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 2009 ANNUAL REPORT

Prepared for:

Edwards Aquifer Authority
1615 North St. Mary's Street
San Antonio, Texas 78215

Prepared by:

BIO-WEST, Inc.
Austin Office
1812 Central Commerce Court
Round Rock, Texas 78664-8546

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TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

EXECUTIVE SUMMARY

This annual summary report presents a synopsis of methodology used and an account of sampling activities conducted during five full sampling events (two Comprehensive Monitoring events and three Critical Period low-flow events) on the San Marcos Springs/River ecosystem in 2009. For ease of comparison, the data are reported here in an annual report format similar to previous reports (BIO-WEST 2001-2009).

Discharge in the San Marcos River in 2009 decreased to levels not observed since this study began in 2000. Springflow was under 100 cubic feet per second (cfs) for 243 days (157 consecutively), with a minimum flow of 83 cfs in June, which was the lowest minimum flow in the river since 1996 (76 cfs). Springflow remained below 120 cfs for three quarters of the year (275 days). Mean monthly flows were below historic average flows for 18 straight months (dating back to March 2008). A myriad of effects were observed as a result of these low flows including elevated water temperatures, changes in aquatic vegetation coverage, and changes in channel morphology. Conditions experienced in 2009 allowed a comprehensive evaluation of the biota over an extended period of time with lower than average flows in the system.

Grab samples for water quality assessment were obtained four times in 2009 from Spring Lake and the San Marcos River. Analyses indicated that water chemistry (conductivity, pH, dissolved oxygen, etc.) were similar to the previous Critical Period low-flow event in 2006. Water temperatures exceeded 26.67 ºC (water quality standard set forth by the Texas Commission on Environmental Quality [TCEQ]) at three sites in 2009. Two were located at off-channel sites (Sessoms Creek and the artificial channel at Thompson's Island) where runoff and reduced flows often increase water temperatures. The other was within the main channel of the San Marcos River upstream of Rio Vista Dam where water is pooled and effects of ambient heating are intensified. Temperatures at this site had not exceeded 26 ºC in the previous nine years.

The five sampling efforts conducted over the course of 2009 provided a unique opportunity to assess aquatic vegetation at three reaches (City Park, Spring Lake Dam, and I-35) in a below-average flow year. Low flows coupled with recreation pressure in summer resulted in the least amount of aquatic vegetation coverage in the City Park Reach since the study's inception. Lower flows in this reach contributed to reduced depths and easier access for recreationists to parts of the river bed that are typically too deep. This resulted in more mechanical disturbance from people walking through these areas and sometimes physically pulling out plants. Aquatic vegetation in the middle of the reach was most affected because this area becomes shallow first during lower than average flows. In particular, *Hydrilla* and *Potamogeton* were most affected because they typically occupy this shallower section of the reach. Aquatic vegetation at the Spring Lake Dam Reach received similar pressure because of multiple access points. By fall, this reach also exhibited the lowest total area of vegetation mapped in the nine years of study. Similarly, *Hydrilla* and *Potamogeton* observed the greatest decline in this reach. Like the City Park Reach, when flows decrease and recreation pressure increases, paths develop through vegetation in areas that were previously too deep to access. Unlike the Spring Lake Dam and City Park reaches, the I-35 Reach receives comparably less recreation pressure because access points to the San Marcos River are limited in this stretch. Total area of aquatic vegetation decreased little from 2008 to 2009 at the I-35 Reach, and changes did not appear to follow any pattern related to flow. Channel morphology, however, was affected by the continued low flows of 2009. Increased sedimentation (from changing Rio Vista Dam to a more flow-through structure in 2006) combined with the lower than average flows resulted in the river right bank expanding near the top of the reach. When flows increased closer to average in fall (due to several precipitation events), this bank was inundated with water, but continued to be shallower than in previous years.

Texas wild-rice (*Zizania texana*) coverage experienced similar declines in 2009, with decreases a result of both lower than average flows and recreational pressure. Overall, the total amount of Texas wild-rice decreased by 14% from summer 2008 to fall 2009. This was the lowest total amount since the Critical Period low-flow event in 2006. However, since this program first started measuring the total amount of Texas wild-rice in the river in 2001, it has shown a steadily increasing trend (with occasional decreases). The highest recorded total area of Texas wild-rice measured in the San Marcos River since the inception of the study occurred in January 2009. This year (2009) was the first year in which coverage of Texas wild-rice was quantified in winter (January), when recreation pressure is at its lowest. As the lower-than-average flows of 2009 continued and winter gave way to summer, the total area of Texas wild-rice began to decrease. Most losses occurred within the upper reaches of the river where recreation access points are numerous. Evidence of mechanical disturbance was observed in these areas, but it is unclear how the plants were uprooted (physically pulled out, or displaced by walking/swimming). Lower flows in certain areas like Sewell Park led to several plants being "stranded" in very shallow water, resulting in many being moved to deeper areas by the United States Fish and Wildlife Service (USFWS). Texas wild-rice in vulnerable areas also displayed signs of damage due to the combination of lower than average flows and recreation pressure. The most notable observation of the extent of Texas wild-rice in vulnerable areas was the decrease in areal coverage of every monitored stand from January to October 2009. The plants at Thompson's Island virtually disappeared in 2009 because of sedimentation and dropping water levels in the area where the plants were found. Additionally, root exposure was highest at all sites since the previous Critical Period low-flow event in 2006.

Changes in aquatic vegetation observed in 2009 influenced fountain darter (*Etheostoma fonticola*) habitat, and thus, population estimates. As stated earlier, by fall 2009 the middle portion of the City Park Reach had become shallower and much of the *Hydrilla* and *Potamogeton* that occupied this area had been uprooted. Since fountain darter population estimates are based on vegetation coverage, the population estimate of fountain darters in this reach declined. In fact, fall 2009 exhibited the lowest overall population estimate of the study period (2000 – 2009). However, it is important to note that this is based solely on changes in vegetation coverage. When fountain darter density is analyzed by sample event, the overall density for City Park Reach in fall 2009 ($8.6/m^2$) is considerably higher than the long-term average for this reach ($4.4/m^2$). When analyzed by vegetation type, fountain darters continue to be most dense in native vegetation like *Cabomba*, filamentous algae, and bryophytes. Only *Cabomba* grows in enough abundance within the main channel of the San Marcos River to be sampled using drop net methods. Dip-netting data from Spring Lake clearly demonstrates the importance of bryophytes and filamentous algae as high quality habitat for this endangered fish, and also displays the ability of fountain darters to engage in year-round reproduction in areas of high-quality habitat. Additional analysis was conducted in 2009 to further explore the relationship between fountain darter abundance/density and discharge. When analyzed over the entire study period, total abundance and overall density show a negative relationship with discharge. That is, as discharge increases, abundance and density of darters decreases. This may be related to darters becoming concentrated into more limited habitat under lower flow conditions or decreased sampling efficiency under high flows.

San Marcos Salamander (*Eurycea nana*) populations did not appear to be affected by the lower than average flows in the San Marcos River in 2009. Densities of salamanders at all sites were within the variability that has been observed over the course of the study.

The recent drought in Central Texas provided a unique opportunity to observe the biota in the San Marcos River over an extended period of lower than average flows. Multiple sampling efforts in 2009 provided valuable data on the effects of these flows combined with increased summer recreational pressure. Immediate effects of this pressure were apparent for Texas wild-rice and other aquatic vegetation types, and thus also influenced important fountain darter habitat. However, other study components such as San Marcos salamanders did not appear to be directly affected. Initial conditions and their effects are similar to those observed in 2006 when discharge was also below average. These Comprehensive and Critical Period Monitoring efforts have provided a valuable measure of ecosystem condition, but additional data during extended periods of drought are necessary to understand the stressors flows can put on this unique ecosystem.

METHODS

Study Location

The upper San Marcos River is part of the Edwards Aquifer system, and extends approximately three 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. The upper portion of the river is characterized by near constant water temperatures (21°C $\pm$ 2°C, Ono et al. 1983) 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*), 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 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 users of this unique ecosystem (Figure 1).

During 2009, two comprehensive sampling efforts (spring and fall), and three Critical Period low-flow events were conducted in the San Marcos River system. In addition, lower flows during early 2009 triggered several Critical Period Texas wild-rice physical observations during periods of average daily discharge below 120 cfs (12 total sampling events in 2009). The 2009 sampling schedule included the following components during each sampling effort unless otherwise noted:

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

<u>Water Quality</u>
- Thermistor Placement
- Thermistor Retrieval
- Fixed Station Photography
- Point Water Quality Measurements
- Surface water grab samples (only Critical Periods)

<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 (includes summer sampling)
- Visual Observations

Low-Flow Sampling

Flows in the San Marcos River began the year below 100 cfs triggering a Critical Period Event in January. Although flows declined below 100 cfs in December 2008, a Critical Period sampling event was performed in January because the 2008 Fall Comprehensive sampling effort was recently completed in November 2008 at 106 cfs (approximately 60 days prior to the January effort). The second Critical Period sampling effort occurred in early April because flows remained below 100 cfs for more than 2 months since the last complete sampling effort (Critical Period 1). Critical Period 3 followed in June because initial springflow data showed flows below 80 cfs (data were later amended by the USGS to show a minimum flow of 83 cfs). When the Texas wild-rice mapping effort of the entire river during early fall occurred, at the time the San Marcos River had been below 100 cfs for a total of 243 days in 2009. Critical Period Texas wild-rice sampling occurred approximately every 3 weeks at vulnerable stands while flows were below 120 cfs (12 total efforts) in 2009.

