in that reach. As the variation in the average density of fountain darters found among vegetation types in the San Marcos River is smaller than observed for the Comal system, changes in coverage of various vegetation types do not have as large of an effect on normalized population estimates. Therefore, population estimates in the San Marcos River are less variable than those from the Comal Springs/River ecosystem. As evident in the Comal River, high flows result in scouring of vegetation and thus, lower normalized population estimates. Fountain darter population estimates under low-flows are quite variable, but impacts have been noted. For example, the lowest population estimate in the study period occurred in fall 2009 after a period of extended low-flows. During this time, the City Park Reach was shallower than in previous years, and recreational activity (swimmers and tubers) in the area uprooted much of the vegetation resulting in a sharp decline in the fountain darter population estimate for this reach. However, the vegetation community quickly recovered once higher flows returned and recreation subsided over the winter months, and the spring 2010 population estimate was the highest recorded during the study period. This high estimate was a result of the recovery of *Hydrilla* by spring 2010 (2,380 m^2 surface area, 6.13 darters/m^2 density). This highlights the recovery potential of aquatic vegetation and resulting fountain darter population estimate (as calculated for this study) following a period of extended low-flows.

Following the high population estimate in spring 2010, flow conditions remained higher than average for most of the remainder of the year. Decreases in aquatic vegetation and corresponding fountain darter abundance were not observed from spring to fall 2010 for the I-35 reach. However, a large decline in both was observed in the City Park Reach, driven largely by recreational pressure in summer.

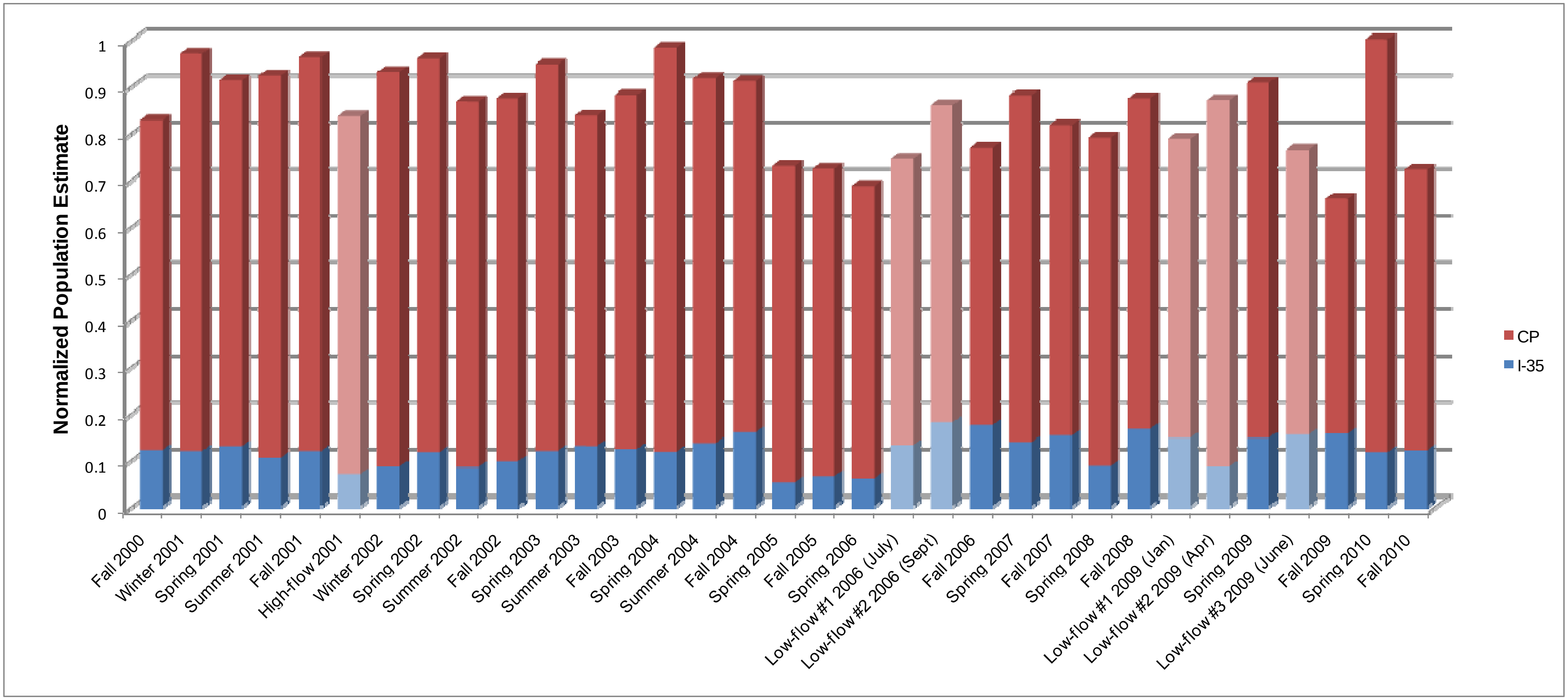


Figure 17. Population estimates of fountain darters in the City Park and I-35 sample reaches; values are normalized to a proportion of the maximum observed in any single sample. Lighter colors represent critical period sampling events.

In addition to fountain darters, there have been 40,591 fishes representing at least 27 other taxa collected by drop netting since 2000 (Table 6). Of these, seven species are considered introduced or exotic to the San Marcos Springs/River ecosystem. Commonly captured exotic or introduced species include the rock bass (*Ambloplites rupestris*), Rio Grande cichlid (*Cichlasoma cyanoguttatum*), redbreast sunfish (*Lepomis auritus*), and the sailfin molly (*Poecilia latipinna*). Although these species are introduced to the system, most have been established for decades, and negative impacts to the fountain darter have not been noted. However, one exotic species of particular concern is the armadillo del rio (*Hypostomus plecostomus.*). Although these fish are rarely captured in drop nets, based on visual observations they are abundant in the system. This herbivorous species has the potential to drastically affect the vegetation community and thus impact critical fountain darter habitats and food supplies.

Table 6. Fish species and the number of each collected during drop-net sampling in the San Marcos River from 2000-2010.

Family	Scientific Name	Common Name	Status	Number Collected	
				2010	2000-2010
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	Native	0	1
Cyprinidae	*Cyprinella venusta*	Blacktail shiner	Native	0	6
	Dionda nigrotaeniata	Guadalupe roundnose minnow	Native	2	44
	Notropis amabilis	Texas shiner	Native	0	65
	Notropis chalybaeus	Ironcolor shiner	Native	13	98
	Notropis sp.	Unknown shiner	Native	0	4
Catostomidae	*Moxostoma congestum*	Gray redhorse	Native	0	2
Characidae	*Astyanax mexicanus*	Mexican tetra	Introduced	1	27
Ictaluridae	*Ameiurus melas*	Black bullhead	Native	0	1
	Ameiurus natalis	Yellow bullhead	Native	5	98
	Noturus gyrinus	Tadpole madtom	Native	0	4
Loricariidae	*Hypostomus plecostomus*	Armadillo del rio	Introduced	6	38
Poeciliidae	*Gambusia* sp.	Mosquitofish	Native	2,135	34,017
	Poecilia latipinna	Sailfin molly	Introduced	2	134
Centrarchidae	*Ambloplites rupestris*	Rock bass	Introduced	58	487
	Lepomis auritus	Redbreast sunfish	Introduced	4	59
	Lepomis cyanellus	Green sunfish	Native	0	8
	Lepomis gulosus	Warmouth	Native	0	23
	Lepomis macrochirus	Bluegill	Native	3	75
	Lepomis megalotis	Longear sunfish	Native	0	18
	Lepomis microlophus	Redear sunfish	Native	0	1
	Lepomis miniatus	Redspotted sunfish	Native	42	884
	Lepomis sp.	Sunfish	Native/Introduced	3	156
	Micropterus salmoides	Largemouth bass	Native	0	46
Percidae	*Etheostoma fonticola*	Fountain darter	Native	298	4,181
	Percina apristis	Guadalupe darter	Native	1	11
	Percina carbonaria	Texas logperch	Native	0	1
Cichlidae	*Cichlasoma cyanoguttatum*	Rio Grande cichlid	Introduced	4	86
	Oreochromis aureus	Blue tilapia	Introduced	0	16
Total				2,577	40,591

Among exotic species, the giant ramshorn snail also elicits concern because of its recent impacts (late 1980s - early 1990s) on aquatic vegetation in the Comal River. During the late 1980s and early 1990s, snails were reported to be extremely abundant in the Comal System, and apparently denuded macrophyte beds in portions of Landa Lake (Horne et al. 1992). During this period, between 2 and 12 million ramshorn snails were believed to be present in the Comal Springs/Landa Lake area (Arsuffi 1993). Although the giant ramshorn snail is present in the San Marcos River, large concentrations of snails have not been reported here. Based on the 480 dropnet samples collected during this study, density of giant ramshorn snail in the San Marcos River is approximately $0.05/m^2$. Data collected over the past decade suggests that current giant ramshorn snail numbers are low, but monitoring should continue because of the impact that this exotic species can have on the vegetation community under higher densities.

Dip Nets

The boundary for each section where dip net collections were conducted is depicted on Figure 18. Section numbers are included to be consistent with the USFWS classification system for the San Marcos River. In 2009, to assess changes occurring on the lower river, a new sample reach was added on the lower San Marcos River in Section 12 near Todd Island. Data gathered from the City Park Reach are presented in Figure 19, and data from the Hotel Reach and I-35 Reach are graphically represented in Appendix B. Given the limited dataset from the new Todd Island Reach, no graphs were generated.

The highest number of fountain darters collected in dip nets at the City Park Reach occurred in fall 2009 (65). In this reach, typical areas sampled are along the river-right edge in vegetation over gravel substrates. During the lower than average discharge in 2009, these areas were first to become shallow and the aquatic vegetation suffered which reduced the overall habitat quality. Prior to the fall 2009 sampling effort flows increased to near average conditions likely redistributing fountain darters to these edge habitats resulting in the high numbers observed in fall 2009. As flows continued to increase in 2010, total fountain darters in the City Park Reach caught in spring were above the long-term spring average (29.5), which included the typical spring reproductive peak. In fall 2010, however, total darters (28) were below the long term fall average (37.8) possibly a result of darters being distributed in a wider area due to the increased flows. The overall number of fountain darters collected in the Hotel Reach by dip nets continues to be much greater than that found in the other three reaches, despite less sampling time at this location (Appendix B). Lower abundance from the Hotel Reach in fall 2010 resulted from moving the sampling area to a nearby location due to walkway construction in the usual sampling area. Filamentous algae present in the Hotel Reach 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 (5-15 mm). This size class represents fountain darters <60 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 length frequency data from these locations. Analysis of seasonal changes in length frequency observed at the Todd Island Reach is not yet possible due to the limited dataset. The overall number of fountain darters collected in the Todd Island Reach is much lower than all other reaches and has ranged from 7 in fall 2009 to 16 in fall 2010. Because this reach is situated in the lower reaches of the San Marcos River, aquatic vegetation is more sparse, and the areas of bare substrate between them large. This lack of connectivity may contribute to the relative lack of fountain darters moving to these areas.

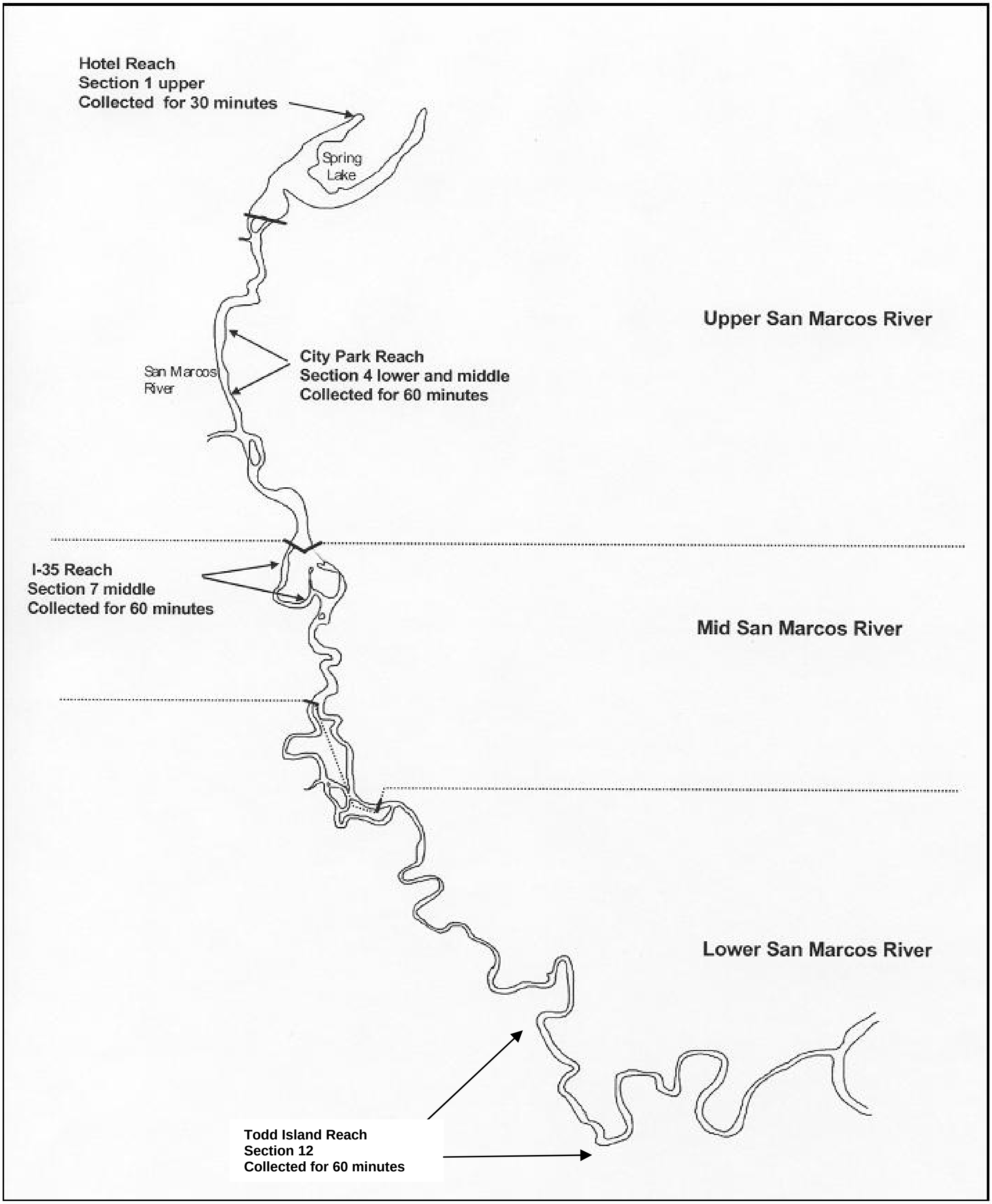


Figure 18. Areas where fountain darters were collected with dip nets, measured, and released in the San Marcos River.

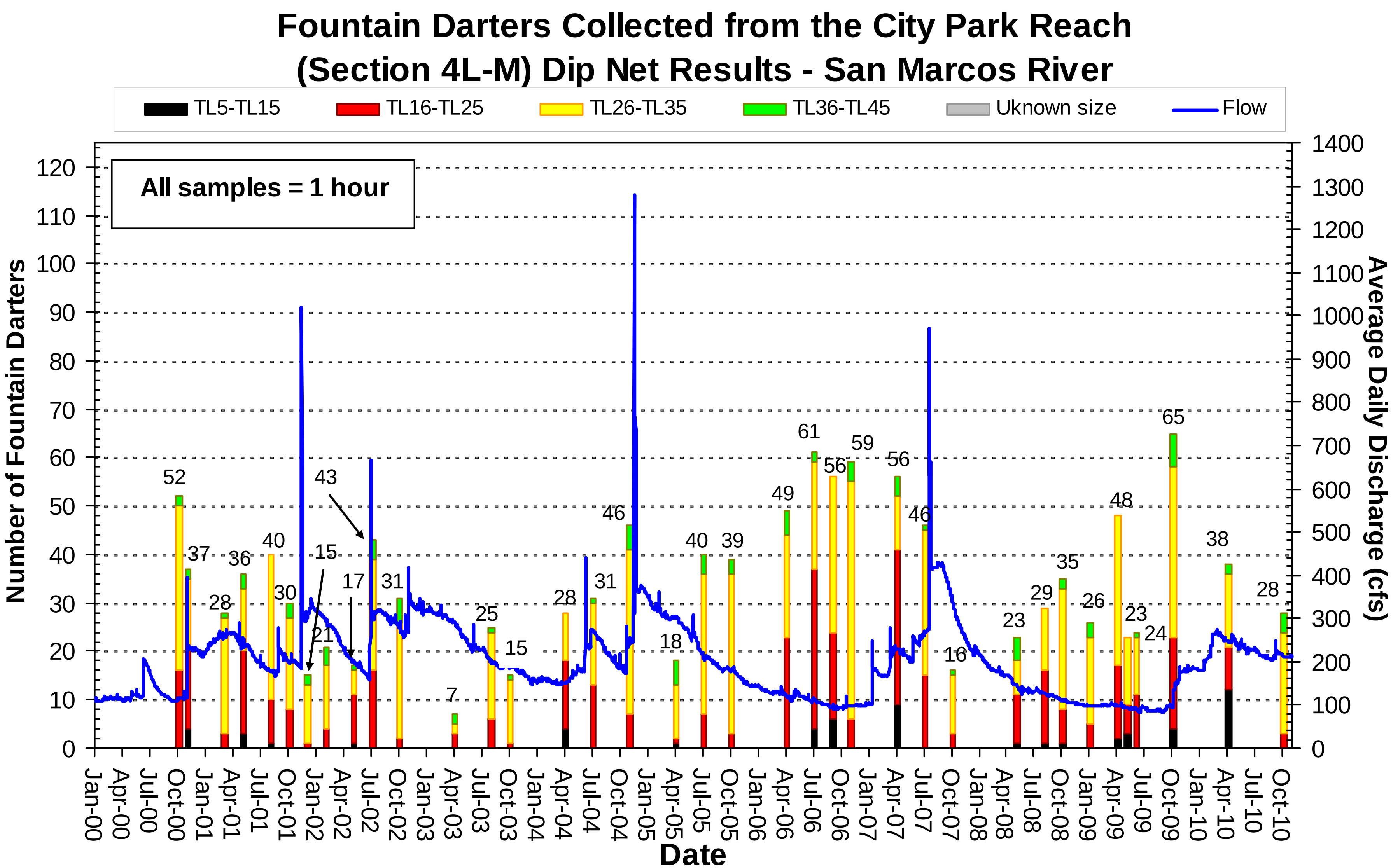


Figure 19. Number of fountain darters collected from the City Park Reach (section 4L-M) of the San Marcos Springs/River ecosystem using dip nets.

Presence/Absence Dipnetting

In 2010, presence/absence dip netting was conducted on the San Marcos River during the annual spring (April 22) and fall (October 20) sampling periods. No Critical Period sampling efforts were conducted on the San Marcos River in 2010.

The percentage of sites in which fountain darters were present during each sample is presented in Figure 20. Although this indicator had dropped to its lowest value (fountain darters present at 36% of sites) in fall 2009 after extended low-flows, it quickly rebounded to its highest value in spring 2010 (62%) reflecting similar changes observed in drop net samples. It then dropped to 46% by fall 2010, which is slightly below the long-term average of 50%. Similar to aquatic vegetation, fountain darter numbers increased over winter when recreation pressure is lessened, and decreased over summer when recreation pressure is highest. 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.