High-Flow Sampling

There were no high-flow sampling events in 2009.

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 2009). 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.

In addition to the standard water quality parameters, surface water grab samples were collected at all sample sites to evaluate conventional water chemistry parameters (Figure 1). Following the same protocols used in previous years (BIO-WEST 2003, BIO-WEST 2007), water quality analysis was conducted during three Critical Period sampling events and the spring comprehensive sampling event in 2009 at eighteen sites within Spring Lake and the San Marcos River. During the 2009 sample collection, two 500-mL surface water samples were collected at each site. One of the two samples was left unpreserved for nitrate, soluble reactive phosphorus (SRP), alkalinity and total suspended solid (TSS) analyses, and the other sample was acidified with sulfuric acid for ammonia, total nitrogen (TN), and total phosphorus (TP) analyses. Turbidity was not determined for water samples in 2009. Chemical analyses of surface water samples for the 2009 sampling events were conducted by the AnalySys, Inc. laboratory in Austin, Texas, where water chemistry parameters were determined utilizing EPA standard methods (Table 1) as described in more detail below.

Nitrate Nitrogen and Soluble Reactive Phosphorus: Following standard EPA Method 300.1, the concentrations of anions in a 10-µL sample are determined using an ion chromatography system equipped with a conductivity detector.

Total Nitrogen: Following standard EPA Method 351.2, the sample is heated in the presence of sulfuric acid, potassium sulfate, and mercuric sulfate for two and one half hours. The resulting residue is cooled, diluted to 25mL and determined by spectroscopy.

Ammonium: Following standard EPA Method 350.2, the sample is buffered at alkaline pH with borate buffer to decrease hydrolysis of cyanates and organic nitrogen compounds, distilled into a solution of boric acid and then determined by spectroscopy.

Total Phosphorus: Following standard EPA Method 365.2, the sample is pretreated to select the phosphorus forms of interest; the forms are then converted to orthophosphate. Ammonium molybdate and antimony potassium tartrate react in an acid medium with dilute solutions of phosphorus to form an antimony-phospho-molybdate complex, which is reduced with ascorbic acid to form an intense blue-colored complex. The absorbance of the complex is measured by spectroscopy, and is proportional to the orthophosphate concentration.

Alkalinity: Following standard EPA Method 310.1, an unaltered sample is titrated to an electrometrically determined end point of pH 4.5.

Total Suspended Solids: Following standard EPA Method 160.2, a well-mixed sample is filtered through a glass fiber filter, and the residue retained on the filter is dried to a constant weight at 103-105°C.

Table 1. A list of the water quality analyses performed on surface water grab samples from 18 sites along the San Marcos Springs/River ecosystem in 2009, along with the analytical method, technique and minimum analytical detection levels of each analysis.

PARAMETER	EPA METHOD	TECHNIQUE (2009)	MINIMUM ANALYTIC LEVELS (per liter)
Total Suspended Solids	160.2	Gravimetric	Appropriate
Alkalinity	310.1	Titration	10 mg
Nitrate Nitrogen	300.1	Ion Chromatography	0.05 mg[a]
Ammonium	350.2	Spectroscopy	0.01 mg
Total Nitrogen	351.2	Spectroscopy	0.5 mg
Soluble Reactive Phosphorous	300.1	Ion Chromatography	0.05 mg
Total Phosphorous	365.2	Spectroscopy	0.01 mg

[a] micrograms.

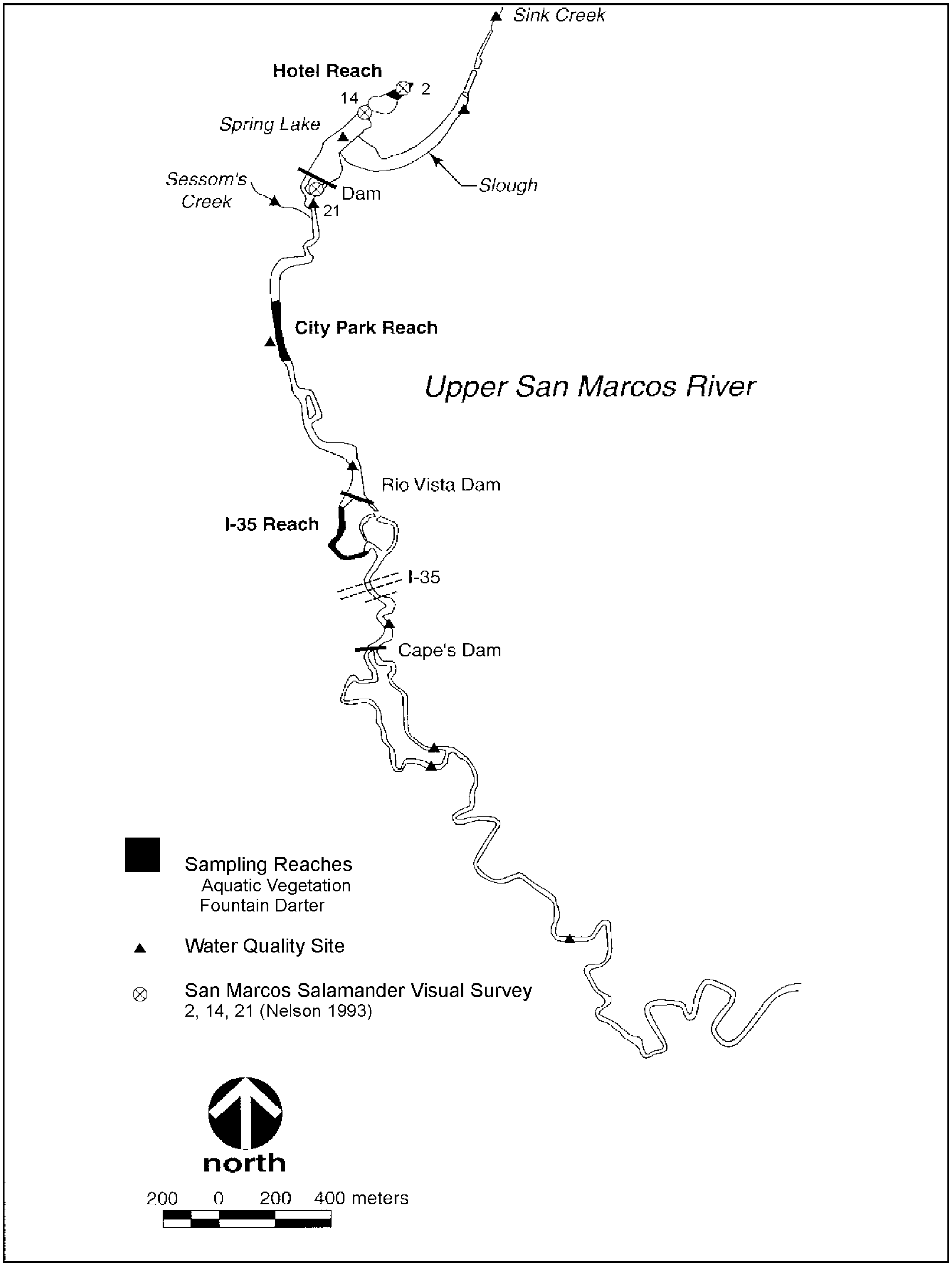
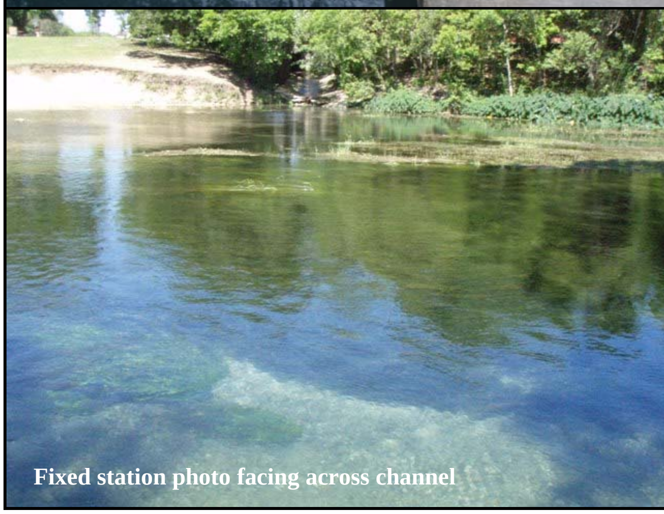


Figure 1. Upper San Marcos River water quality and biological sampling areas.


Measuring standard water quality parameters


Fixed station photo facing upstream


Fixed station photo facing across channel


Fixed station photo facing downstream

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; each 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 (and/or during Critical Period events) in the entire 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 feet (ft) 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 equipment used during aquatic vegetation mapping

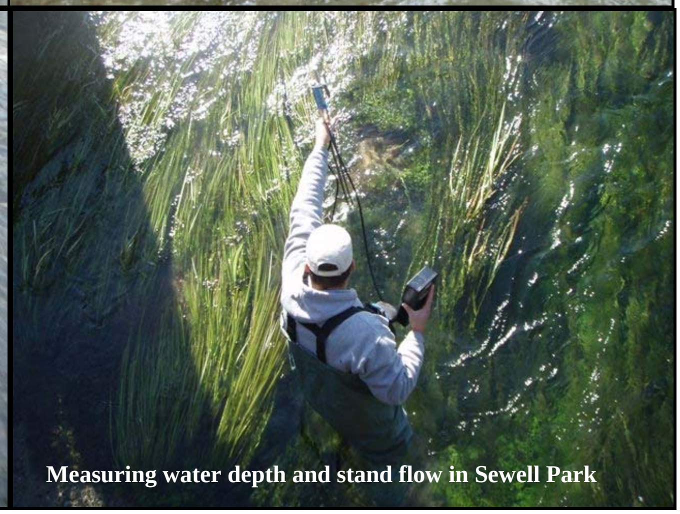
Texas Wild-Rice Physical Observations

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, (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 aerial coverage of Texas wild-rice stands in vulnerable locations were determined in 2009 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.


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), 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 were monitored. To complement all of the measurements made during each survey, photo sets were made for each of the sampling events in 2009.

Fountain Darter Sampling

Drop Net Sampling

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

Drop netting in 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 the adjacent area within three meters of the net. 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

(2000-2009). 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 had great variation and population estimates based on those densities are 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).

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 Net Sampling

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.

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.

During each sample, 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 are chosen in the Spring Lake Dam Reach, 22 sites are chosen in the City Park Reach, and 14 sites are chosen in the I-35 Reach. 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 near 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 2009 Comprehensive and Critical Period sampling events on the dates shown in Table 2. Additionally, Texas wild-rice physical observation data were collected following periods of average daily discharge less than 120 cfs on January 29, February 20, March 23, July 17, August 5, August 19, and September 4.

Table 2. Study components of the 2009 sampling events.

Event	Date(s)
Critical Period 1	
Vegetation and Texas wild-rice mapping	January 7-15
Texas wild-rice physical observations	January 7
Fountain darter sampling	January 12-13
San Marcos salamander observations	January 15
Water quality sample collection	January 9
Critical Period 2	
Vegetation Mapping	April 8-9
Texas wild-rice physical observations	April 13
Fountain darter sampling	April 6-7
San Marcos salamander observations	April 16
Water quality sample collection	April 10
Spring	
Vegetation mapping	April 28-29
Texas wild-rice physical observations	May 18
Fountain darter sampling	May 11-12
San Marcos salamander observations	May 14
Water quality sample collection	May 19
Critical Period 3	
Vegetation and Texas wild-rice mapping	June 22 - July 2
Texas wild-rice physical observations	June 22
Fountain darter sampling	June 25-26
San Marcos salamander observations	July 1
Water quality sample collection	June 24
Fall	
Vegetation and Texas wild-rice mapping	October 5-12
Texas wild-rice physical observations	October 19
Fountain darter sampling	October 15-16
San Marcos salamander observations	November 5

San Marcos Springflow

Springflows continued to decline throughout most of 2009 in the San Marcos River. The springflow was below 100 cfs for 243 days (Figure 2) in 2009; this is the second highest number of days under 100 cfs during the period of record for the San Marcos River (although 1956 may have had more, spring flow was only recorded for a total of 221 days). Springflow remained below 120 cfs for three quarters of the year (275 days). This resulted in our team assessing vulnerable Texas wild-rice stands a total of 12 times in 2009 (these stands were monitored approximately every 3 weeks while the flows remained below 120 cfs). The minimum flow level of 83 cfs was reached on June 15 and 16, 2009. This is the lowest recorded springflow during the ten year study period, and the lowest flow recorded since 1996. The maximum mean daily flow was not reached until December when the river reached 206 cfs due to rains in October and November. The mean monthly discharge remained well below the historic discharge in 2009, continuing a trend observed starting in March 2008 (Figure 3). Mean monthly discharge did not exceed the historic average until October 2009 resulting in 18 straight months where the flows of the San Marcos River were below the historical average. Discharge of the river remained below 120 cfs for 384 consecutive days from 2008 to 2009 (September 14, 2008 to October 2, 2009) and flows were under 100 cfs for 157 consecutive days in 2009 (April 18 to September 21, 2009). Previous to this extended below average discharge, the longest stretch of days below 120 cfs during the study period was 120 days in 2006 and below 100 cfs was 41 days also in 2006. The prolonged drought in Central Texas that resulted in this extended period below average discharge afforded the unique opportunity to study the physical and biological components in the San Marcos River during these rarely witnessed conditions.

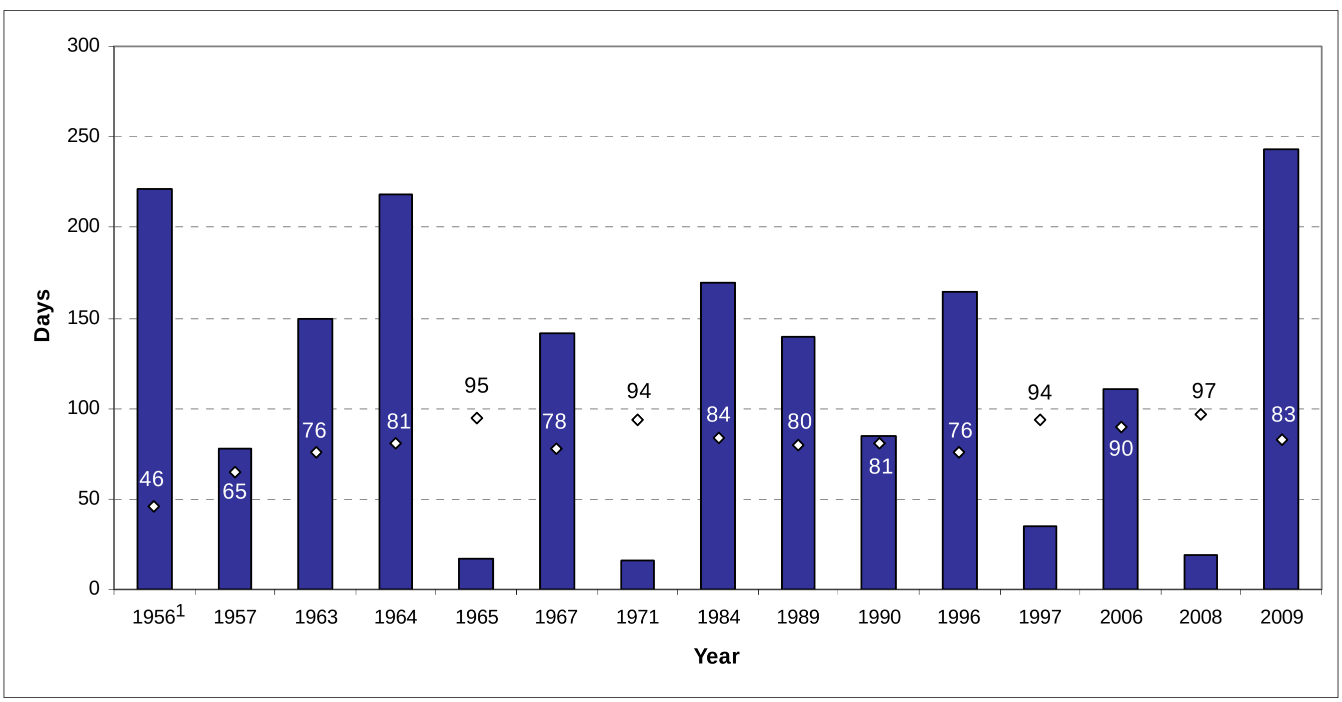


Figure 2. Number of days during the historical period of record the discharge in the San Marcos River was below 99 cfs. Numbers on the graph indicated the minimum flow (cfs) for each year. [1]Discharge was measured for only 221 days in 1956.