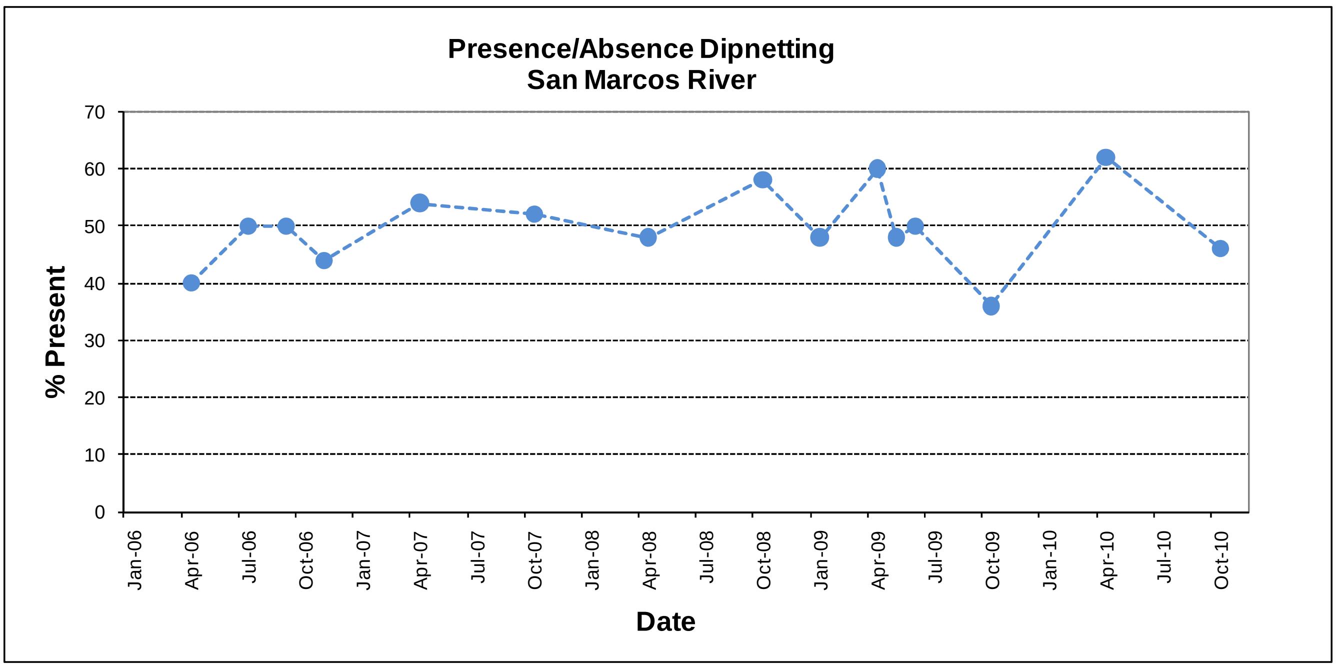


Figure 20. Percentage of sites (N = 50) in which fountain darters were present in the San Marcos River.

San Marcos Salamander Visual Observations

Salamander populations varied widely in 2010, as observed in previous years (Figures 21-23). Salamander densities increased at each site from fall 2009 to spring 2010 as flows increased above the historical average. However, decreases were observed from spring to fall 2010 at all sites. Overall, salamander densities observed during 2009 are not considerably different than observed in 2008 or 2010 indicating that the extended duration of low flows experienced that year had little overall effect on the

San Marcos salamander population. Interestingly, the fall 2010 (near average flow conditions) salamander densities were considerably lower than observed during spring 2010 (higher than average flow conditions) or the previous two years under lower spring flow conditions. This same trend is evidenced in fall 2007 at above average flow conditions. By fall 2010, salamander densities decreased by 50% at Sample Area 2 (Hotel Reach), 40% at Sample Area 14, and 60% at Sample Area 21 (upper section of the Spring Lake Dam Reach). The large decrease at Sample Area 21 is likely explained by recreational impacts following summer time activities. As experienced in 2009, rocks that are important salamander habitat were moved to create dams and sculptures (Figure 9) in this section of the San Marcos River in 2010. At this time, we are unable to explain the considerable decrease at the two Spring Lake sample areas in 2010. Continued monitoring of these sites will help us in understanding how changes in spring flow, vegetation composition, and recreation pressure can affect this federally threatened species.

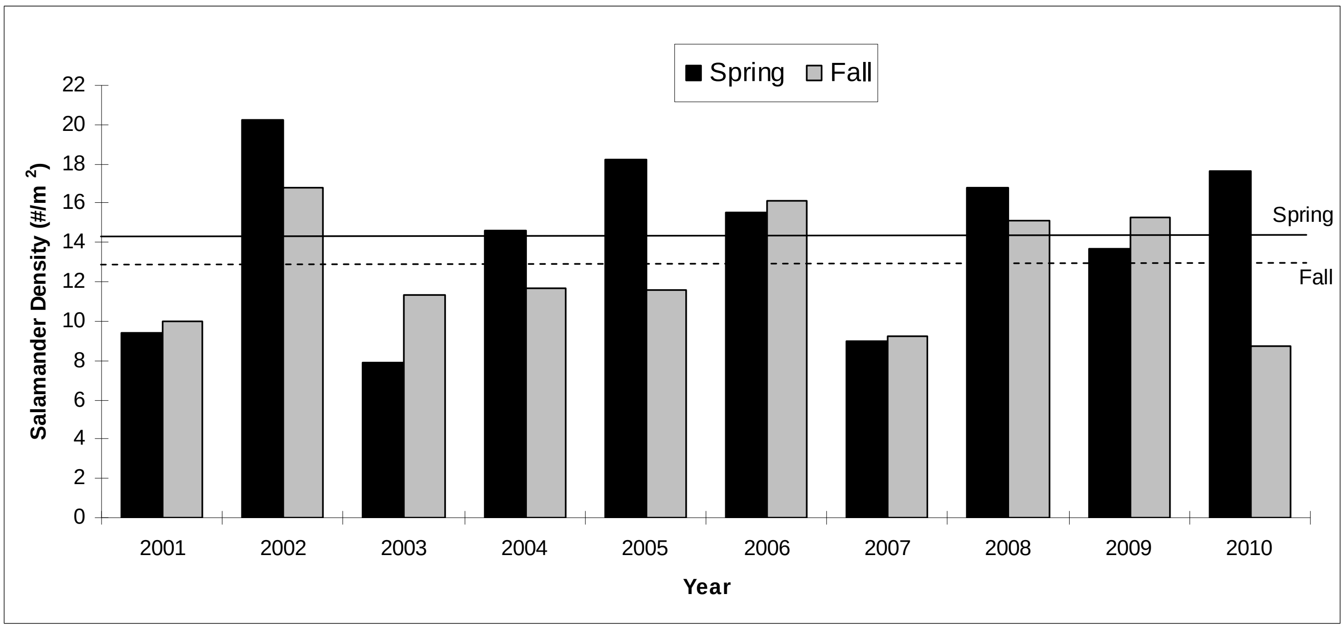


Figure 21. Salamander densities at Sample Area 2 (Hotel Reach) from 2001 – 2010. Lines represent average spring and fall densities.

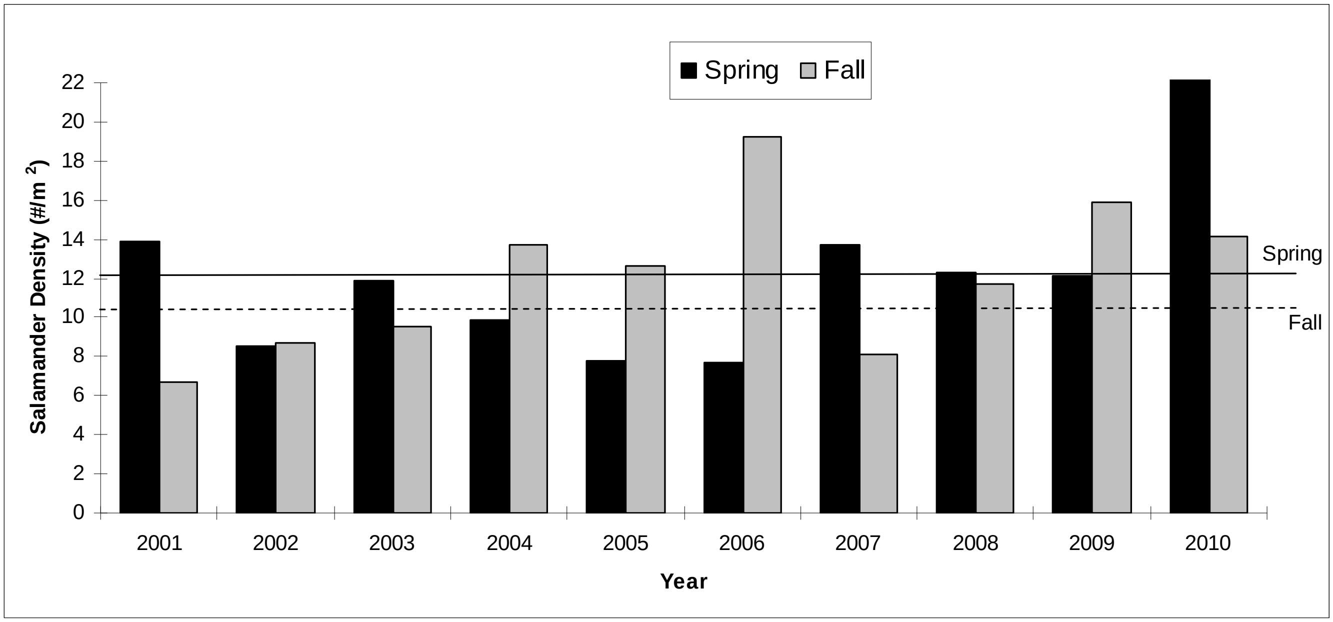


Figure 22. Salamander densities at Sample Area 14 (Riverbed Site) from 2001 – 2010. Lines represent average spring and fall densities.

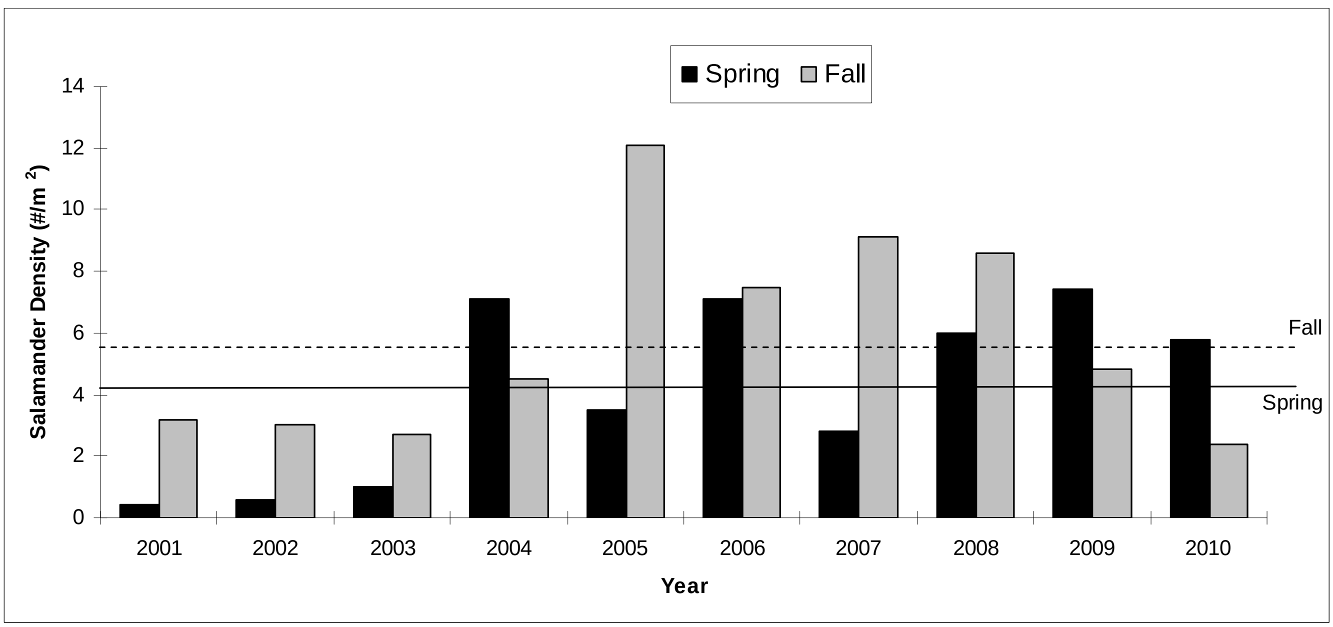


Figure 23. Salamander densities at Sample Area 21 (Spring Lake Dam) from 2001 – 2010. Lines represent average spring and fall densities.

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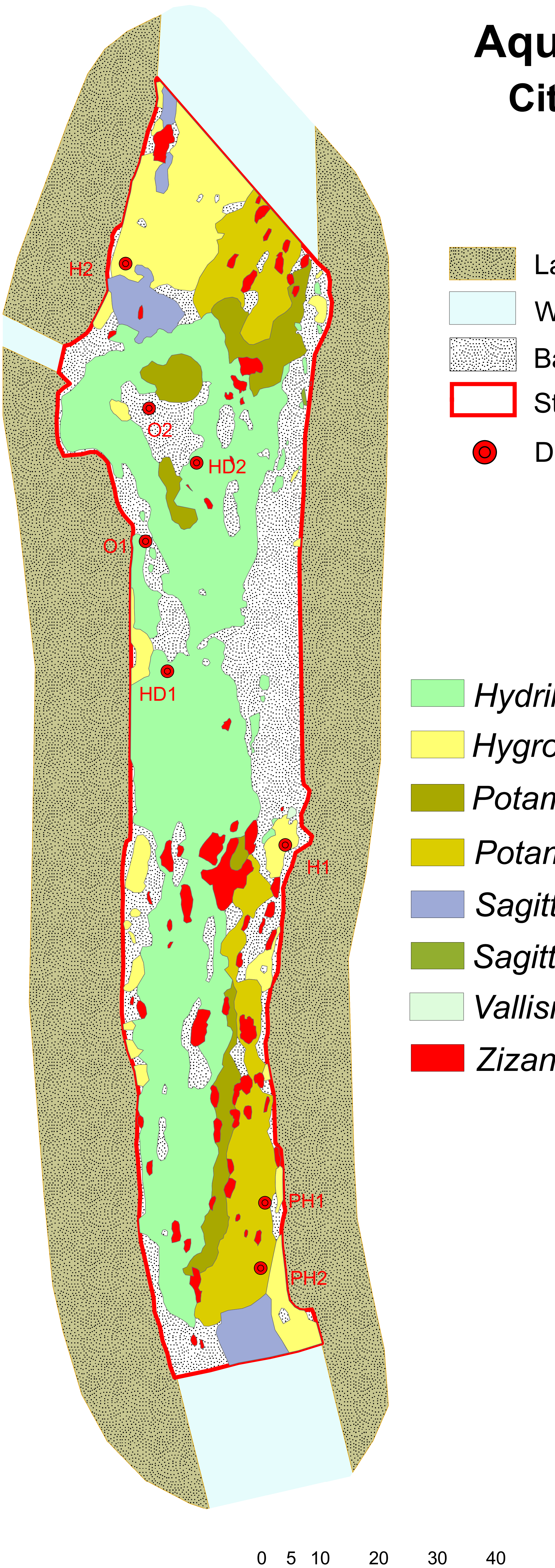
APPENDIX A:
AQUATIC VEGETATION MAPS

City Park Reach

San Marcos River Aquatic Vegetation

City Park - Spring

April 21, 2010



Land

Water

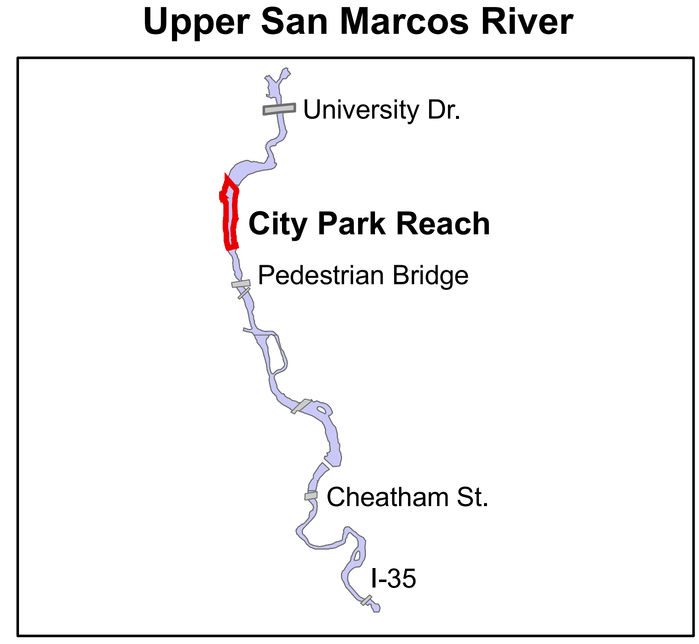
Bare Substrate

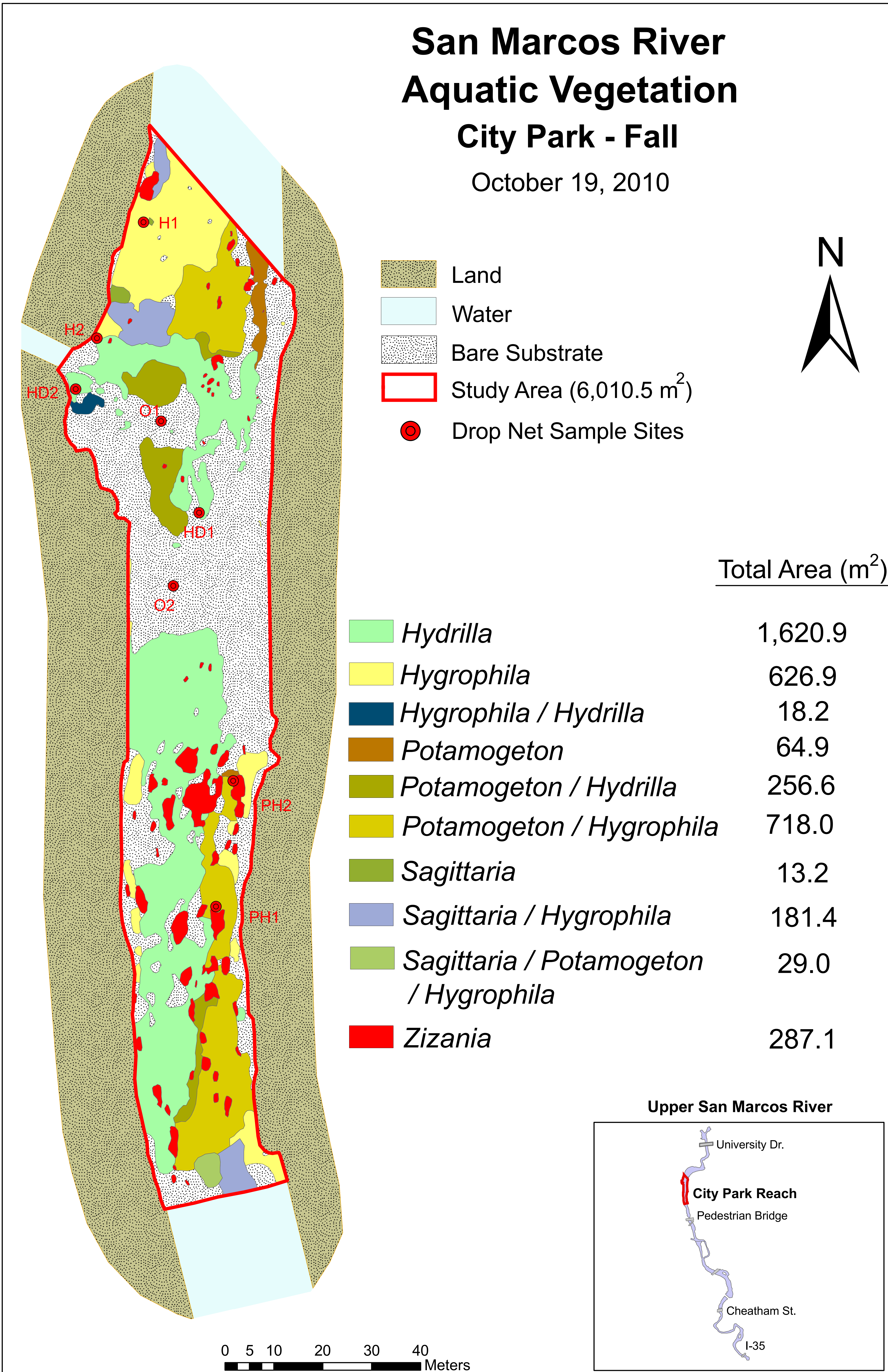
Study Area (6,010.5 m^2)

Drop Net Sample Sites

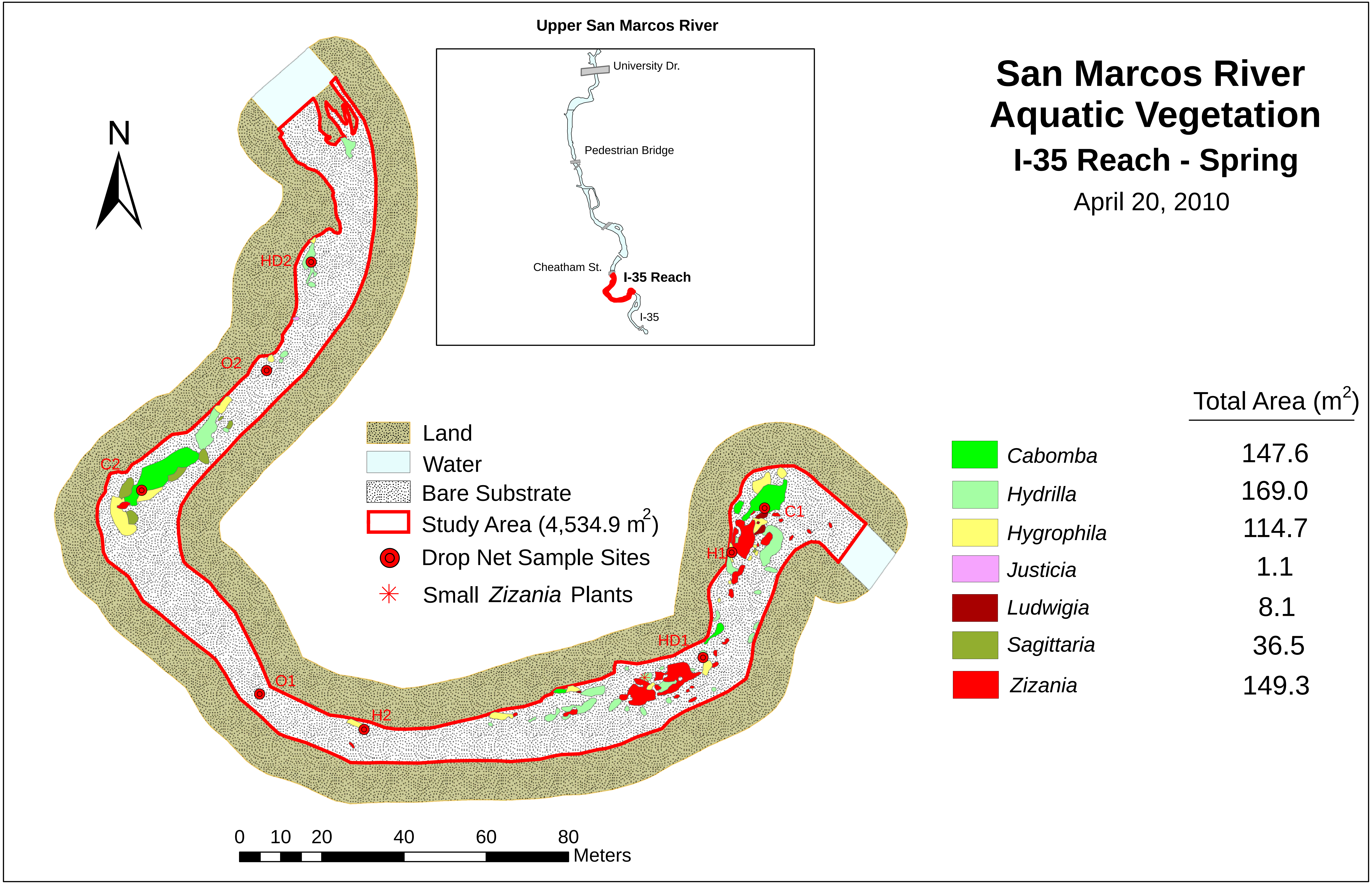
	Total Area (m^2)
Hydrilla	2,379.7
Hygrophila	668.8
Potamogeton / Hydrilla	355.7
Potamogeton / Hygrophila	651.1
Sagittaria / Hygrophila	209.4
Sagittaria	1.8
Vallisneria	2.3
Zizania	276.2

Upper San Marcos River




San Marcos River
Aquatic Vegetation
City Park - Fall
October 19, 2010
N
Land
Water
Bare Substrate
Study Area (6,010.5 m2)
Drop Net Sample Sites
H1
H2
HD2
O1
HD1
O2
PH2
PH1
Total Area (m2)
Hydrilla 1,620.9
Hygrophila 626.9
Hygrophila / Hydrilla 18.2
Potamogeton 64.9
Potamogeton / Hydrilla 256.6
Potamogeton / Hygrophila 718.0
Sagittaria 13.2
Sagittaria / Hygrophila 181.4
Sagittaria / Potamogeton / Hygrophila 29.0
Zizania 287.1
Upper San Marcos River
University Dr.
City Park Reach
Pedestrian Bridge
Cheatham St.
I-35
0 5 10 20 30 40
Meters

IH-35 Reach

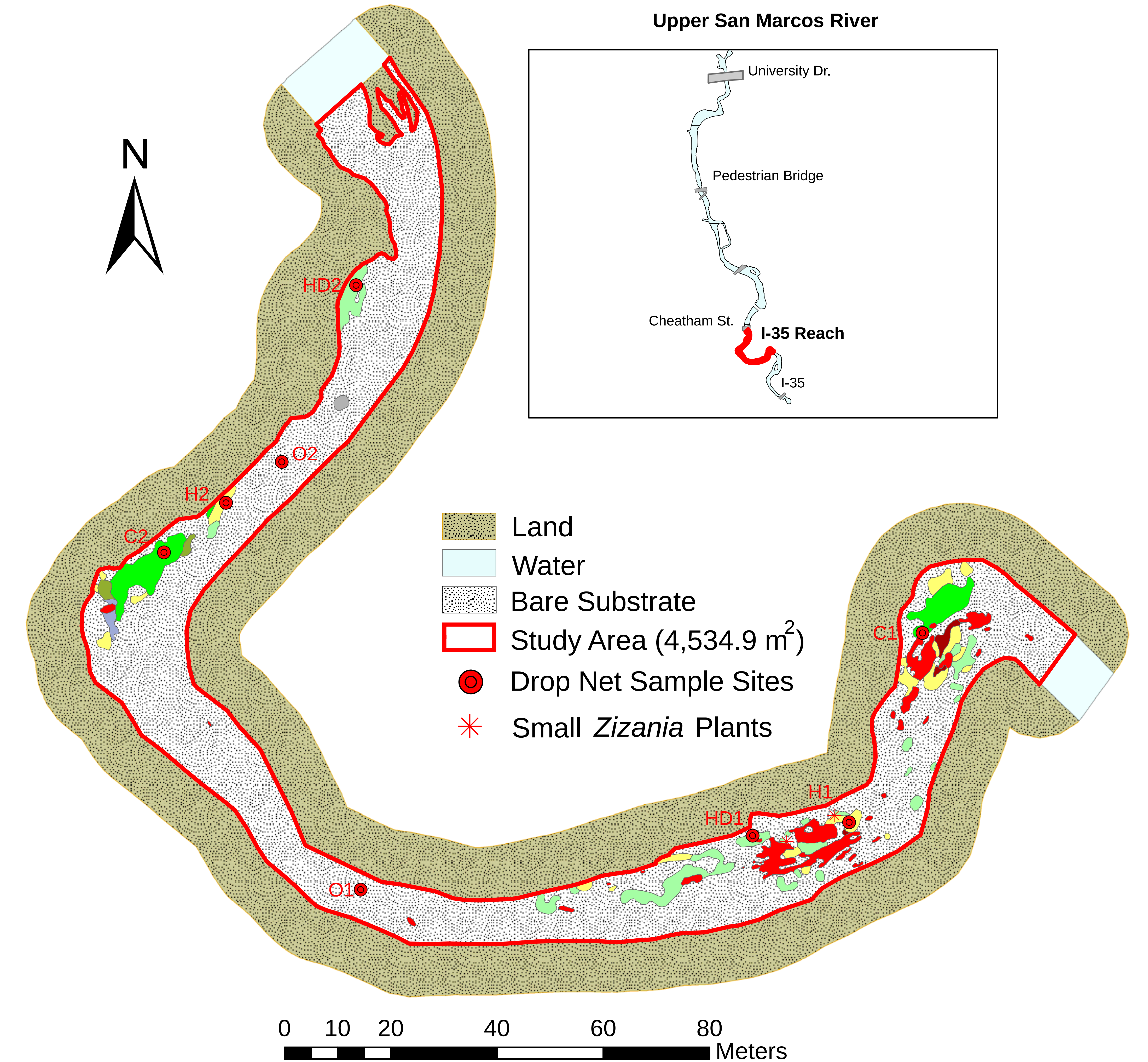


San Marcos River
Aquatic Vegetation
I-35 Reach - Spring
April 20, 2010
Upper San Marcos River
University Dr.
Pedestrian Bridge
Cheatham St.
I-35 Reach
I-35
N
HD2
O2
C2
O1
H2
HD1
H1
C1
Land
Water
Bare Substrate
Study Area (4,534.9 m2)
Drop Net Sample Sites
Small Zizania Plants
Total Area (m2)
Cabomba 147.6
Hydrilla 169.0
Hygrophila 114.7
Justicia 1.1
Ludwigia 8.1
Sagittaria 36.5
Zizania 149.3
0 10 20 40 60 80
Meters

San Marcos River Aquatic Vegetation

I-35 Reach - Fall

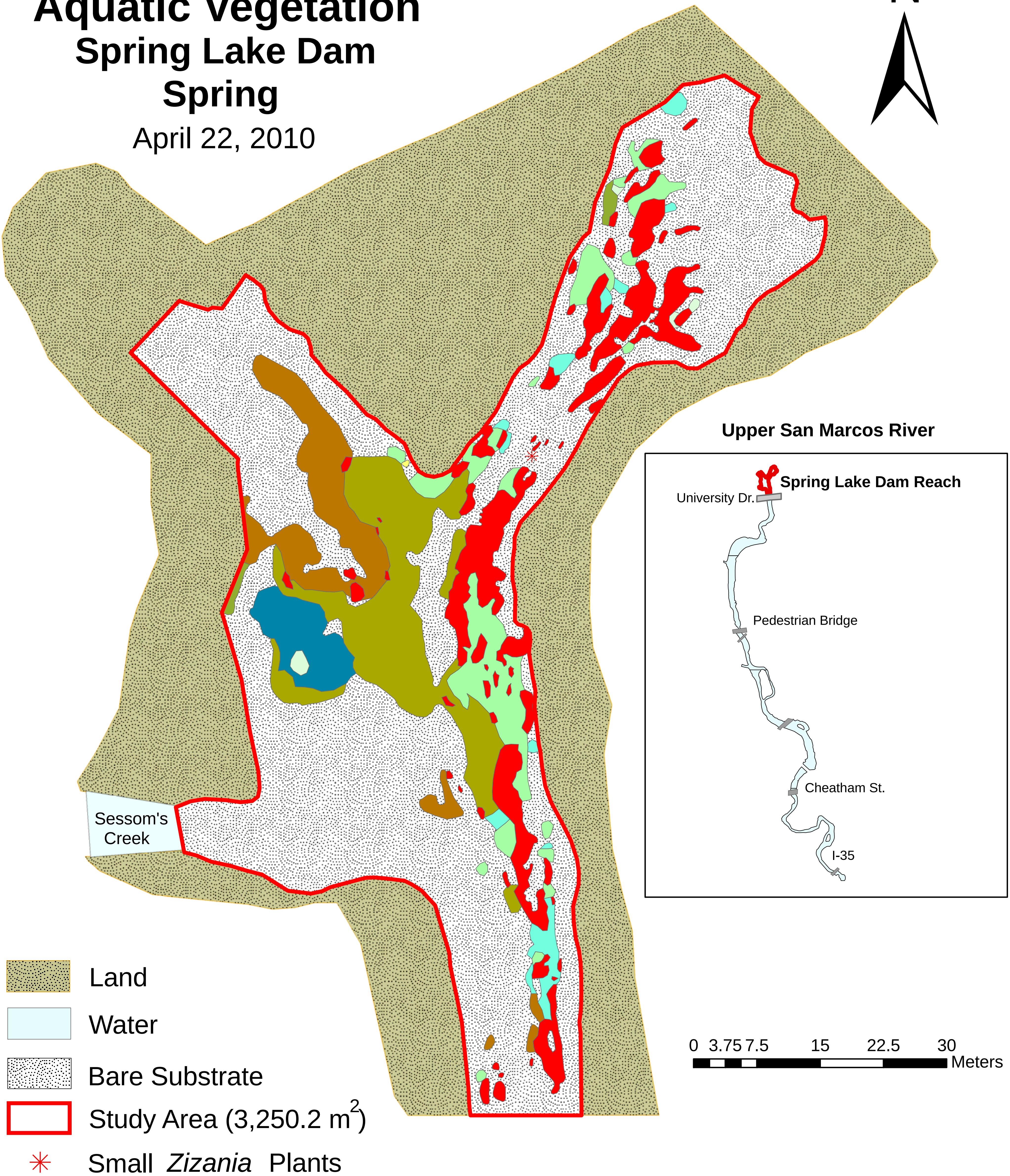
October 21, 2010



	Total Area (m^2)
Algae	6.1
Cabomba	142.4
Hydrilla	185.3
Hygrophila	120.9
Ludwigia	14.1
Sagittaria	13.7
Zizania	166.1
Sagittaria / Hygrophila	10.3

Spring Lake Dam Reach

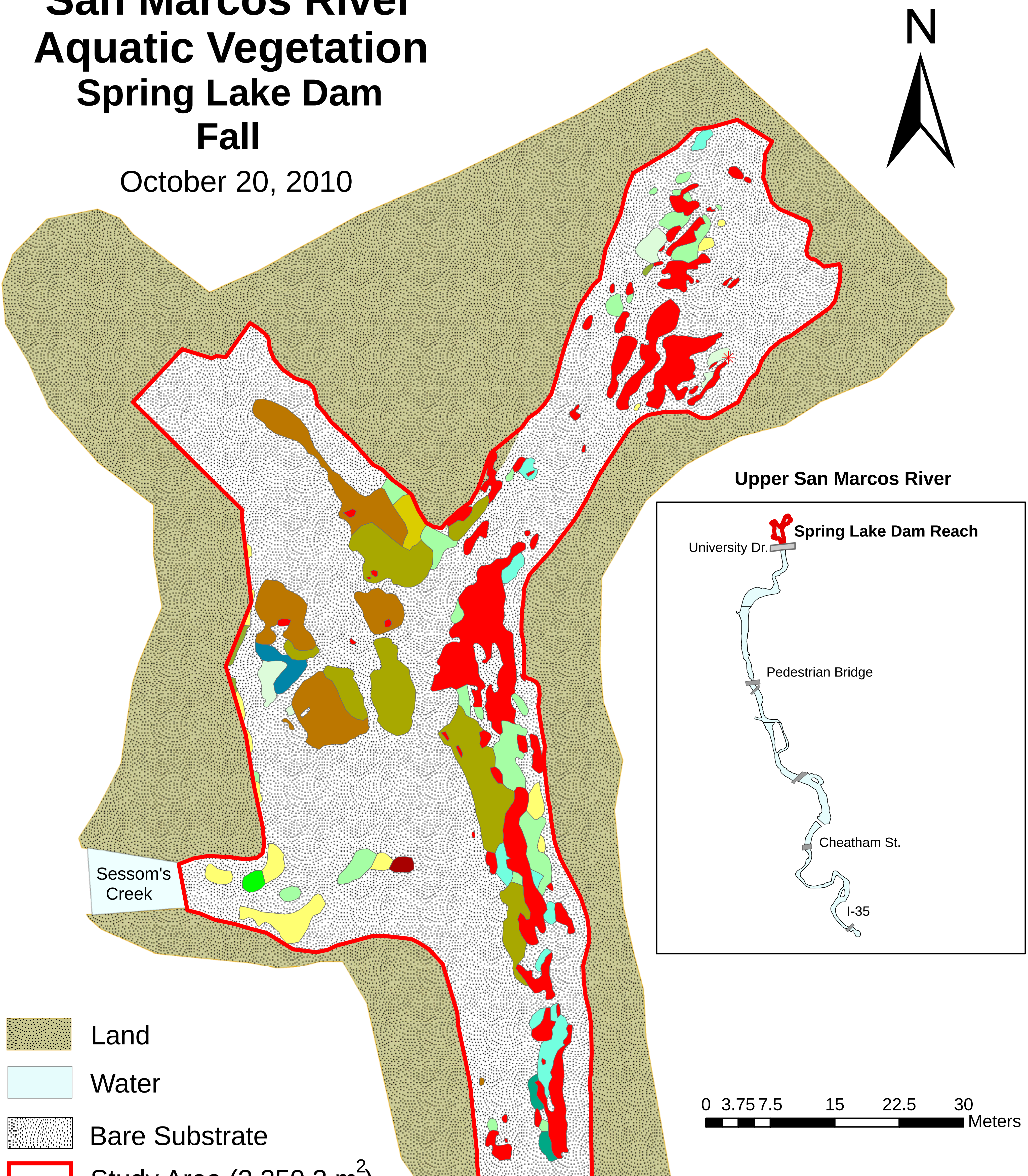
San Marcos River Aquatic Vegetation
Spring Lake Dam
Spring
April 22, 2010



	Total Area (m^2)
Hydrilla	178.0
Hydrocotyle	50.7
Hygrophila	0.5
Potamogeton	191.8
Sagittaria	12.1

	Total Area (m^2)
Zizania	347.8
Vallisneria	8.3
Potamogeton / Hydrilla	332.6
Potamogeton / Vallisneria	83.3

San Marcos River Aquatic Vegetation
Spring Lake Dam
Fall
October 20, 2010



Land
Water
Bare Substrate
Study Area (3,250.2 m^2)
✳ Small *Zizania* Plants

	Total Area (m^2)
Cabomba	5.1
Hydrilla	103.4
Hydrocotyle	42.8
Hygrophila	58.2
Ludwigia	4.3
Potamogeton	195.1

	Total Area (m^2)
Sagittaria	5.5
Zizania	339.4
Vallisneria	24.6
Potamogeton / Hydrilla	195.1
Potamogeton / Hydrocotyle	8.0
Potamogeton / Hygrophila	13.0
Potamogeton / Vallisneria	13.9