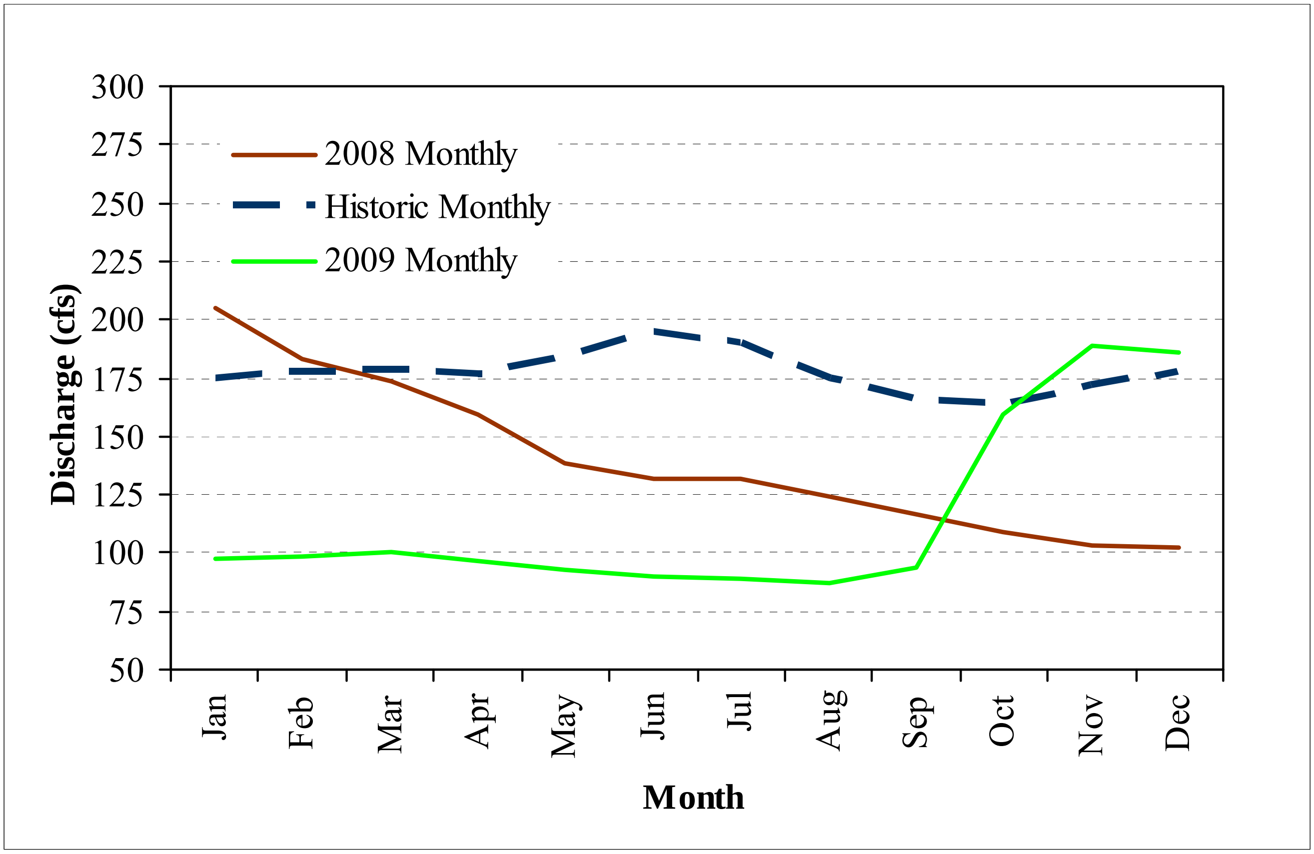


Figure 3. Mean monthly discharge in the San Marcos River during the 1956-2009 period of record.

Water Quality Results

Spring Lake

The original sampling sites (2000-2002) for Spring Lake were chosen based on historical locations that have been used during basic limnological sampling conducted at Texas State University (Figure 1). Those same nine water quality sampling sites were sampled during four sampling events in 2009 (Critical Periods 1, 2, 3, and the Spring comprehensive). The Spring Lake sampling site locations were as follows:

Site A was located directly in front of the hotel on Spring Lake in a deep hole,

Site B was located in front of the "submarine" area,

Site C was located across from "The Landing,"

Site D was just upstream from the chute at Saltgrass Steakhouse,

Site E was located just upstream of the dam,

Site F was chosen to represent the mixing of the slough and spring arms,

Site G was located behind the softball fields and under a powerline in the slough,

Site H was located downstream of the road crossing in the slough arm, and

Site S was in Sink Creek.

The Spring Lake water quality sampling sites can be grouped into Spring Arm, Slough Arm, and Sink Creek sites. Spring Arm sites include A through E. Site A is closest to the headwaters and E is closest to the dam. Slough Arm sites include F through H. Site F is closest to the dam while H is closest to the Sink Creek. Site S is located in Sink Creek, which often goes dry during the late summer months.

Information on standard water quality parameter point measurements for each water quality site in Spring Lake is presented in Table 3. Average values from seven sampling events during 2000-2002 (Average 2000-2002; this mean does not include the high-flow event), values from the 2002 high flow event (High Flow), average values from the two 2006 low-flow Critical Period events (Low Flow 2006), and average values from the four 2009 low-flow sampling events (Low Flow 2009) are presented for comparison between varying annual discharge conditions. Similarly, information on water chemistry measurements for each site in Spring Lake is presented in Table 4. It should be noted that the 2009 low-flow Critical Period events occurred in January, April, May and June. Therefore, some water quality variables may reflect seasonal differences (e.g., temperature).

Table 3. Average standard water quality parameters of surface water at sampling sites in Spring Lake during normal conditions (Mean), a high-flow event in 2002 (High Flow), low-flow conditions in 2006 (Low Flow 2006), and low-flow conditions in 2009 (Low Flow 2009).

Sampling Period	Site								
	A	B	C	D	E	F	G	H	S
Temperature (°C)									
Mean*	21.73	21.97	22.18	22.54	22.56	23.83	22.85	22.49	20.61
High Flow[a]	21.56	21.63	22.00	22.28	22.44	25.49	26.16	24.79	23.59
Low Flow 2006[b]	21.86	22.72	22.86	22.84	22.81	22.61	27.01	23.89	24.02
Low Flow 2009[c]	21.76	22.03	22.18	22.15	22.00	22.91	23.85	21.41	20.30
Conductivity (μS/cm)[a]									
Mean*	563	558	560	561	560	545	541	562	642
High Flow[a]	577	574	562	564	568	600	607	615	610
Low Flow 2006[b]	542	551	547	563	556	554	516	523	534
Low Flow 2009[c]	547	552	552	562	558	554	513	513	576
pH									
Mean*	7.11	7.14	7.13	7.17	7.24	7.35	7.49	7.61	7.51
High Flow[a]	6.80	6.83	6.81	6.83	6.87	7.13	7.20	7.11	7.17
Low Flow 2006[b]	7.12	7.15	7.21	7.11	7.19	7.16	7.29	7.17	7.16
Low Flow 2009[c]	7.53	7.59	7.62	7.66	7.62	7.57	7.75	7.74	7.75
DO (mg/l)									
Mean*	5.54	6.23	6.45	8.45	8.60	9.58	8.07	10.07	6.64
High Flow[a]	4.81	4.74	5.66	6.39	6.68	6.24	6.38	4.60	5.98
Low Flow 2006[b]	5.38	5.98	7.25	6.5	6.49	6.60	3.65	1.58	2.52
Low Flow 2009[c]	4.72	5.21	7.14	5.3	5.58	8.13	8.34	6.38	4.13

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high-flow sampling event in fall 2002.
[a] High-flow sampling event conducted on August 5, 2002.
[b] Low-flow sampling events conducted on July 25 and September 14, 2006.
[c] Low-flow sampling events conducted on January 9, April 10, May 19, and June 24, 2009.

Table 4. Average water chemistry parameters of surface water at sampling sites in Spring Lake during normal conditions (Mean), a high-flow event in 2002 (High Flow), low-flow conditions in 2006 (Low Flow 2006), and low-flow conditions in 2009 (Low Flow 2009).

Sampling Period	Site								
	A	B	C	D	E	F	G	H	S
Alkalinity (mg/l)									
Mean*	232	233	244	245	242	249	240	247	278
High Flow[a]	263	261	261	257	257	265	257	267	271
Low Flow 2006[b]	260	255	260	265	265	260	210	230	230
Low Flow 2009[c]	260	257	265	265	260	265	223	240	250
Ammonium (mg/l)									
Mean*	0.040	0.036	0.018	0.048	0.023	0.051	0.049	0.044	0.043
High Flow[a]	0.032	0.017	0.039	0.035	0.043	0.035	0.048	0.046	0.043
Low Flow 2006[b]	0.039	0.051	0.060	0.065	0.076	0.060	0.085	0.100	0.069
Low Flow 2009[c]	0.046	0.060	0.063	0.093	0.072	0.070	0.079	0.095	0.080
Nitrate Nitrogen (mg/l)									
Mean*	1.261	1.327	1.512	1.621	1.717	0.890	0.680	0.559	0.195
High Flow[a]	2.621	1.608	1.813	1.659	1.532	1.431	1.174	1.251	1.404
Low Flow 2006[b]	1.320	1.205	1.158	1.360	1.220	1.120	0.166	0	0.084
Low Flow 2009[c]	1.042	1.018	0.909	1.078	1.028	0.939	0.479	0.632	0.143
Total Nitrogen (mg/l)									
Mean*	1.497	1.634	1.889	2.055	2.002	1.126	0.910	0.885	0.938
High Flow[a]	2.458	2.218	2.325	2.109	1.952	1.813	1.598	1.692	1.894
Low Flow 2006[b]	3.53	2.415	4.085	2.280	2.115	2.110	1.215	1.065	2.360
Low Flow 2009[c]	2.05	1.970	2.125	2.073	2.210	2.013	1.454	1.873	2.030
Soluble Reactive Phosphorus (mg/l)									
Mean*	0.016	0.018	0.014	0.016	0.015	0.018	0.024	0.019	0.039
High Flow[a]	0.010	0.013	0.008	0.007	0.009	0.009	0.010	0.008	0.019
Low Flow 2006[b]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Low Flow 2009[c]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total Phosphorus (mg/l)									
Mean*	0.021	0.048	0.017	0.027	0.037	0.023	0.048	0.024	0.073
High Flow[a]	0.004	0.022	0.018	0.028	0.043	0.028	0.065	0.027	0.059
Low Flow 2006[b]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Low Flow 2009[c]	0.009	0.016	0.008	0.004	0.003	0.005	<0.01	0.012	0.045

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high-flow sampling event in fall 2002.
[a] High-flow sampling event conducted on August 5, 2002.
[b] Low-flow sampling events conducted on July 25 and September 14, 2006.
[c] Low-flow sampling events conducted on January 9, April 10, May 19, and June 24, 2009.