Texas Wild-Rice

San Marcos River

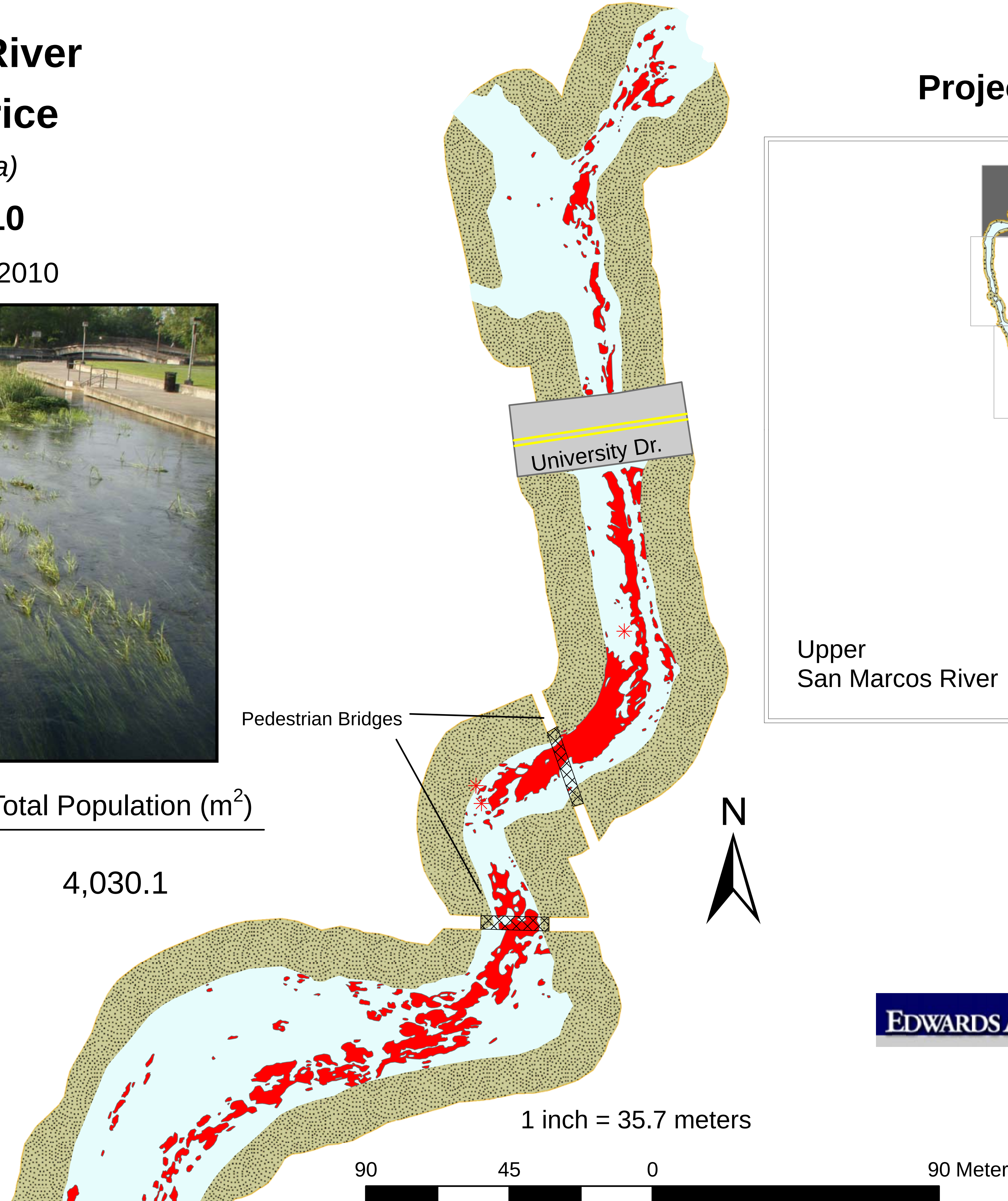
Texas wild-rice

(Zizania texana)

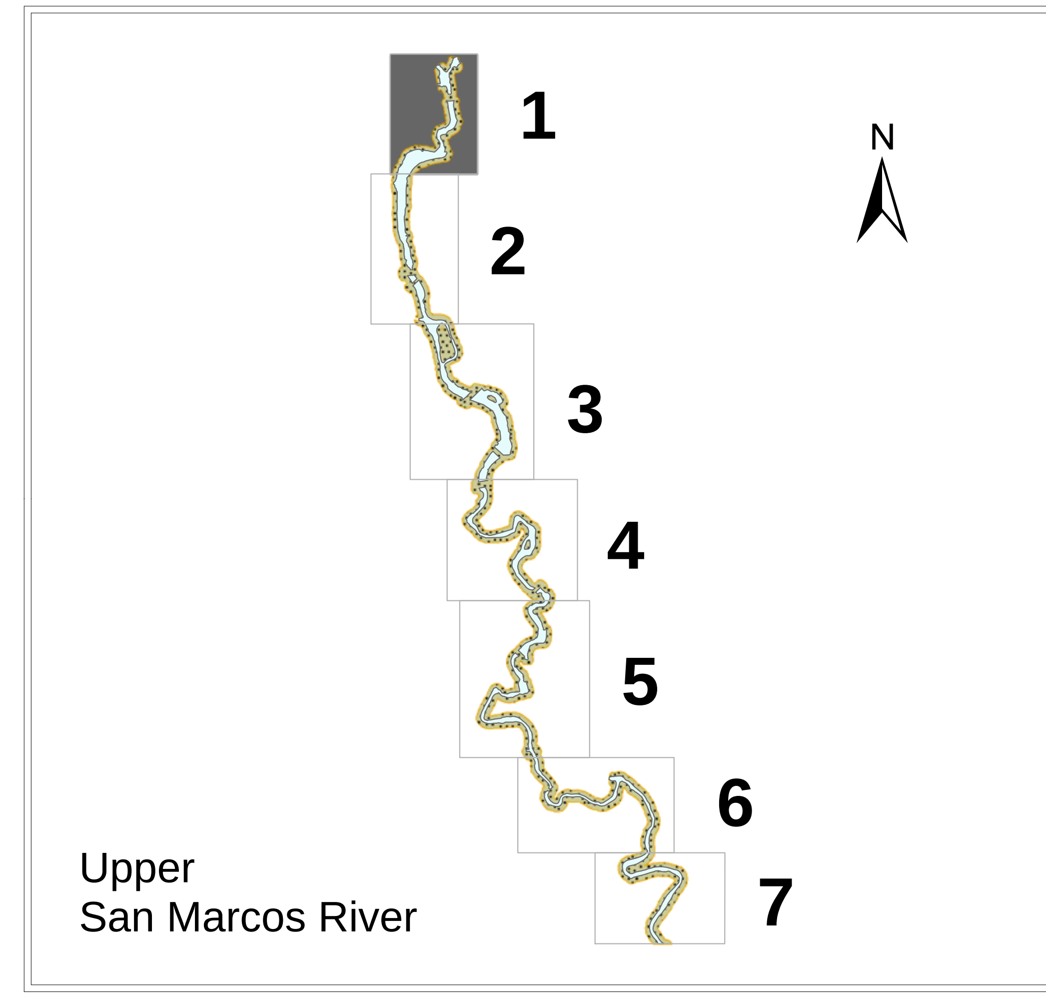
Summer 2010

July 28 - August 3, 2010

	Map 1 (m^2)	Total Population (m^2)
Zizania	2,518.6	4,030.1
Small *Zizania* Plants		



Project Location



BIO-WEST, Inc.

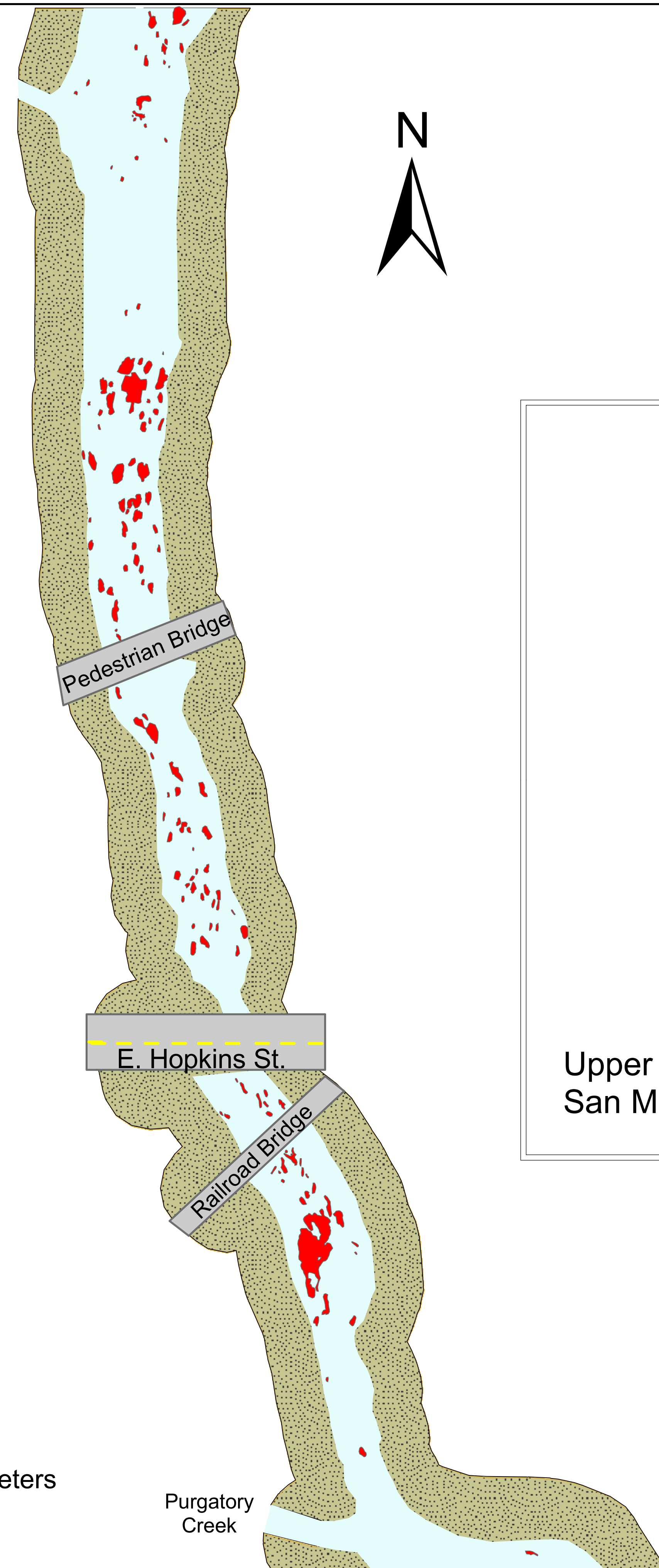
EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2010
July 28 - August 3, 2010

	Map 2 (m^2)	Total Population (m^2)
Zizania	696.6	4,030.1

1 inch = 45.8 meters

140 70 0 140 Meters



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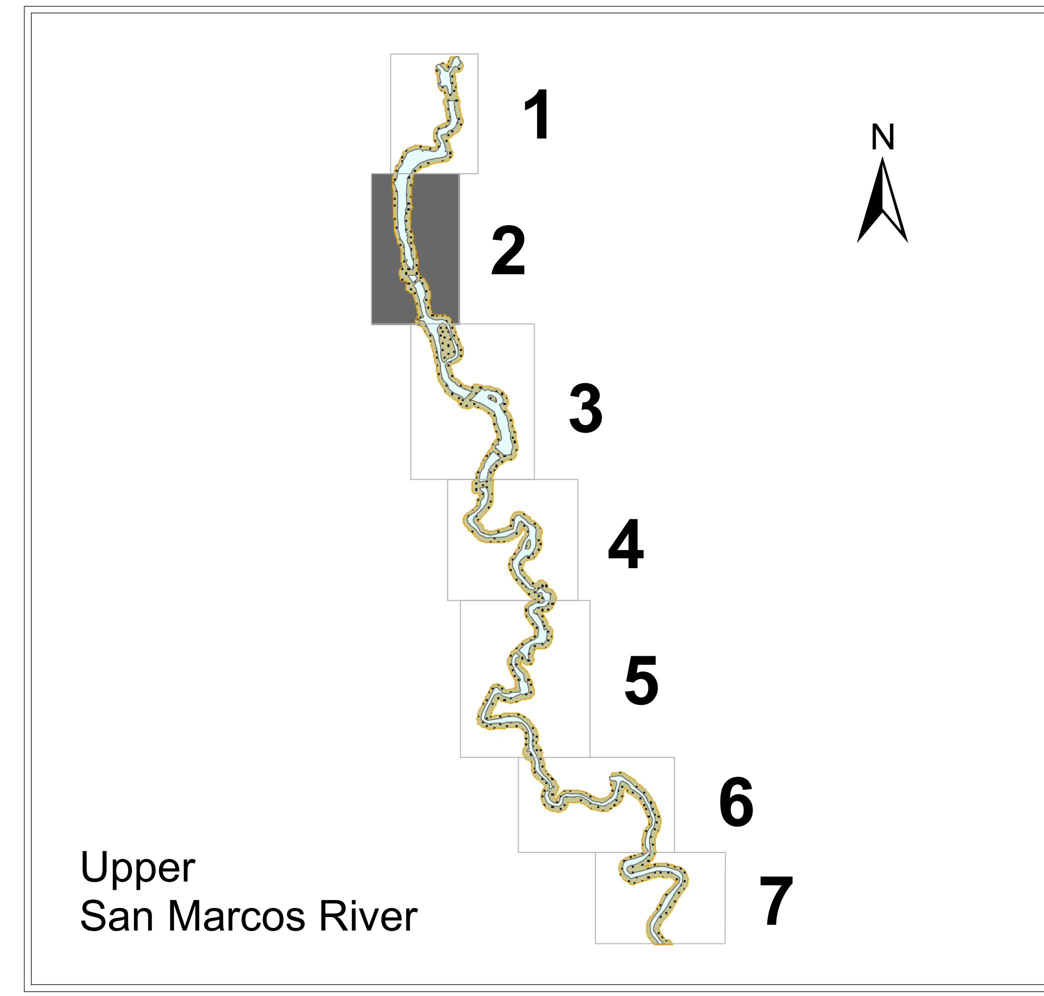

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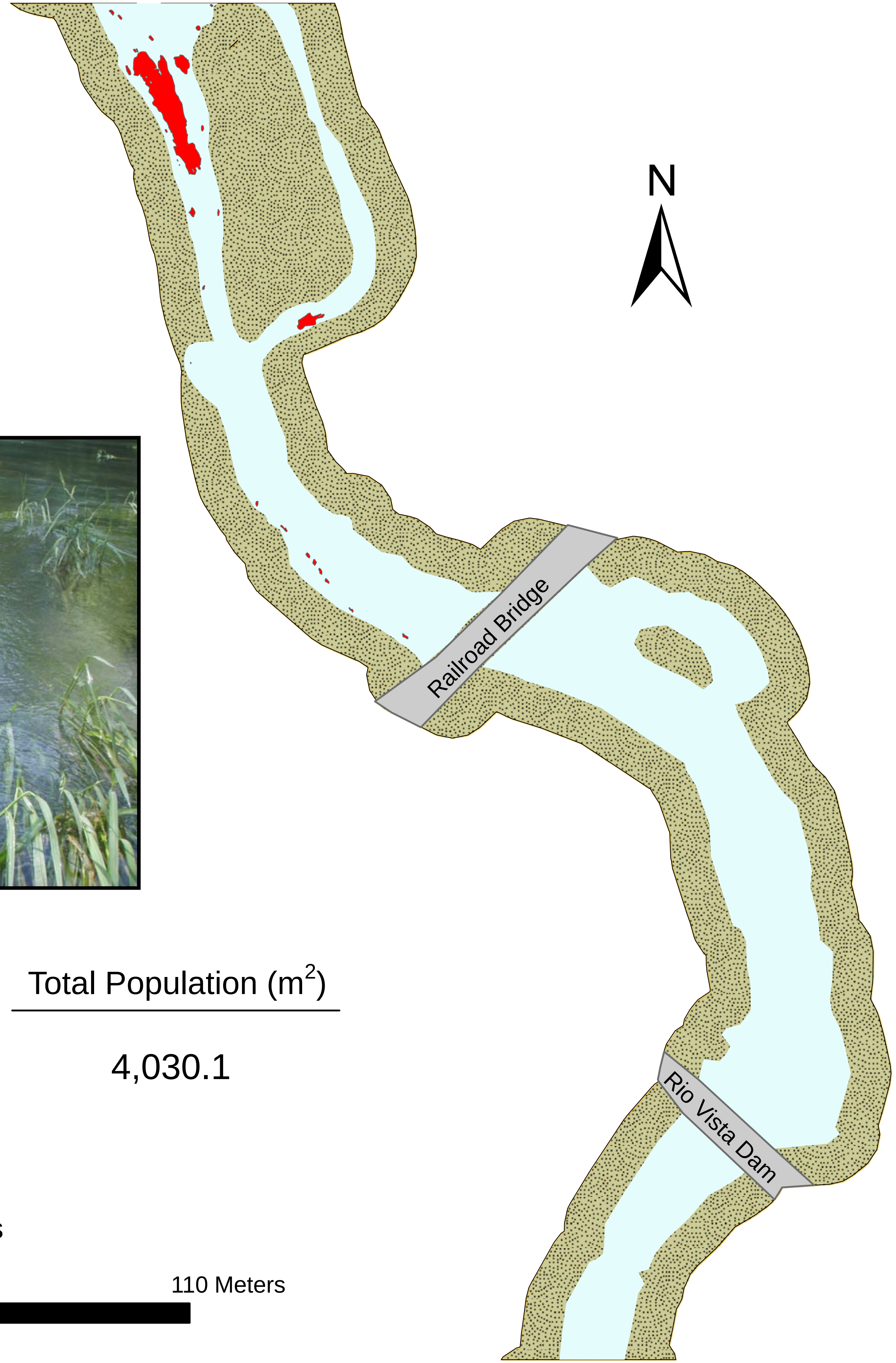
San Marcos River

Texas wild-rice

(Zizania texana)

Summer 2010

July 28 - August 3, 2010

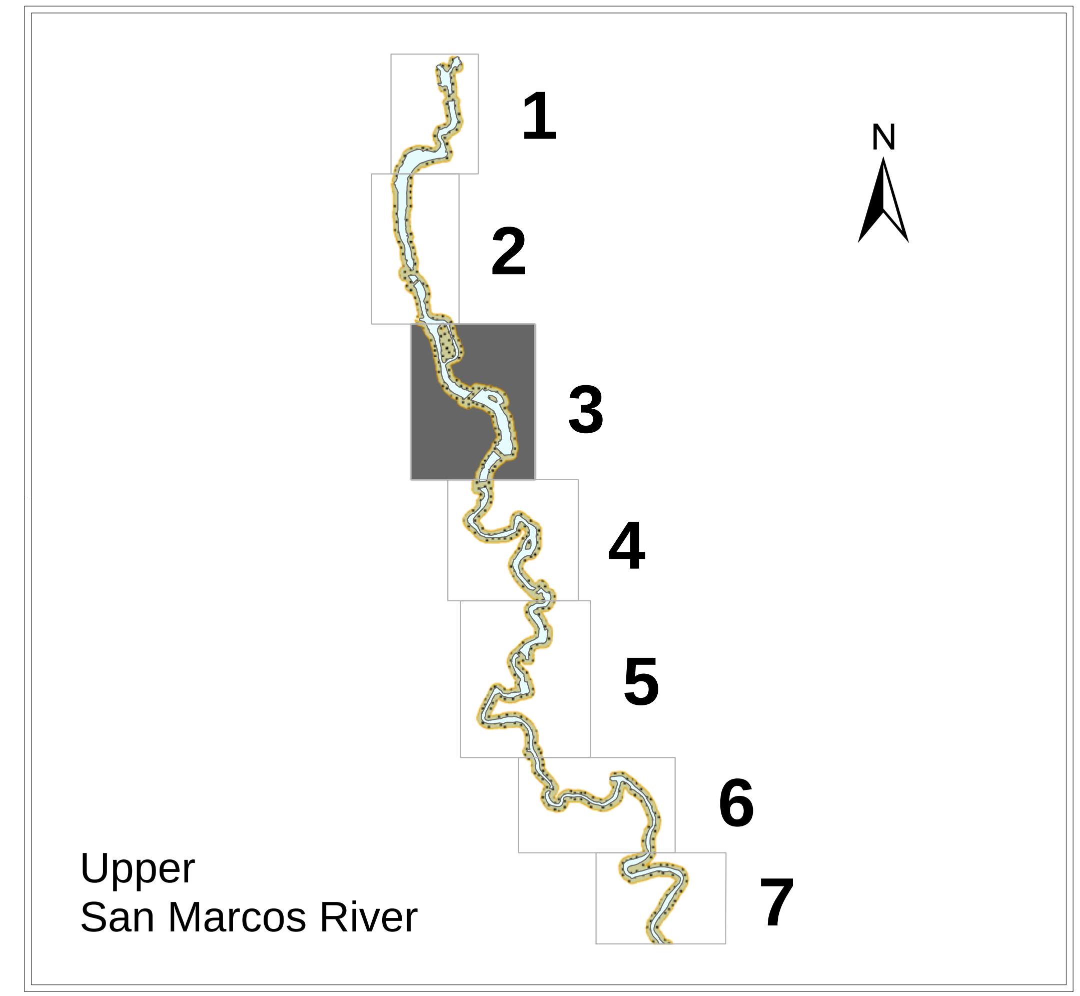


	Map 3 (m^2)	Total Population (m^2)
Zizania	383.8	4,030.1

1 inch = 48 meters

110 55 0 110 Meters

Project Location



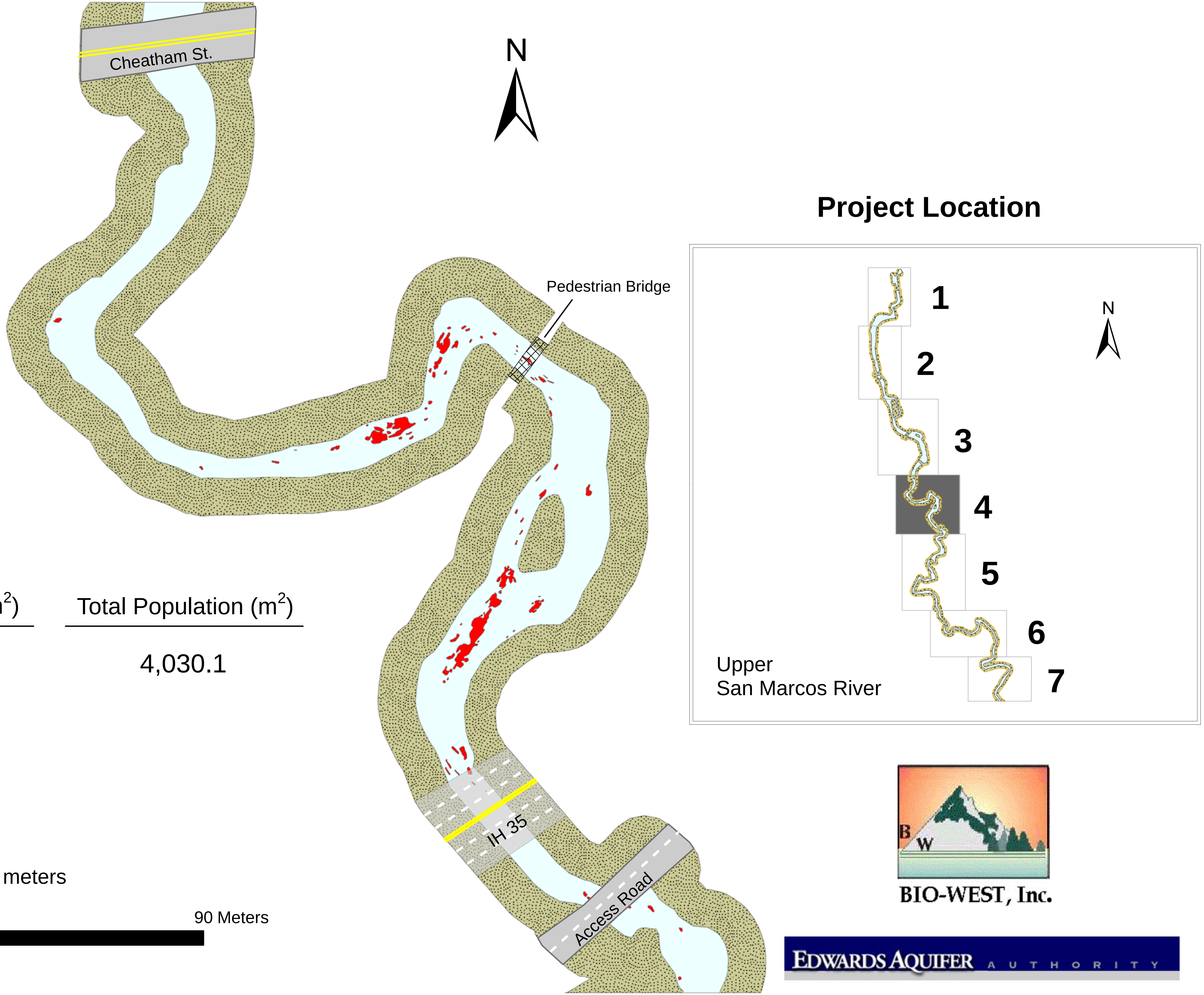
BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

San Marcos River
Texas wild-rice
(Zizania texana)

Summer 2010

July 28 - August 3, 2010



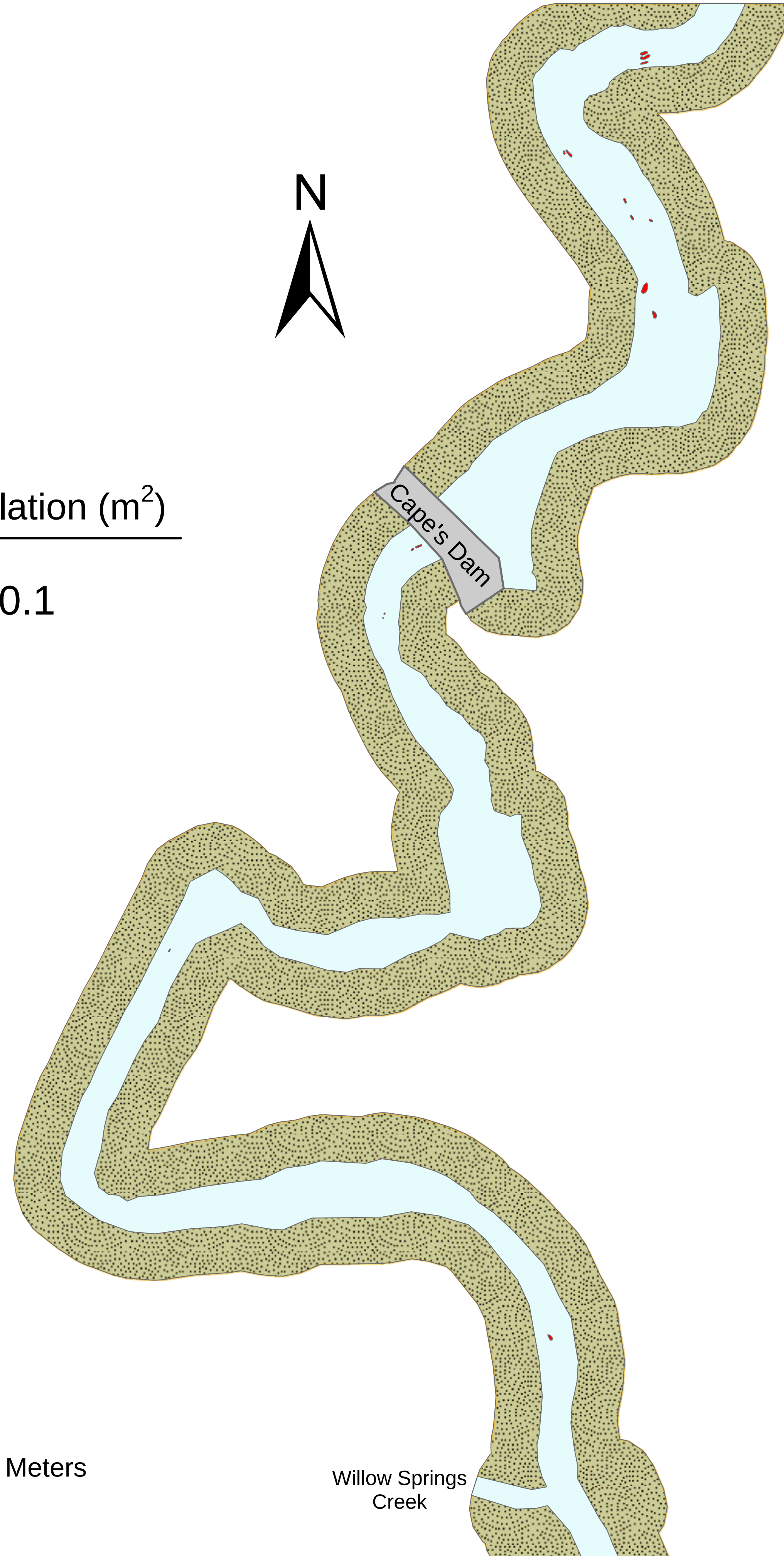
	Map 4 (m^2)	Total Population (m^2)
Zizania	372.7	4,030.1

1 inch = 37.2 meters

90 45 0 90 Meters

San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2010
July 28 - August 3, 2010

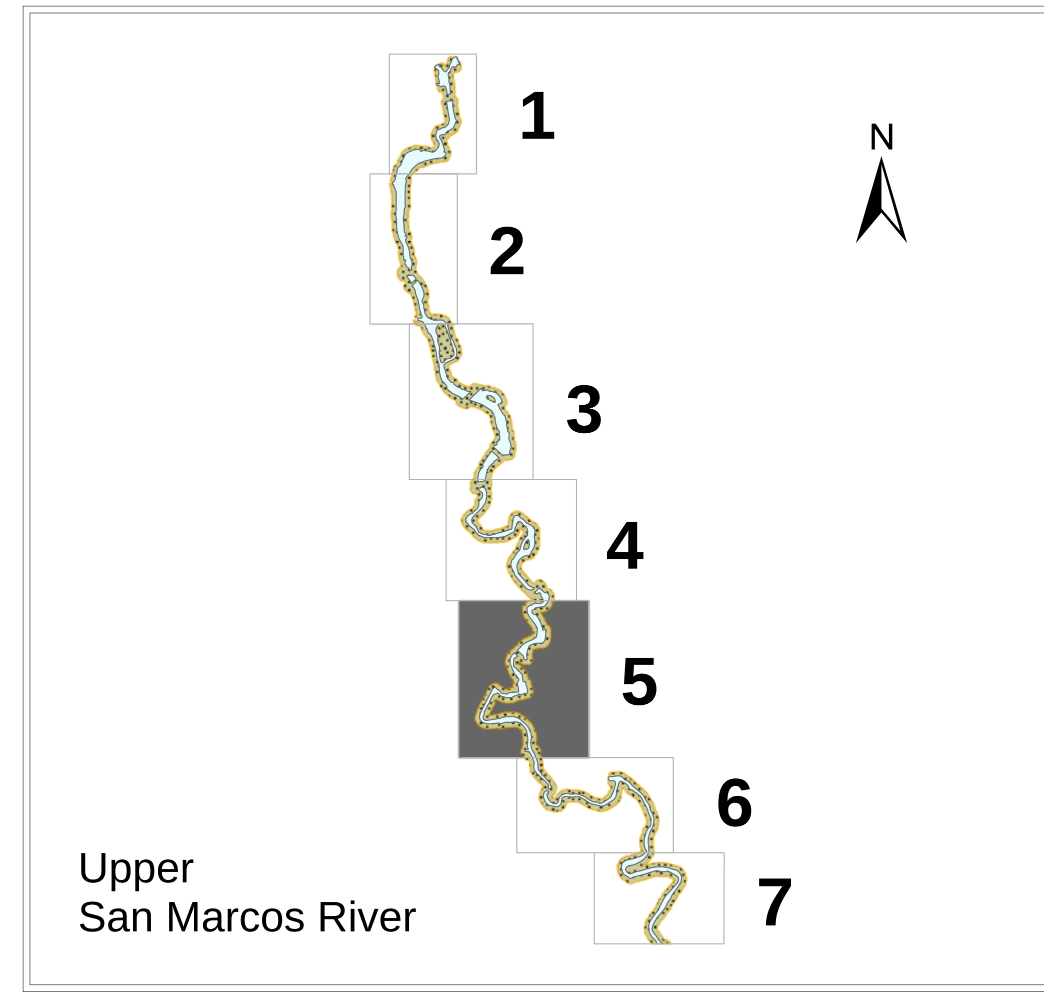
	Map 5 (m^2)	Total Population (m^2)
Zizania	19.3	4,030.1



1 inch = 48.1 meters

120 60 0 120 Meters

Project Location



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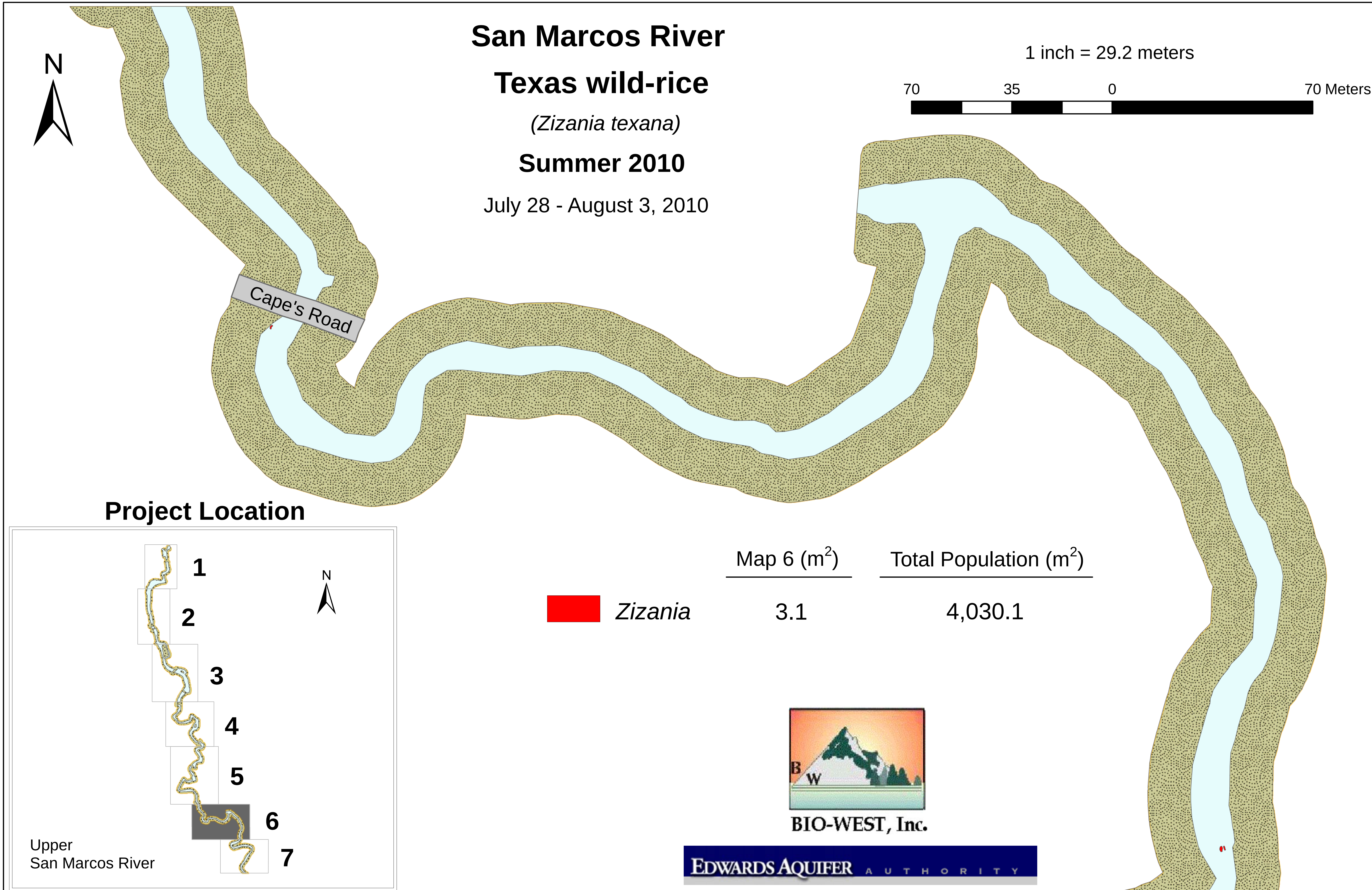

San Marcos River
Texas wild-rice
(Zizania texana)
Summer 2010
July 28 - August 3, 2010
1 inch = 29.2 meters
70 35 0 70 Meters
N
Cape's Road
Project Location
1
2
3
4
5
6
7
N
Upper
San Marcos River
Map 6 (m2)
Total Population (m2)
Zizania
3.1
4,030.1
BIO-WEST, Inc.
EDWARDS AQUIFER AUTHORITY