Temperatures within the Spring Arm (Sites A through E) are very similar, while temperatures at the Slough Arm sites generally have larger mean and maximum values and lower minimum values than the Spring Arm sites (Table 3; Appendix B). This may be attributed to shallower water depths with less of a temperature buffer within the Slough Arm and in Sink Creek. Temperatures measured during the 2009 low-flow sampling events were similar to the mean of temperatures measured in all previous sampling years, with the exception of Sites G and H in the Slough Arm (Table 3). At these sites, higher maximum temperatures were recorded during the low-flow Critical Period sampling events in both 2006 and 2009 than during previous sampling events (Appendix B).

Conductivity did not vary among sites within the lake for the period of the study. A conductivity-to-TDS conversion of 0.65 was used so that a comparison could be made with the TDS water quality standard. During the August 2002 sampling event TDS values at each of the Slough Arm sites approached or met the water quality standard value of 400 milligrams per liter (mg/l), which equals 615 micromhos per centimeter (µmhos/cm). During the 2006 and 2009 low-flow Critical Period sampling events, conductivity values were very similar or lower than the average during 2000-2002 at all sites (Table 3).

As during previous sampling events, dissolved oxygen (DO) concentrations measured during the 2009 low-flow sampling events at sites A and B (nearest the springs) and site S in Sink Creek did not always meet the TCEQ "high" water quality standard of 6.0 mg/l for DO for the Upper San Marcos River Segment No. 1814 (Appendix B). After prolonged lower discharge conditions, DO levels were lower during 2009 within the Spring Arm than in 2006. Lower DO concentrations at the headwaters may occur due to aquifer water naturally having lower DO concentrations. Low DO concentrations in the Slough Arm have previously occurred due to the higher water temperatures in the summer and decomposition of the abundant plant material, which requires oxygen. DO concentrations within the Slough Arm in 2009 were highest in April (>8.5 mg/l) and lowest (at two of the three sites) in June.

Total suspended solids (TSS) values were low at all sites in Spring Lake in 2009, reflecting the clear water conditions present in the lake, slough and creek during all four 2009 sampling events. The maximum TSS value of 8 mg/l was measured at Sink Creek in April 2009 (Appendix B). Alkalinity was fairly constant throughout Spring Lake for the duration of the study (Table 4, Appendix B).

Ammonium values were well below the TCEQ screening level of 1.0 mg/l during all sampling events (Appendix B). Average ammonium levels were very similar between 2006 and 2009, and very slightly higher than average levels measured under 2000-2002 conditions and the high-flow event. Nitrate values of surface water in Spring Lake were very close to the TCEQ water quality standards screening level of 1.0 mg/l in most cases, during both the 2006 and the 2009 low-flow Critical Period events. The nitrate levels in the Spring Arm were slightly lower in 2009 than in 2006 (Appendix B). However, nitrate concentrations were slightly higher in the Slough Arm in 2009 than in 2006. Similar to the three previous sampling periods, TN concentrations in Spring Lake during the 2009 low-flow sampling events consisted of a high percentage of nitrate and a low percentage of ammonium. TN concentrations were generally lower during 2009 than in 2006, although TN concentrations during both the high-flow and low-flow periods were higher than average conditions in 2000-2002. As discussed below for the San Marcos River, the high nitrate values found in the San Marcos River and Spring Lake were not the result of anthropogenic inputs to the immediate surface waters (rainfall and overland flow was very low in 2006 and 2009). Spring flow is the most likely source of high nitrate values found at all sites in the San Marcos River and Spring Lake. The median concentration of nitrate in the Edward's Aquifer ranges from 1.4 to 1.7 mg/l (Bush et al. 1998). Nitrate values at the Spring Arm sites are fairly constant among these sites and throughout the year (Appendix B). Whereas nitrate concentrations at the Slough Arm sites and Sink Creek fluctuate throughout the year, they are actually much lower than the Spring Arm sites for most sampling events (Table 4). These lower concentrations may be due to uptake of nitrate by the abundant plants and algae in the Slough Arm and Sink Creek.

Soluble Reactive Phosphorus concentrations (SRP) and Total Phosphorous (TP) concentrations in Spring Lake during all sampling periods were well below the TCEQ's screening values of 0.1 and 0.2 mg/l, respectively (Table 4). The SRP and TP values fluctuated from season to season and site to site throughout the 2000-2002 sampling period. During this period, the Slough Arm and Sink Creek sites generally had higher concentrations of SRP than the Spring Arm sites (Appendix B). The higher SRP concentrations probably occurred due to recycling of SRP (as plant material decayed) and inputs of phosphorus from the immediate watershed. Due to the use of different analytical methods for these two analytes in 2006 and 2009, the detection limit was not as sensitive, but SRP and TP levels during the 2006 low-flow Critical Period were determined to be less than 0.05 mg/l and 0.01 mg/l, respectively (Table 4). SRP levels were also below detection of 0.05 mg/l in 2009, and TP concentrations were slightly higher than in 2006, but still below levels measured in 2000-2002 (Table 4).

San Marcos River

The nine water quality sampling sites in the San Marcos River were the same in 2009 as the sites sampled during the initial water quality assessment in 2000-2002 and subsequent sampling events in 2002 and 2006. The sites were as follows:

Site 1 was located directly downstream of the chute at Saltgrass Steakhouse;

Site 2 was located just downstream of Spring Lake Dam;

Site 3 was located in Sessoms Creek at the Texas State University Aquatic Biology building, before the confluence with the San Marcos River;

Site 4 was located within the City Park / Lion's Club Reach;

Site 5 was located in the far channel at Rio Vista Park;

Site 6 was located just upstream of the I-35 highway crossing;

Site 7 was located upstream of the falls within the artificial channel near the state fish hatchery;

Site 8 was located upstream of state fish hatchery outflow; and

Site 9 was located directly behind the old San Marcos Animal Shelter, near the current WWTP.

Information on standard water quality parameter point measurements for each water quality site in the San Marcos River is presented in Table 5. Average values from seven sampling events during 2000-2002 (Average 2000-2002; this mean does not include the high-flow event), values from the 2002 high-flow event (High Flow), average values from the two low-flow Critical Period sampling events in 2006 (Low Flow 2006), and average values from the four low-flow sampling events in 2009 (Low Flow 2009) are presented to compare between varying discharge conditions. Similarly, information on water chemistry measurements for each site in the San Marcos River is presented in Table 6. It should be noted that the 2009 low-flow Critical Period events occurred in January, April, May and June. Therefore, some water quality variables may reflect seasonal differences (e.g., temperature).

Generally, an upstream-to-downstream pattern in water quality values other than temperature and pH has not been observed during the study. Values remain fairly constant throughout the system or they fluctuate minimally among sites. There does not appear to be much influence on water quality from surface water inflow to the river. The spring water quality conditions generally prevail within the study reaches of the San Marcos River system.

Conductivity did not vary among sites within the river system during the period of the study (Appendix B). A conductivity-to-TDS conversion of 0.65 was used so that a comparison could be made with the

TDS standards for each system. The TDS values at each San Marcos River site during the August 2001 sampling event and two other sampling events on Sessoms Creek exceeded the TCEQ water quality standard value of 400 mg/l. The high TDS values recorded in August 2001 were thought to have been due to relatively low-flow conditions in the river at the time. However, average and below-average conductivity values measured during the 2009 low-flow sampling events do not support this assumption (Table 5). No previous mention of exceedences has been indicated by the TCEQ, which suggests that this water quality parameter is not a concern.

Dissolved oxygen concentrations at the San Marcos River sampling locations met the TCEQ "high" water quality standard of 6.0 mg/l for DO during the first three water quality sampling events in 2009, with the exception of Site 3 (5.0 mg/l in May), and Site 7 (5.76 mg/l and 5.81 mg/l in January and April, respectively [Appendix B]). Sites 1 and 2 had the highest DO levels, likely because they are each located below dam structures that provide mixing of the water column. Dissolved oxygen values were below 6.0 mg/l at sites 3, 4, 5, 6, 7, and 8 during the third Critical Period low-flow sampling event (June) in 2009. However, on average, DO levels were higher in the San Marcos River than in Spring Lake. In general, there was not an upstream-downstream gradient in DO, but concentrations were lower during the low-flow sampling events than the high-flow Critical Period in 2002 or the average quarterly sampling periods in 2000-2002.