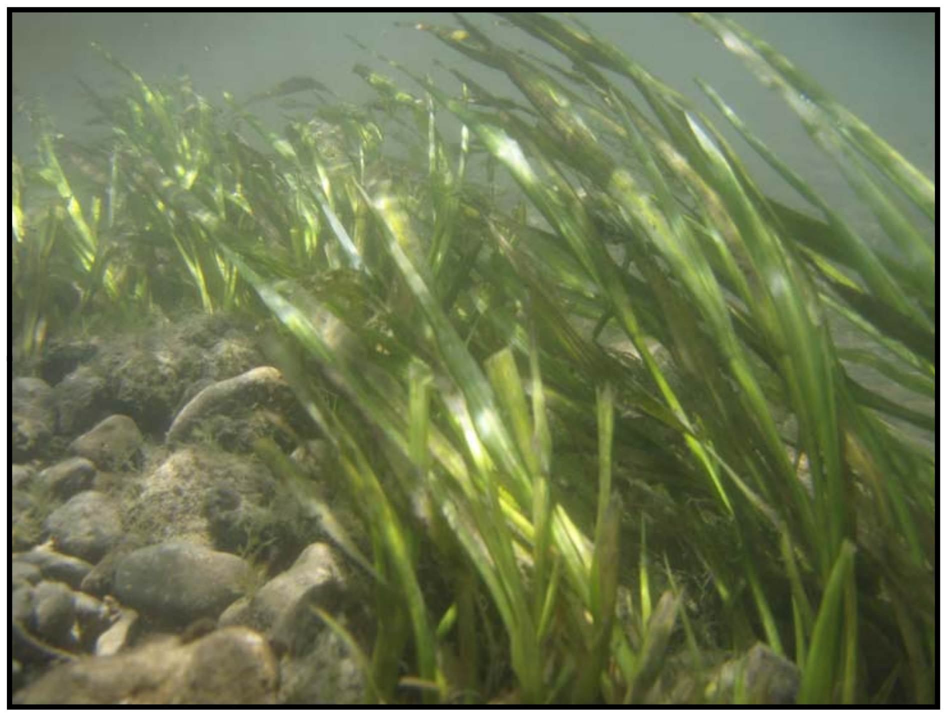
San Marcos River

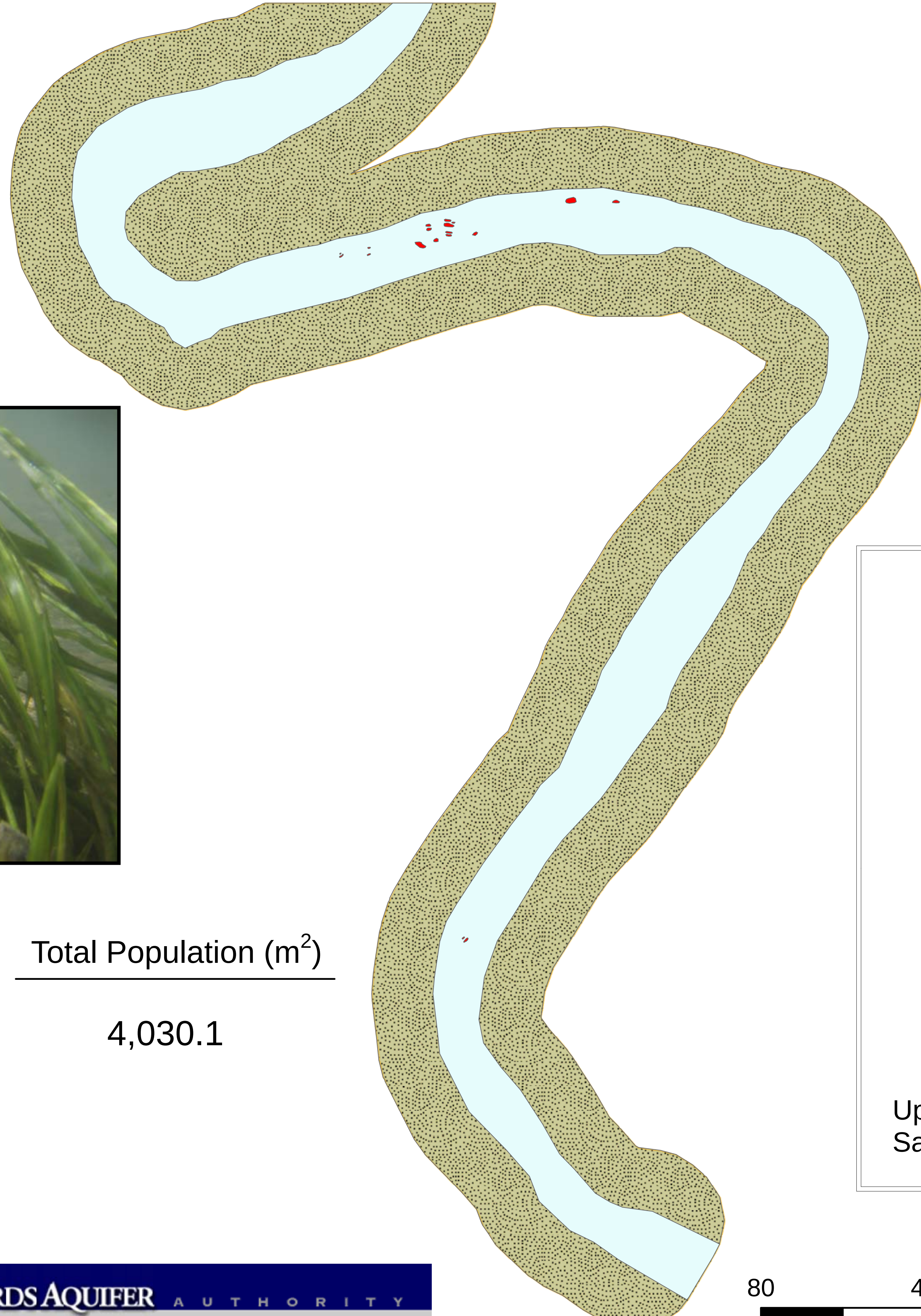
Texas wild-rice

(Zizania texana)

Summer 2010

July 28 - August 3, 2010





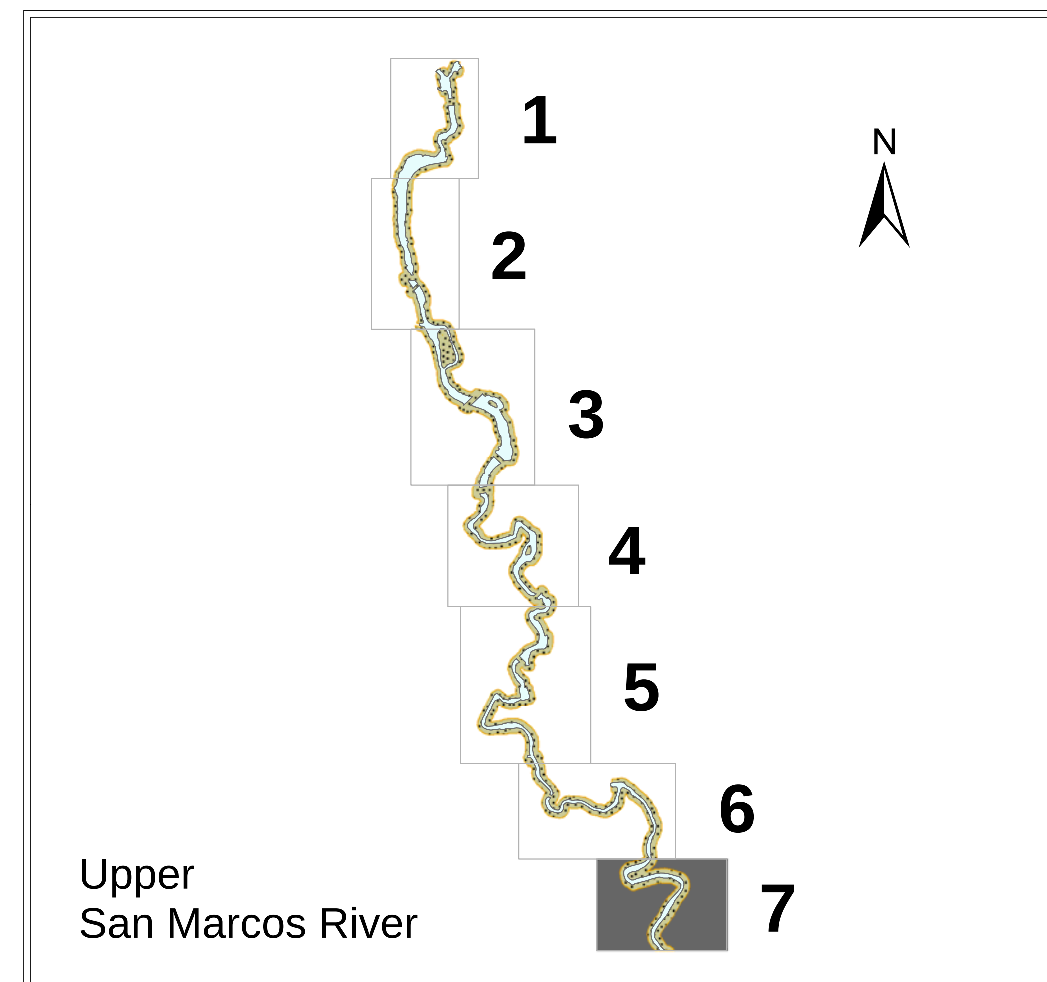
	Map 7 (m^2)	Total Population (m^2)
Zizania	14.0	4,030.1

BIO-WEST, Inc.

EDWARDS AQUIFER AUTHORITY

N

Project Location

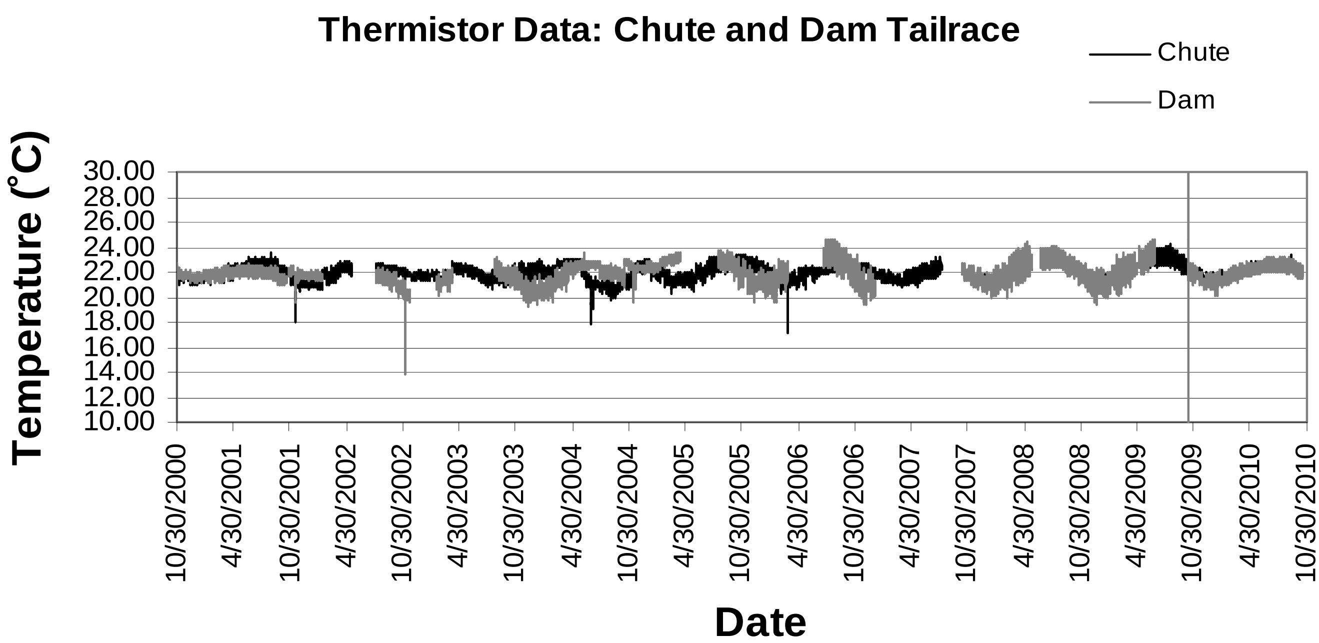


1 inch = 30.6 meters

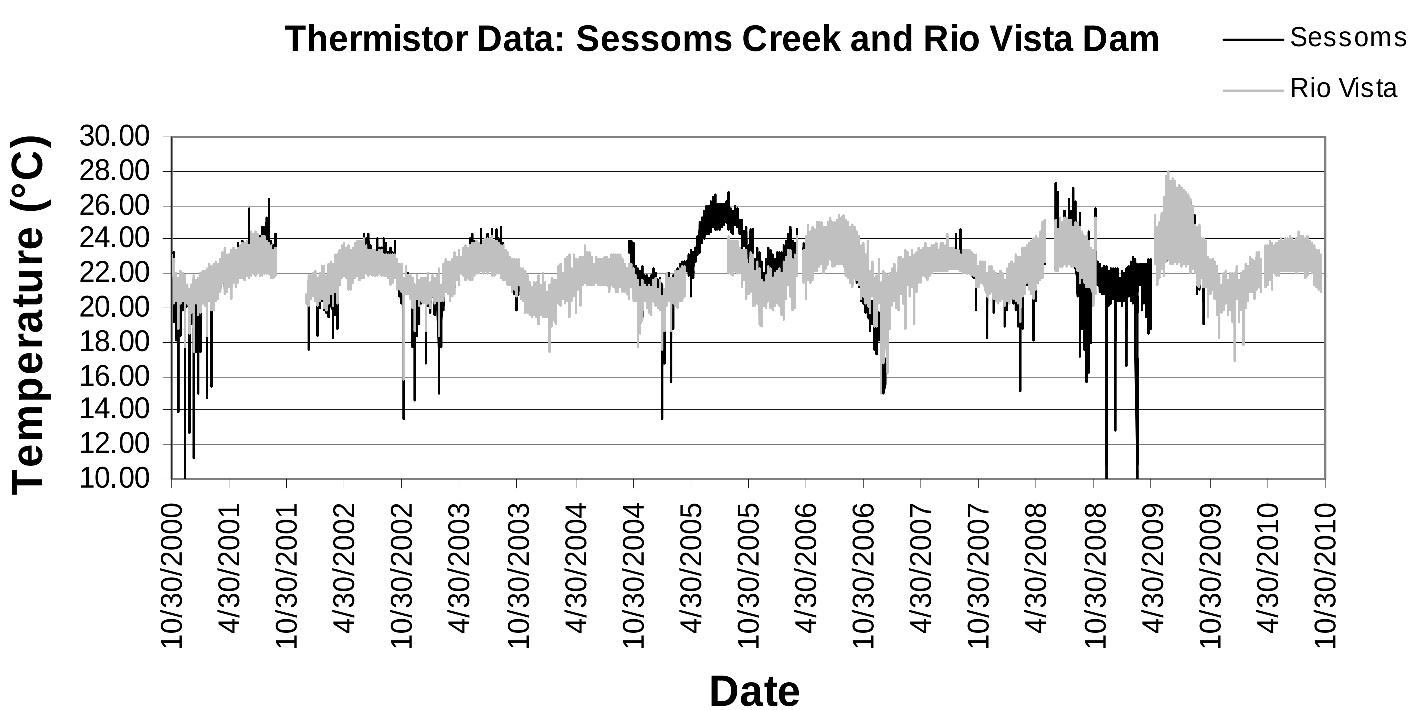
80 40 0 80 Meters

APPENDIX B:
DATA AND GRAPHS

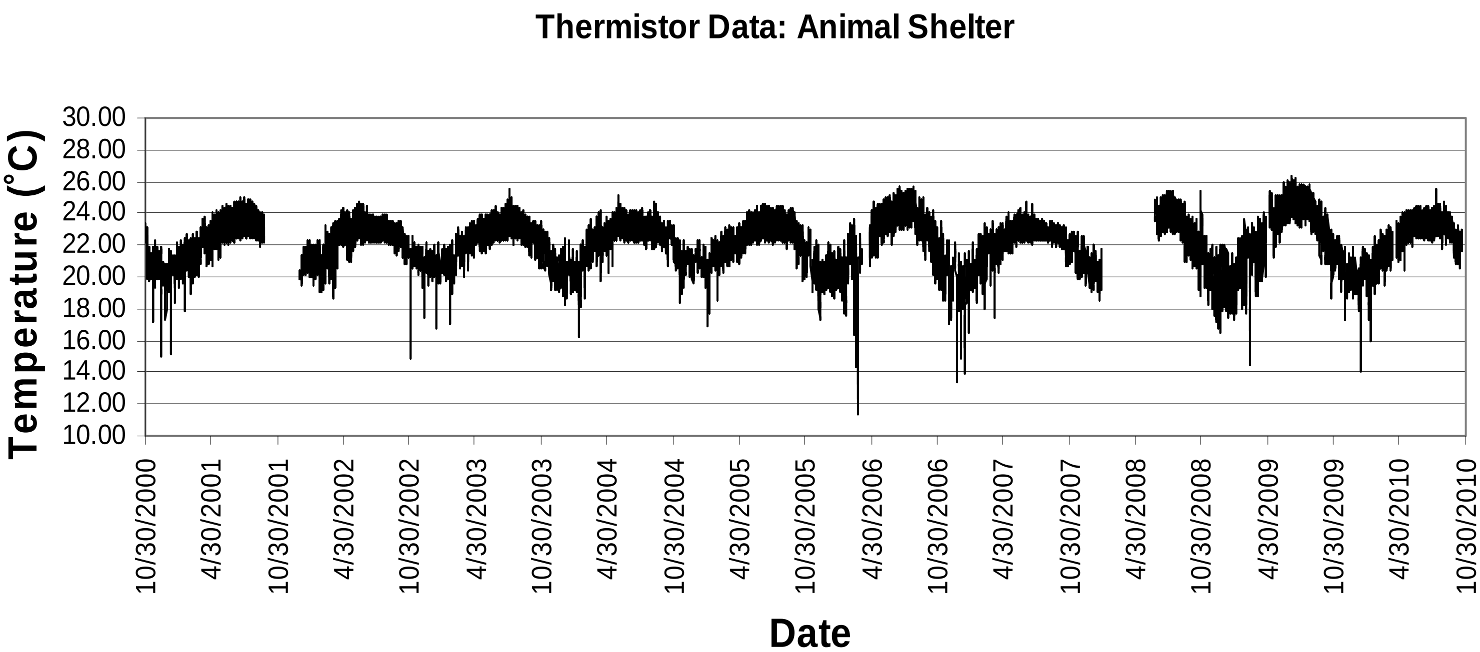
Water Quality Data
and
Thermistor Graphs