As previously mentioned, the TSS analysis conducted on 2006 and 2009 water samples was less sensitive than during the initial characterization, therefore one should be cautious when making comparisons to previous years. Total suspended solids values were very low at all sites in the San Marcos River in 2009, reflecting the clear water conditions present in the river during all four 2009 sampling events. The maximum TSS value in 2009 was 6 mg/l, measured at the downstream-most site (Site 9) in May and June 2009 (Appendix B). Alkalinity was constant throughout the river during all 2009 sampling events, with values similar to those in Spring Lake (Appendix B).

Nitrate values slightly exceeded the TCEQ water quality standard screening level of 1.0 mg/l in most cases throughout the study, whereas ammonium values were well below the screening level of 1.0 mg/l at all sites throughout the study (Appendix B). The TN values for the San Marcos River consist of a high percentage of nitrate rather than ammonium. These TN values varied only slightly between sampling events and between sites. The nitrogen levels are likely not the result of anthropogenic inputs to the immediate surface waters, but rather springflow. Nitrate values in the San Marcos River were fairly constant throughout the river and between 2009 sampling events (Appendix B). In contrast, ammonium concentrations vary throughout the sampling period and among sites and the values are very low (Appendix B).

Generally, SRP and TP concentrations in the San Marcos River were well below the TCEQ's screening values of 0.1 and 0.2 mg/l, respectively (Appendix B). Due to the use of different analytical methods for these two analytes in 2006 and 2009, the detection limit was not as sensitive. However, these analyses determined that during the 2009 low-flow sampling events, SRP was generally below 0.05 mg/l. Only one exceedence of the SRP screening value was measured during 2009, at Site 8 in January (0.177 mg/l; Appendix B). A maximum concentration of 0.094 mg/l of TP was measured at Site 8 in January as well. Phosphorus concentrations subsequently dropped to below detection limits during the following three sampling events. Similar to previous years, the two downstream-most sites (Thompson's Island Natural Canal and Animal Shelter) had slightly elevated levels of SRP and TP in 2009. These higher SRP values in the river could be caused by point or non-point source loads within the immediate watershed. The only permitted discharge upstream of the last sampling site is the TPWD fish hatchery. The City of San Marcos wastewater treatment plant is located downstream of the last sampling site. Non-point source discharges include the San Marcos urban area as well as agricultural areas. Although values are higher at these sites, it should be stressed that these SRP values are well below TCEQ's screening levels for surface waters.

Table 5. Average standard water quality parameters of surface water at sampling sites in the San Marcos River during normal conditions (Mean), a high-flow event in 2002 (High Flow), low-flow conditions in 2006 (Low Flow 2006), and low-flow conditions in 2009 (Low Flow 2009).

Sampling Period	Site								
	1	2	3	4	5	6	7	8	9
Temperature (°C)									
Mean*	22.53	22.55	22.75	22.67	22.64	22.47	22.00	22.22	22.08
High Flow[a]	22.78	22.76	22.90	22.83	23.17	23.12	22.71	22.97	22.65
Low Flow 2006[b]	22.48	22.61	23.18	22.35	22.37	22.18	22.33	22.28	22.56
Low Flow 2009[c]	22.18	22.03	19.97	21.93	20.77	21.45	20.49	20.40	21.28
Conductivity (μS/cm)[a]									
Mean*	571	570	593	570	570	570	570	570	568
High Flow[a]	580	584	598	583	582	582	583	582	581
Low Flow 2006[b]	558	555	581	560	559	560	558	559	549
Low Flow 2009[c]	561	558	605	560	583	560	578	584	553
pH									
Mean*	7.29	7.36	7.42	7.43	7.49	7.62	7.62	7.71	7.62
High Flow[a]	7.01	7.03	7.07	7.03	7.14	7.26	7.27	7.37	7.38
Low Flow 2006[b]	7.36	7.38	7.33	7.39	7.46	7.56	7.53	7.67	7.76
Low Flow 2009[c]	7.67	7.71	7.81	7.68	7.81	7.73	7.54	7.54	7.58
DO (mg/l)									
Mean*	8.59	8.54	7.48	9.28	10.30	9.46	8.66	9.04	8.99
High Flow[a]	10.61	9.1	8.17	10.91	11.50	10.48	10.00	9.83	9.46
Low Flow 2006[b]	8.07	7.85	5.97	8.99	7.73	7.82	6.61	7.62	7.76
Low Flow 2009[c]	7.12	7.16	6.22	6.99	6.53	6.23	5.78	6.83	6.21

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high-flow sampling event in fall 2002.
[a] High-flow sampling event conducted on August 5, 2002.
[b] Low-flow sampling events conducted on July 25 and September 14, 2006.
[c] Low-flow sampling events conducted on January 9, April 10, May 19, and June 24, 2009.

Table 6. Average water chemistry parameters of surface water at sampling sites in the San Marcos River during normal conditions (Mean), a high-flow event in 2002 (High Flow), low-flow conditions in 2006 (Low Flow 2006), and low-flow conditions in 2009 (Low Flow 2009).

Sampling Period	Site								
	1	2	3	4	5	6	7	8	9
Alkalinity (mg/l)									
Mean*	239	233	231	239	236	237	232	236	226
High Flow[a]	259	259	259	259	262	263	259	261	259
Low Flow 2006[b]	270	260	270	270	260	270	265	265	260
Low Flow 2009[c]	260	260	260	260	265	270	260	265	265
Ammonium (mg/l)									
Mean*	0.032	0.066	0.041	0.080	0.088	0.069	0.026	0.048	0.041
High Flow[a]	0.030	0.043	0.023	0.018	0.030	0.028	0.068	0.036	0.071
Low Flow 2006[b]	0.038	0.067	0.073	0.064	0.050	0.057	0.069	0.055	0.073
Low Flow 2009[c]	0.071	0.066	0.063	0.057	0.103	0.087	0.070	0.067	0.065
Nitrate Nitrogen (mg/l)									
Mean*	1.284	1.439	1.631	1.453	1.531	1.421	1.331	1.318	1.278
High Flow[a]	1.661	1.169	1.598	1.116	1.218	1.218	1.577	1.207	1.217
Low Flow 2006[b]	1.455	1.245	1.368	1.380	1.330	1.350	1.300	1.310	1.250
Low Flow 2009[c]	1.115	1.058	1.138	1.090	1.048	1.068	1.010	1.055	1.030
Total Nitrogen (mg/l)									
Mean*	1.477	1.798	1.766	1.664	1.983	1.560	1.550	1.528	1.506
High Flow[a]	2.019	1.396	1.719	1.299	1.410	1.658	1.948	1.616	1.542
Low Flow 2006[b]	2.395	3.030	2.430	2.380	2.740	2.395	3.395	2.395	3.635
Low Flow 2009[c]	1.943	2.155	2.540	2.338	2.325	1.958	2.135	2.180	2.393
Soluble Reactive Phosphorus (mg/l)									
Mean*	0.008	0.008	0.007	0.010	0.005	0.007	0.007	0.006	0.011
High Flow[a]	0.006	0.006	0.010	0.008	0.009	0.008	0.049	0.009	0.006
Low Flow 2006[b]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Low Flow 2009[c]	<0.05	0.044	0.025	<0.05	<0.05	<0.05	<0.05	0.044	<0.05
Total Phosphorus (mg/l)									
Mean*	0.014	0.012	0.016	0.021	0.012	0.014	0.011	0.012	0.018
High Flow[a]	0.010	0.010	0.015	0.015	0.016	0.014	0.052	0.014	0.016
Low Flow 2006[b]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.013	0.023
Low Flow 2009[c]	0.007	0.016	0.020	0.003	0.018	0.015	0.025	0.031	0.022

* Mean value is calculated from all seven sampling events in 2000-2002, not including the high-flow sampling event in fall 2002.
[a] High-flow sampling event conducted on August 5, 2002.
[b] Low-flow sampling events conducted on July 25 and September 14, 2006.
[c] Low-flow sampling events conducted on January 9, April 10, May 19, and June 24, 2009.

The thermistor temperature data for the Sessoms Creek and Rio Vista Dam 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 2000-2009. 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).

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. Temperatures at three sites exceeded the TCEQ water quality standards value of 26.67 ºC in 2009. This occurred at Sessoms Creek, which is a flashy stream draining an urban area where fountain darters are not found. This also occurred in the artificial channel at Thompson's Island (TI-art), where flow is substantially less than the main river channel, and temperatures are more responsive to ambient air temperatures. Temperatures at TI-art were recorded over 26.67 ºC at least once per day for a total of 12 days in 2009, on 7/8/-7/12, 8/21-8/26 and finally on 8/28. The highest temperature observed at TI-art was 28.29 ºC on July 8th 2009. The third and final site where water temperatures exceeded the TCEQ standards was Rio Vista Dam. This site had the highest number of days with temperatures exceeding 26.67 ºC at 65 days in 2009 and the most consecutive days over the TCEQ standard at 17 days. The highest temperature recorded at Rio Vista dam was 28.24 ºC on June 23rd 2009. The lowest temperature was recorded at the Sessoms Creek site on March 12th 2009 and was 9.51 ºC.