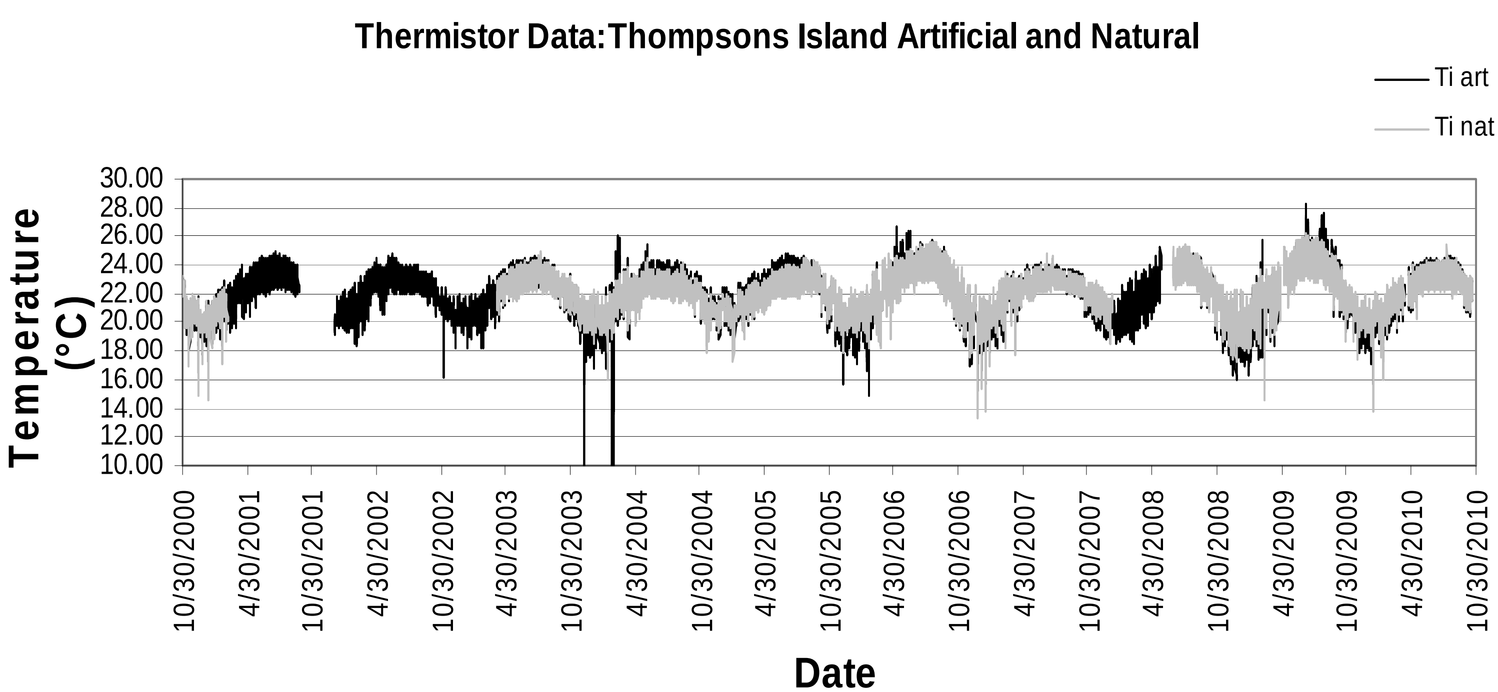


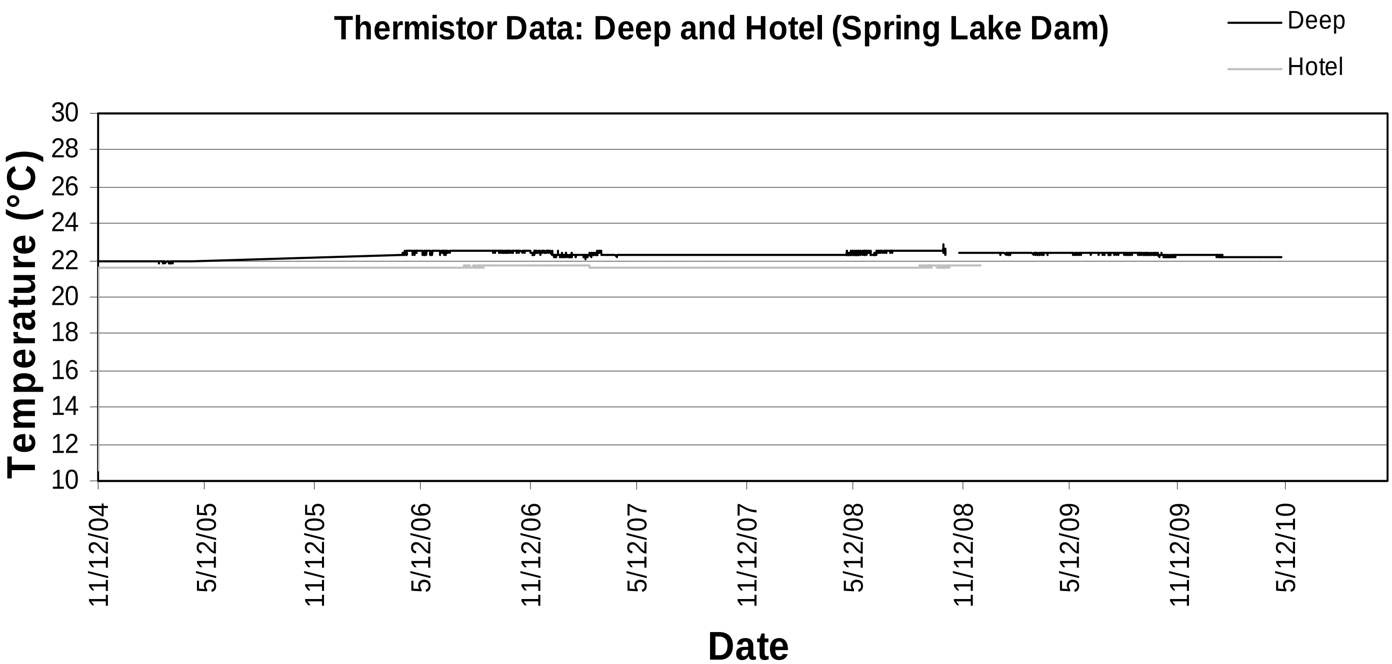
Thermistor Data: Chute and Dam Tailrace
Chute
Dam
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
10/30/2000
4/30/2001
10/30/2001
4/30/2002
10/30/2002
4/30/2003
10/30/2003
4/30/2004
10/30/2004
4/30/2005
10/30/2005
4/30/2006
10/30/2006
4/30/2007
10/30/2007
4/30/2008
10/30/2008
4/30/2009
10/30/2009
4/30/2010
10/30/2010
Date



Thermistor Data: Sessoms Creek and Rio Vista Dam
Sessoms
Rio Vista
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
10/30/2000
4/30/2001
10/30/2001
4/30/2002
10/30/2002
4/30/2003
10/30/2003
4/30/2004
10/30/2004
4/30/2005
10/30/2005
4/30/2006
10/30/2006
4/30/2007
10/30/2007
4/30/2008
10/30/2008
4/30/2009
10/30/2009
4/30/2010
10/30/2010
Date

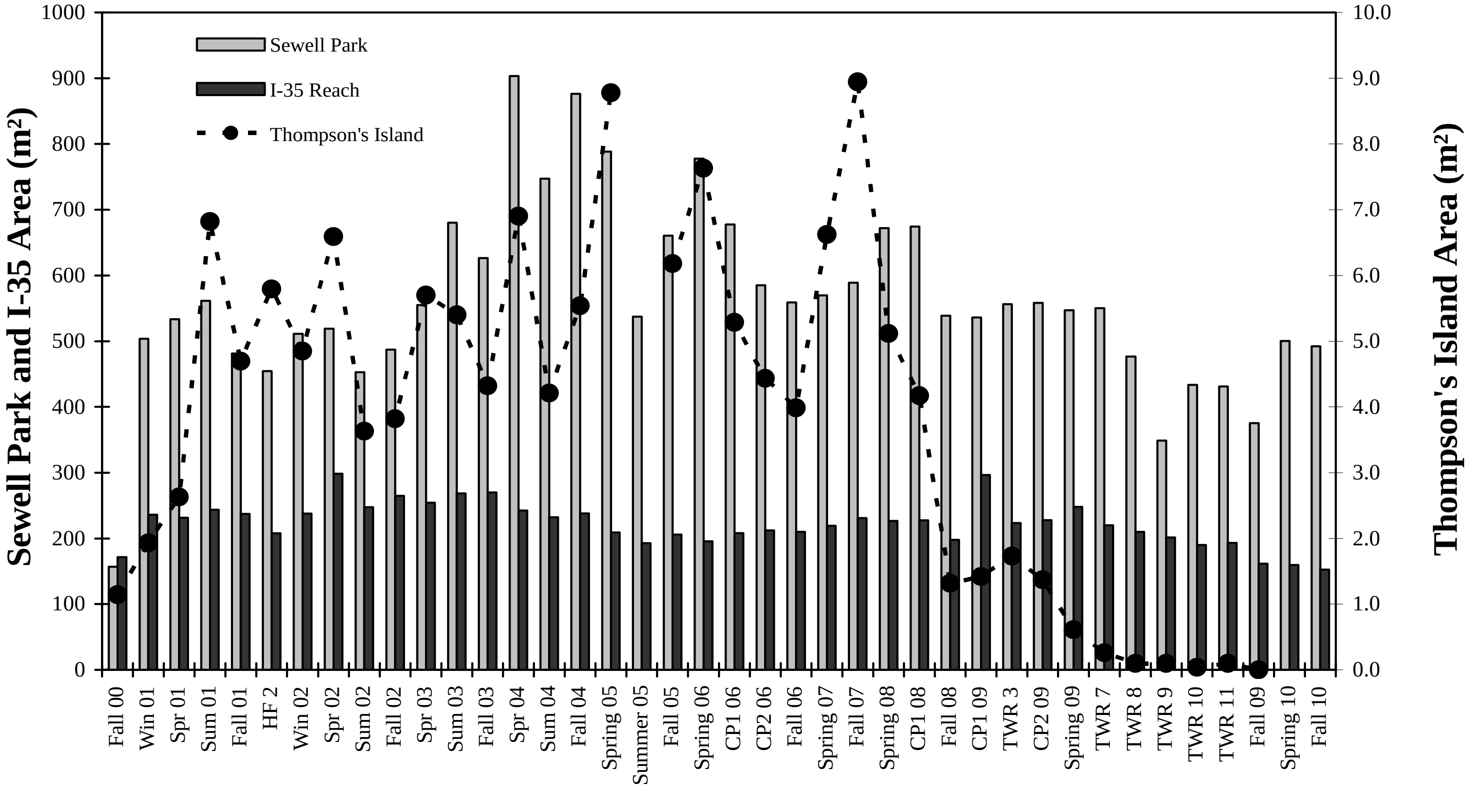

Thermistor Data: Animal Shelter
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
10/30/2000
4/30/2001
10/30/2001
4/30/2002
10/30/2002
4/30/2003
10/30/2003
4/30/2004
10/30/2004
4/30/2005
10/30/2005
4/30/2006
10/30/2006
4/30/2007
10/30/2007
4/30/2008
10/30/2008
4/30/2009
10/30/2009
4/30/2010
10/30/2010
Date


Thermistor Data:Thompsons Island Artificial and Natural
Ti art
Ti nat
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
10/30/2000
4/30/2001
10/30/2001
4/30/2002
10/30/2002
4/30/2003
10/30/2003
4/30/2004
10/30/2004
4/30/2005
10/30/2005
4/30/2006
10/30/2006
4/30/2007
10/30/2007
4/30/2008
10/30/2008
4/30/2009
10/30/2009
4/30/2010
10/30/2010
Date

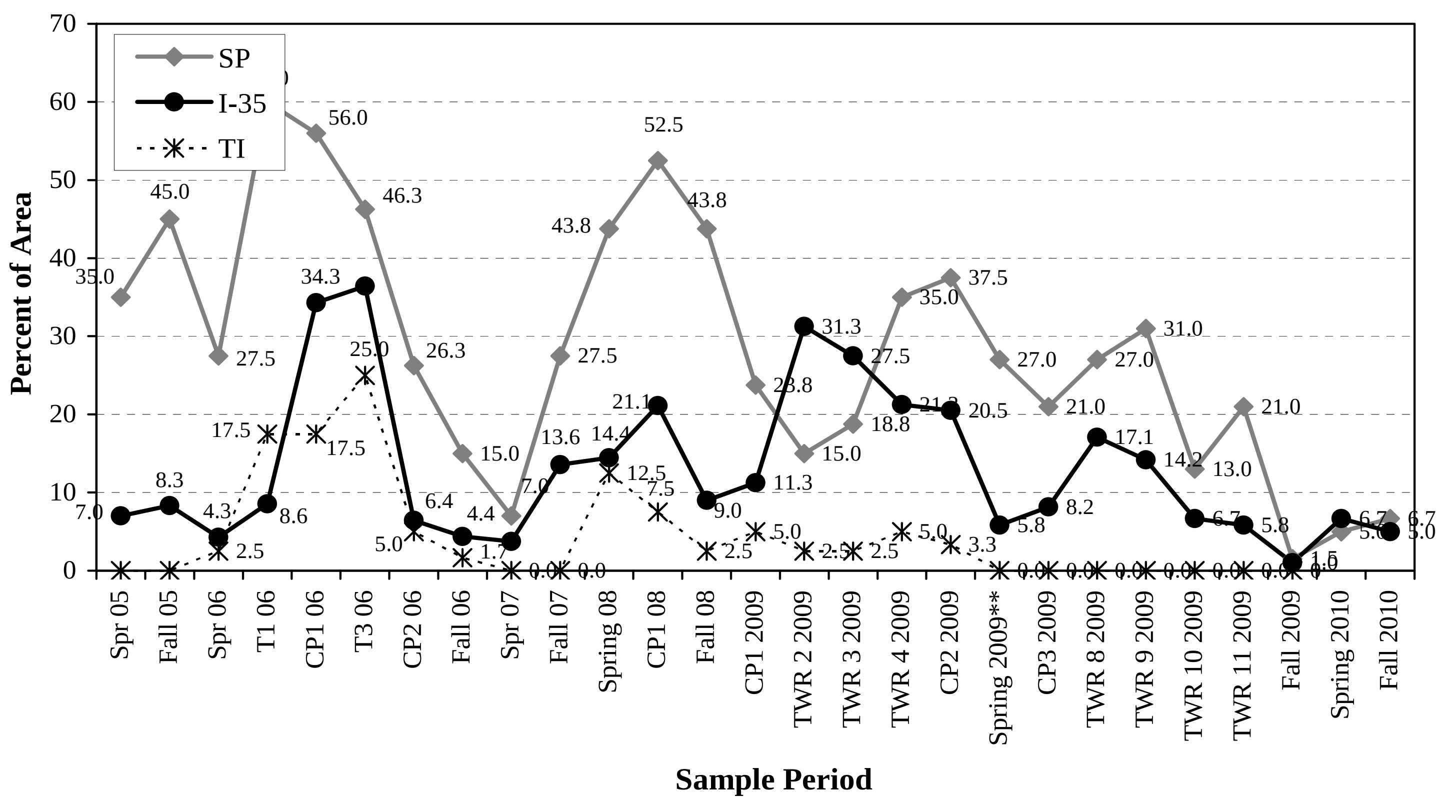

Thermistor Data: Deep and Hotel (Spring Lake Dam)
Deep
Hotel
Temperature (°C)
30
28
26
24
22
20
18
16
14
12
10
11/12/04
5/12/05
11/12/05
5/12/06
11/12/06
5/12/07
11/12/07
5/12/08
11/12/08
5/12/09
11/12/09
5/12/10
Date

Texas Wild-Rice Observation Data

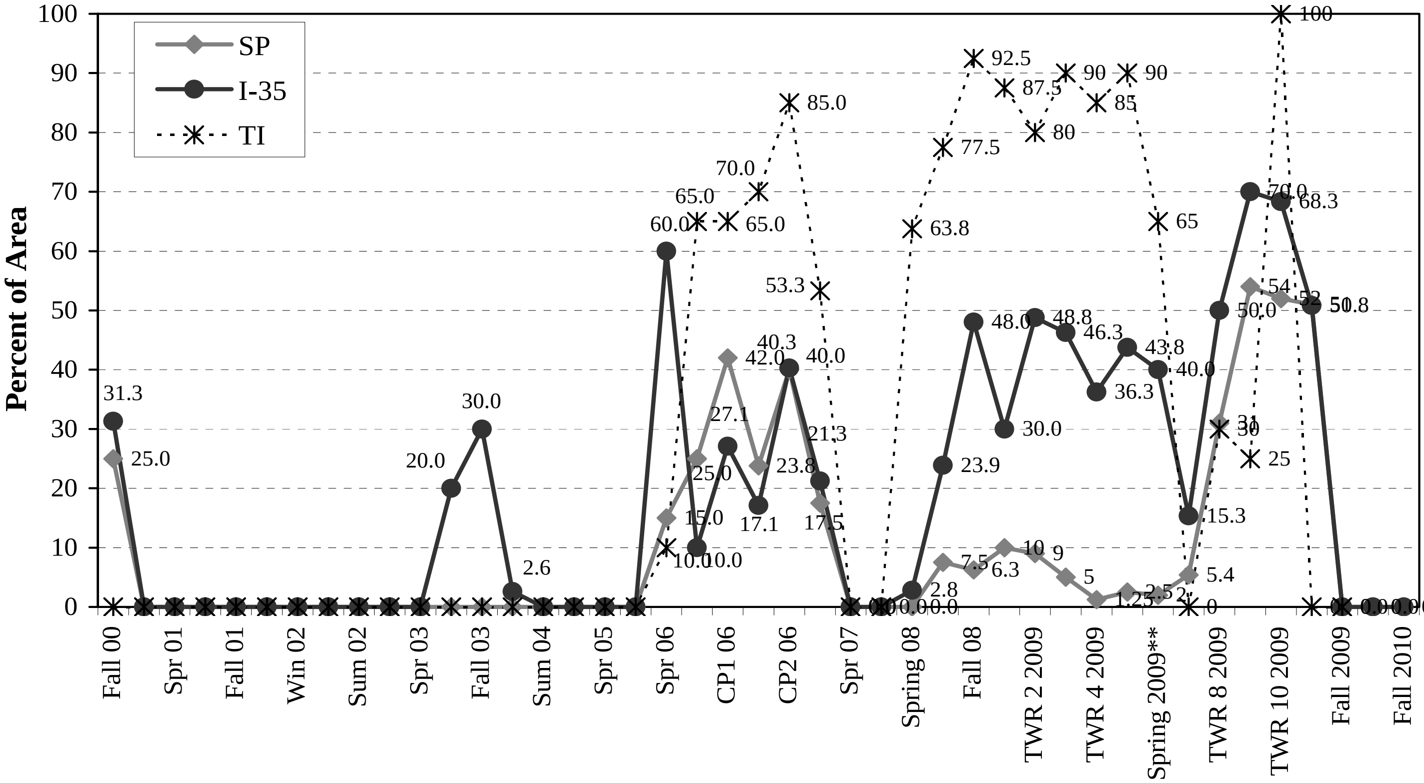
TWR Area by Season



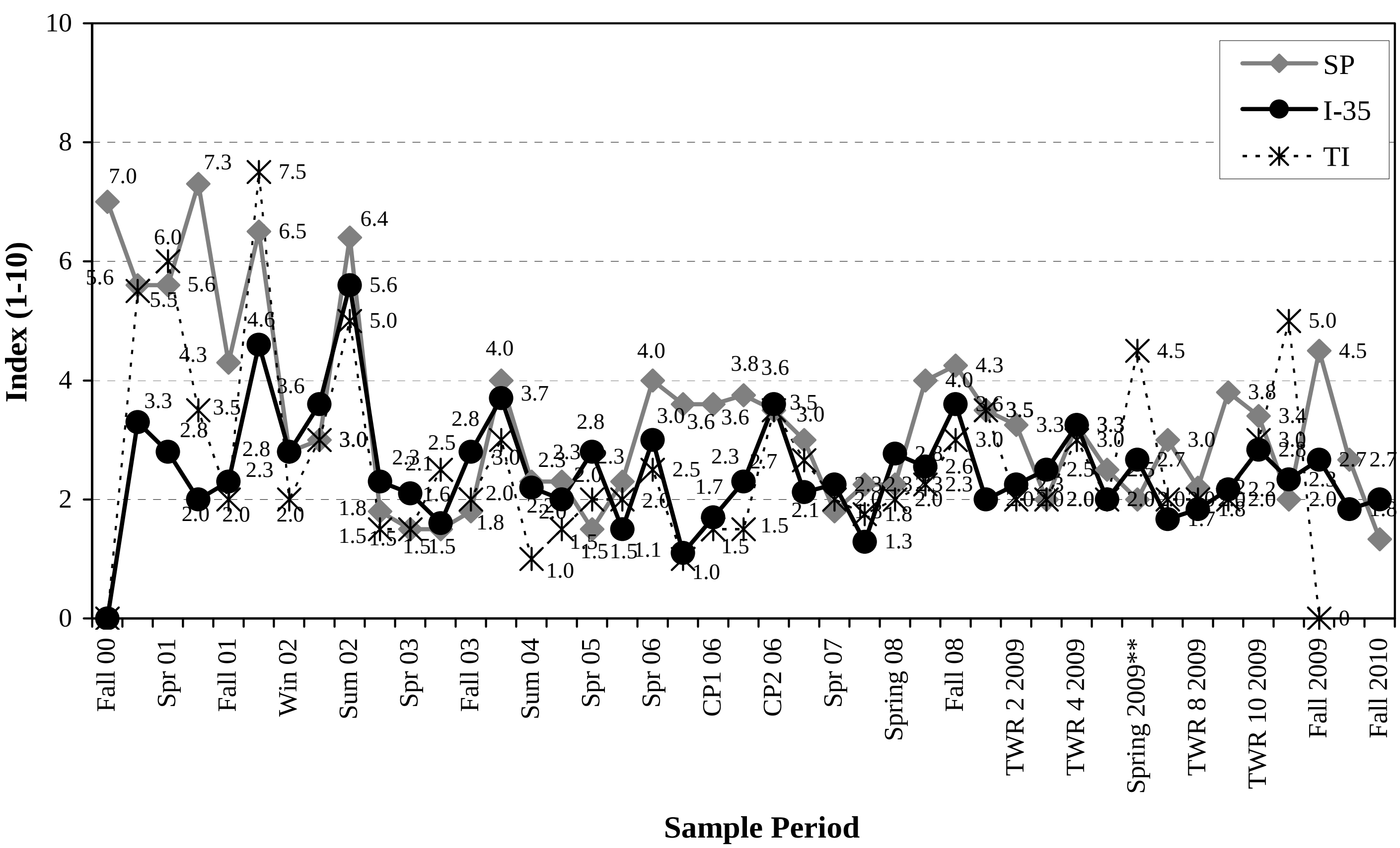
Percent of TWR Covered by Vegetation Mats