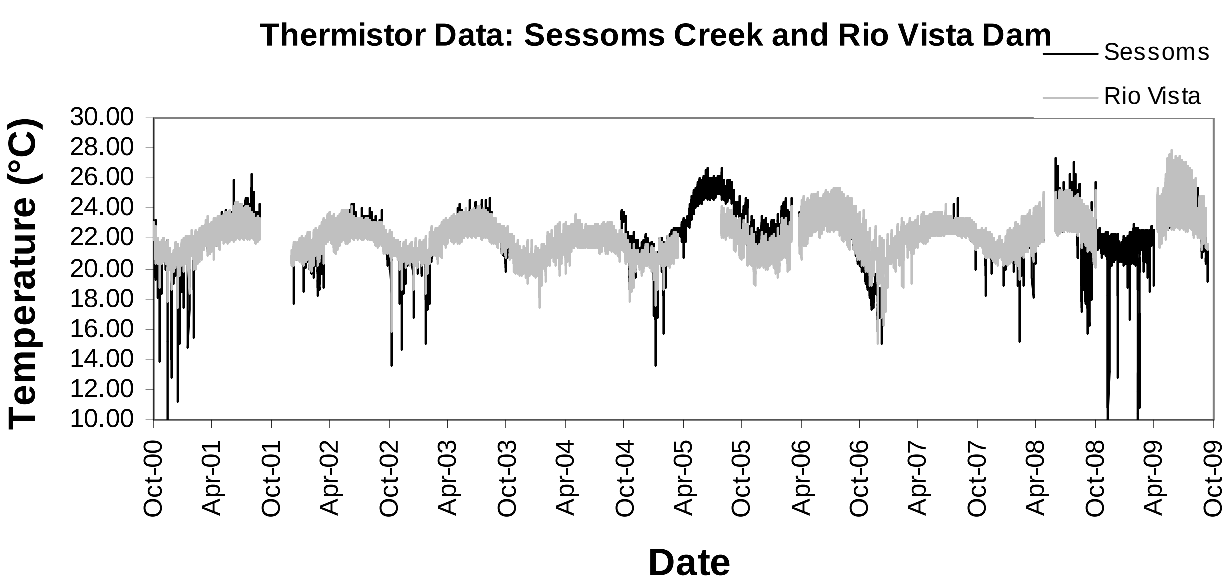


Figure 4. Thermistor data from the Sessoms Creek and Rio Vista Dam.

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 drought afflicting Central Texas that started in 2007 continued to affect aquatic vegetation in all reaches in 2009. The continued low flows coupled with increased recreation during the summer months resulted in a decrease of approximately 1,093 m^2 of aquatic vegetation from January (Critical Period 1) to October (fall, Figure 5). This is the least amount of vegetation observed in the City Park Reach since the study's inception in 2000. As flows declined from January to May, the amount of vegetation actually increased in the San Marcos River. However, by July, large segments of vegetation began to fragment. City Park can attract large crowds of people in the summer months because it is a free access point to the river and a large tube rental business is located adjacent to it. These factors result in a large influx of people using the river here during the hot summer months. When flows are reduced below 100 cfs for extended periods of time, it allows access to areas of the riverbed that are usually too deep for recreationists to wade. In addition, increased sedimentation over the years from multiple sources (most notably Sessoms Creek and a drainage culvert within the City Park Reach) has increased the amount of shallow areas accessible to people. All of these factors contributed to fragmentation of aquatic vegetation in the middle section of the reach. In particular the non-native plant *Hydrilla*, and the native plant *Potamogeton* experienced a large decrease in area in the middle and upper sections of the reach (Figure 6). These sections in particular display recreation effects because as the discharge decreases these areas become more accessible. In addition, Texas wild-rice decreased substantially in this area from both recreation and the compounding effect of adjacent (and often intertwined) vegetation becoming dislodged and likely dislodging the Texas wild-rice with it. This area will be closely monitored in the future to assess changes in vegetation coverage as flows increase and the recreation season subsides.

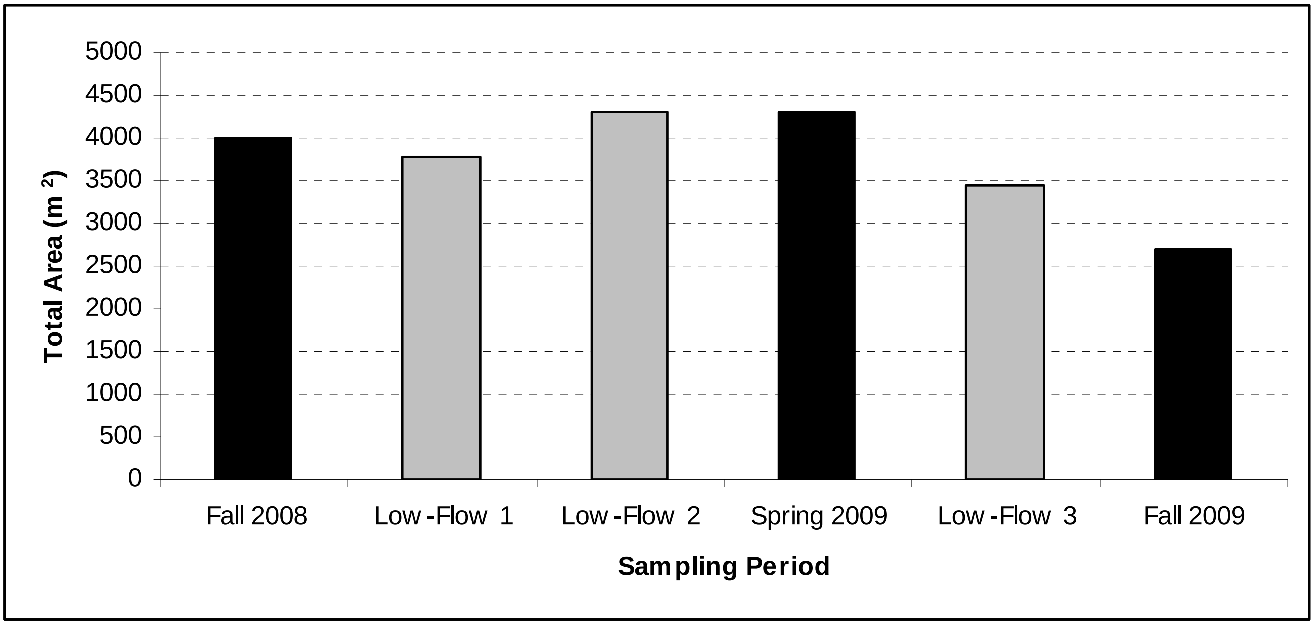


Figure 5. Total coverage of aquatic vegetation in the City Park Reach from fall 2008 to fall 2009.

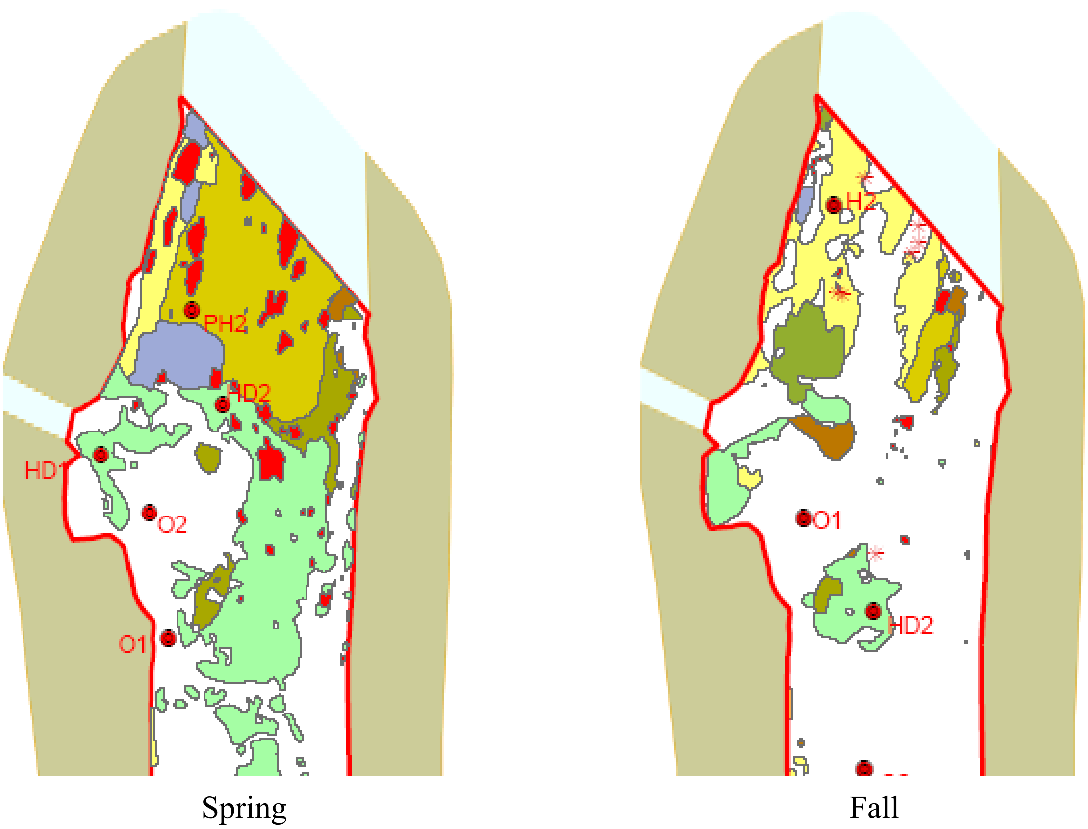


Figure 6. Changes in aquatic vegetation in the middle and upper section of the City Park Reach from spring to fall 2009.