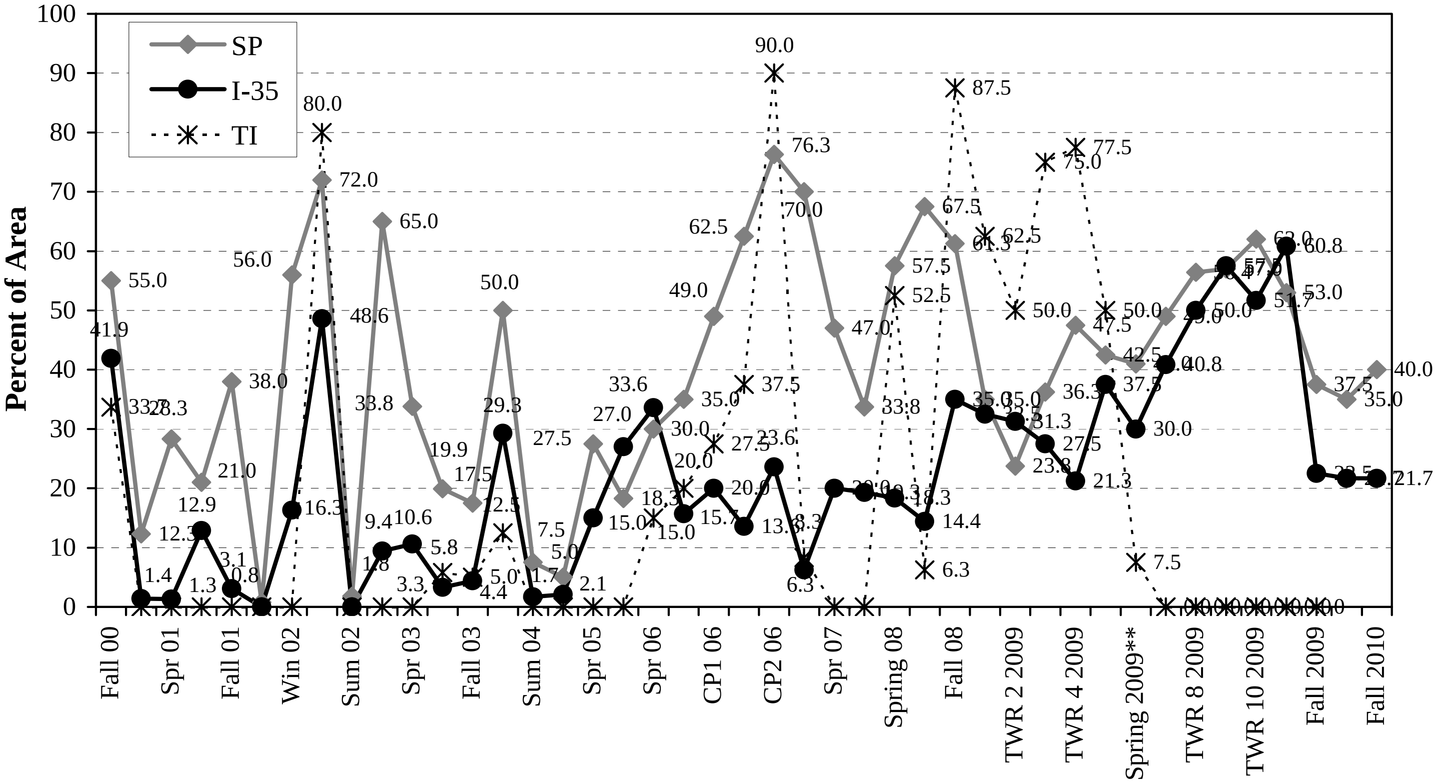
Percent of TWR Stands < 0.5 Feet



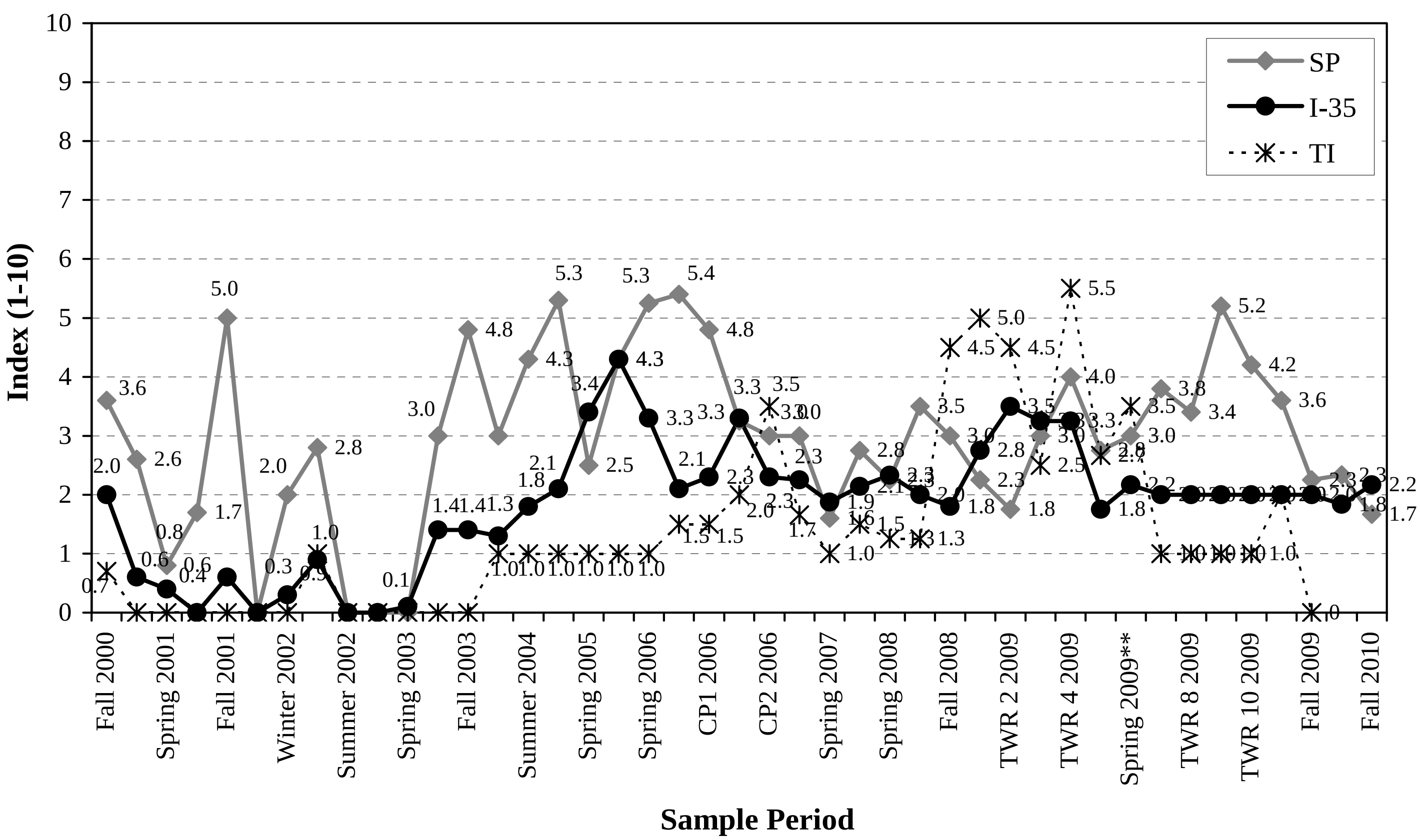
Index of Root Exposure for TWR Stands



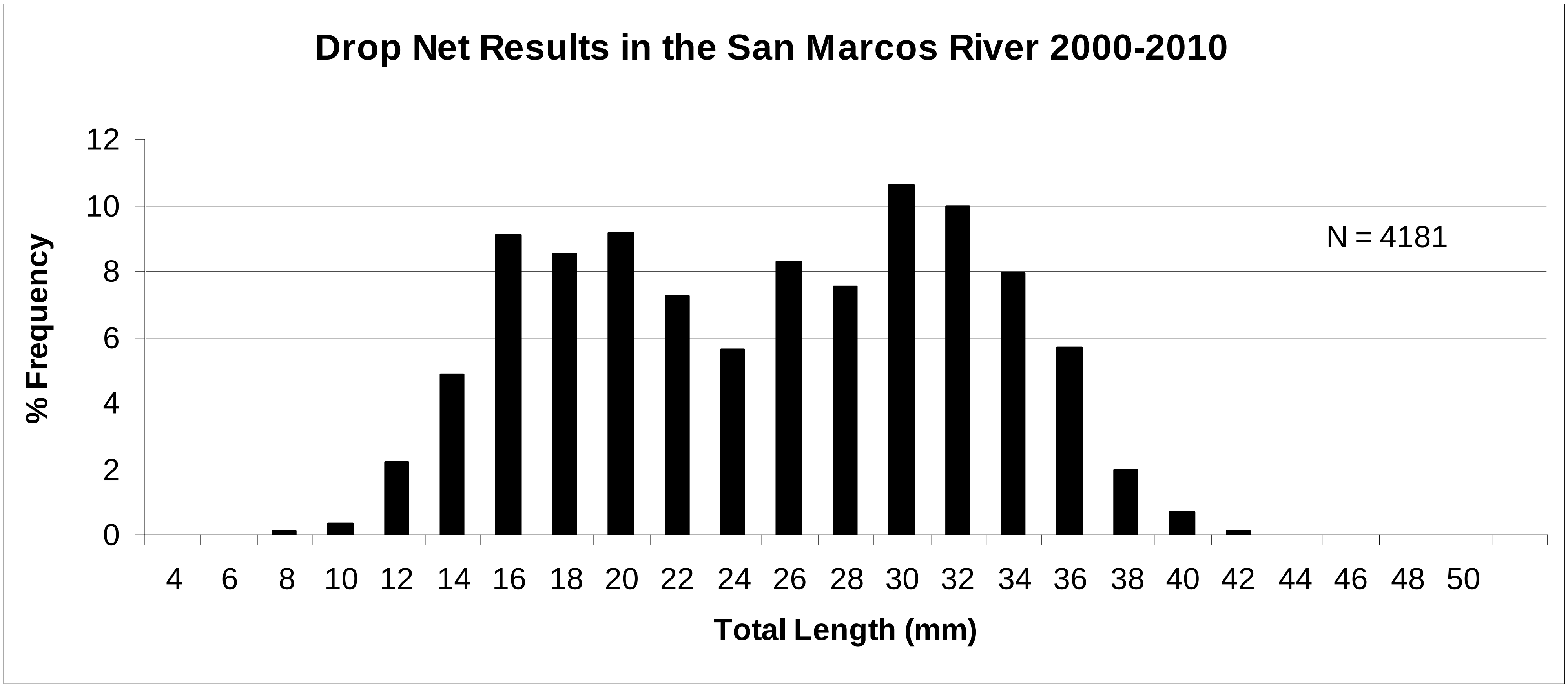
Percent Emergent TWR



Index of Herbivory for TWR Stands



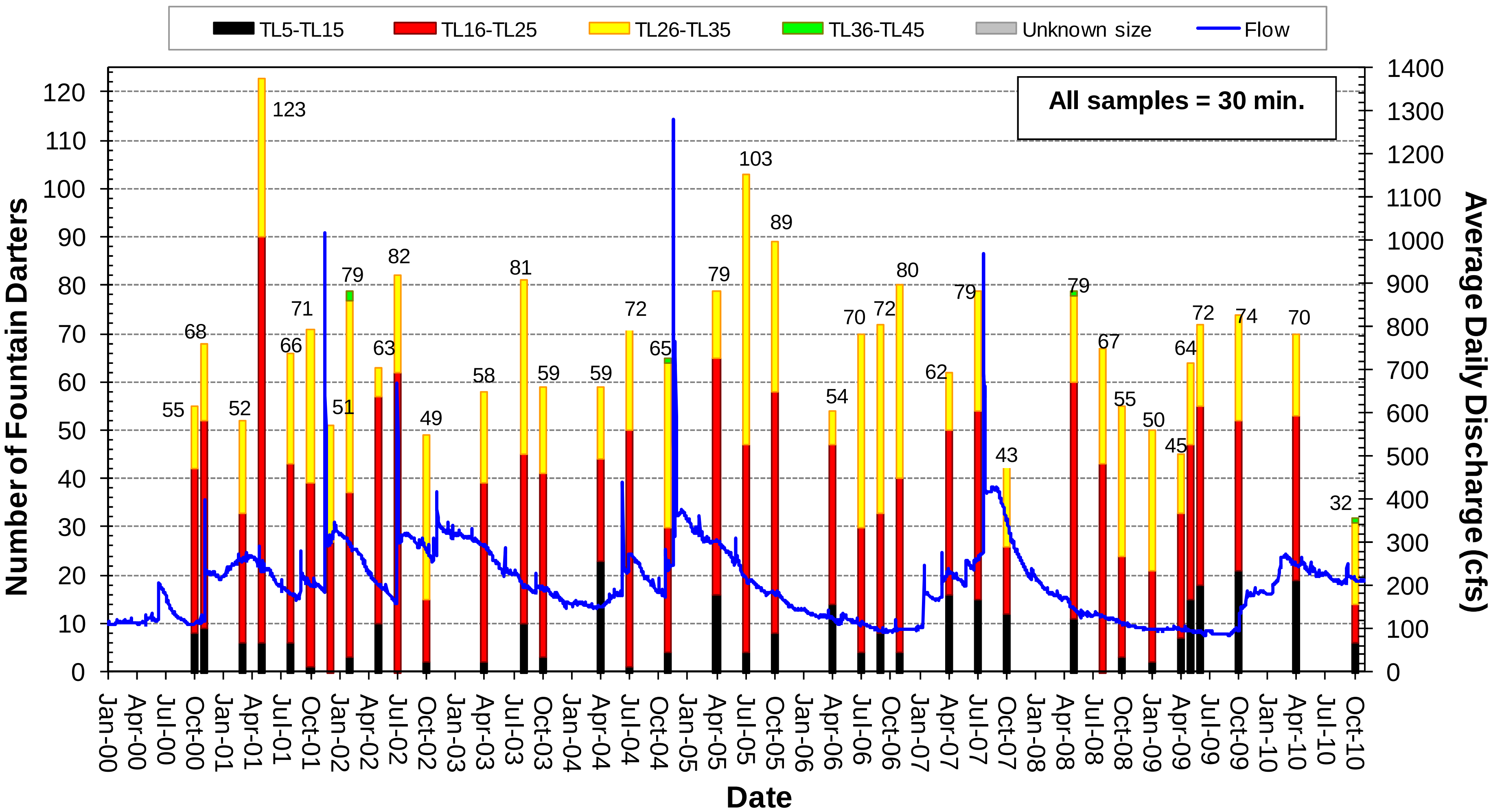
Drop Net Graph

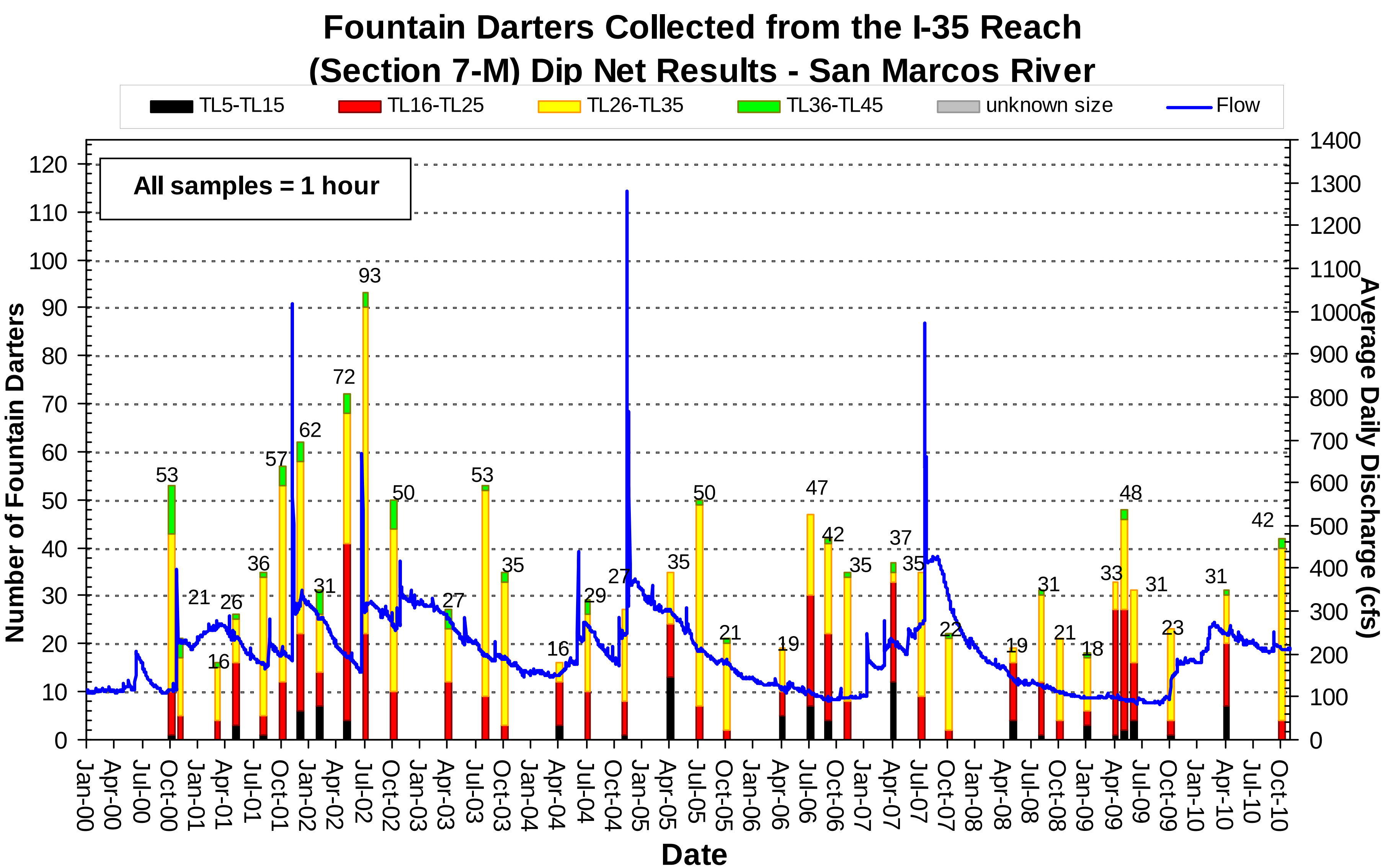


Drop Net Results in the San Marcos River 2000-2010
N = 4181
% Frequency
0
2
4
6
8
10
12
4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
Total Length (mm)

Dip Net Graphs

Fountain darters collected from the Hotel Reach (Section 1U) Dip Net Results - San Marcos River





Fountain Darters Collected from the I-35 Reach
(Section 7-M) Dip Net Results - San Marcos River
TL5-TL15
TL16-TL25
TL26-TL35
TL36-TL45
unknown size
Flow
All samples = 1 hour
Number of Fountain Darters
Average Daily Discharge (cfs)
Date
0
10
20
30
40
50
60
70
80
90
100
110
120
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
53
21
16
26
36
57
62
31
72
93
50
27
53
35
16
29
27
35
50
21
19
47
42
35
37
35
22
19
31
21
18
33
48
31
23
31
42
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Jul-08
Oct-08
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
Apr-10
Jul-10
Oct-10

APPENDIX C:
DROP NET RAW DATA

(not available online)