I-35 Reach

The flows of 2009 affected the aquatic vegetation in the I-35 Reach differently than other sections of the San Marcos River. Of the three reaches sampled, this reach likely receives the least amount of recreation pressure since it is downstream of tubing areas, and has limited access to the river. Total surface area of all vegetation types combined only decreased by 45.9 m^2 from fall 2008 to fall 2009, and did not appear to follow any pattern as flows decreased throughout the year (Figure 7). *Cabomba* exhibited its lowest surface area (88.3 m^2) since the inception of the study during the Critical Period 2 sampling effort. In the fall, the coverage of the plant had increased to 231.2 m^2, which is an above average (168.4 m^2) area for this reach. This vegetation type is important because it provides the highest-quality fountain darter habitat (of those sampled quantitatively) in the San Marcos River. This native vegetation is often found in silt substrates in backwaters where flow is reduced, and is often negatively affected by flood events because it is not firmly rooted. However, it appears extended periods of low flow may also affect this important plant.

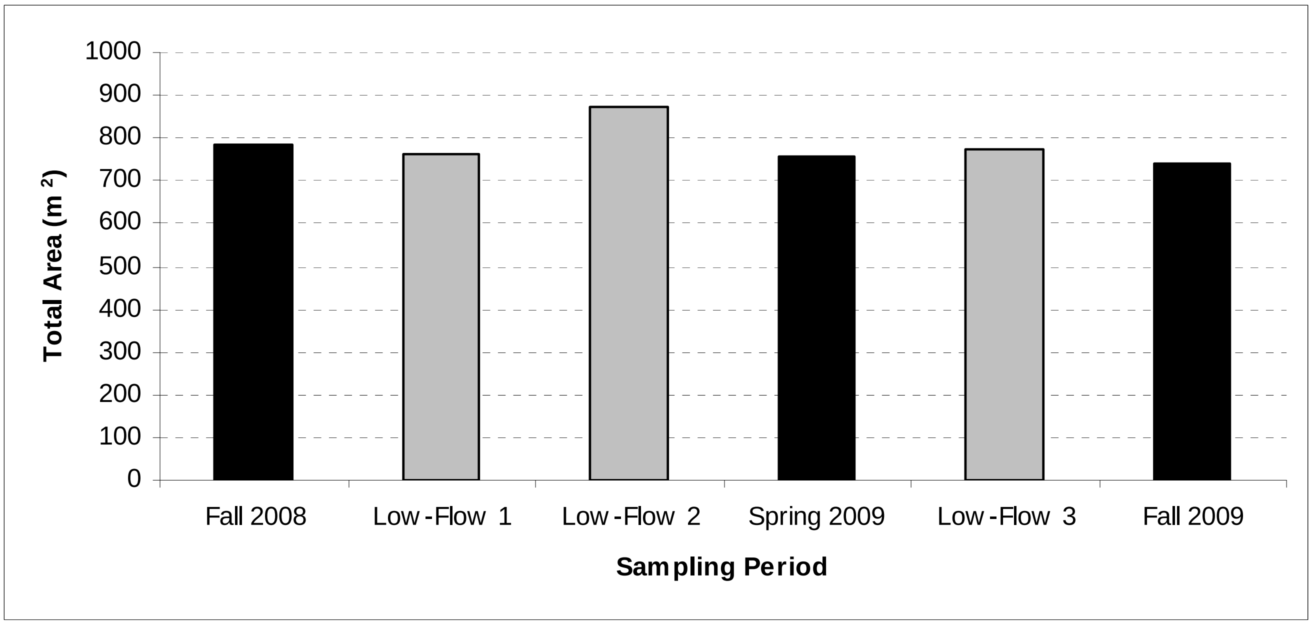


Figure 7. Total coverage of aquatic vegetation in the I-35 Reach from fall 2008 to fall 2009.

Decreasing flows in combination with construction at Rio Vista Dam in 2006 (allowing more sediment to pass downstream) have contributed to a change in channel morphology within the I-35 Reach (Figure 8). Sedimentation in this reach resulted in the creation of new gravel bars, and increased the bank width in some areas. Cross-sectional data have been collected in the upper portion of this reach coinciding with Texas wild-rice vulnerable stands. By fall 2008 the wetted width had decreased by 21 feet, by January this channel shrunk 2 more feet (see photos next page). In August 2009 (2nd photo, Figure 8) it was 29 feet narrower than in previous years. As flows increased in the latter part of 2009, the channel increased in width and was only 18 feet from the original bank line (3rd photo, Figure 8). These changes are an example of how man-made changes in the river can be exacerbated by extended periods of low flow.

Figure 8. Examples of changes in channel morphology in the I-35 Reach. Photo #1 (top) – January 2009. Photo #2 (middle) – August 2009. Photo #3 (bottom) – October 2009.

Spring Lake Dam Reach

Total area of aquatic vegetation in the Spring Lake Dam Reach (Figure 9) followed similar patterns to that of the City Park Reach (Figure 5). Total area varied by less than 200 m^2 in the early part of the year, but the extended duration of low flows exhibited a greater effect on this reach during the summer. After the spring, aquatic vegetation began to decrease and finished with a total of 802 m^2. This was the lowest amount of vegetation mapped in this reach since the inception of this study (less than half of the greatest amount of vegetation [1,726.9 m^2] mapped in this reach in 2002). Much of this decrease is attributed to the loss of *Hydrilla* throughout the reach. This non-native plant decreased by more than half over the course of the year (131.0 m^2 to 63.1 m^2). In addition, the *Potamogeton*/*Hydrilla* mix decreased by 74% in 2009 (278.5 m^2 to 71.4 m^2), which resulted in an overall increase of the native vegetation *Potamogeton* (163.0 m^2 to 272.1 m^2). This reach can be highly impacted during the summer months from recreation because it has multiple access points and is adjacent to an apartment complex and Texas State University. As a result, paths often develop cutting through vegetation and fragmenting it during these critical months. These paths appeared again in 2009, but it is difficult to assess how much long-term impact they have as the vegetation often grows back during other times of the year. As in other reaches it is likely a combination of the durational component of the low-flows and the increased recreation during summer months that has led to the lowest amount of vegetation mapped in this reach since 2002.

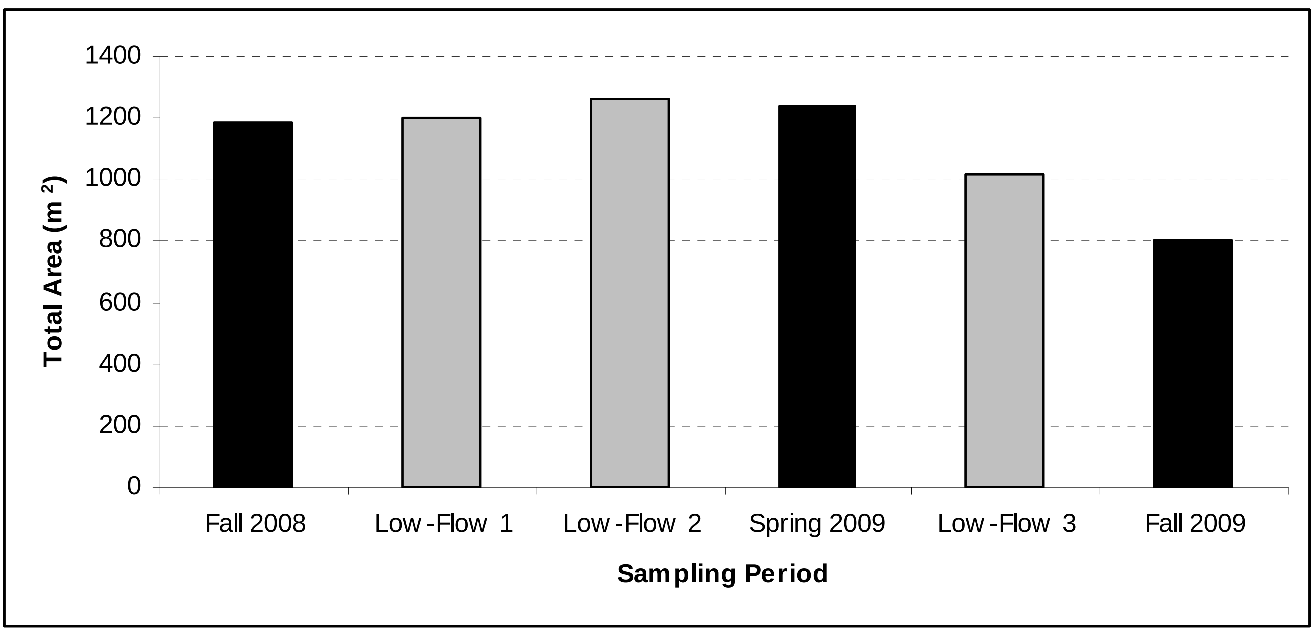


Figure 9. Total coverage of aquatic vegetation in the Spring Lake Dam Reach from fall 2008 to fall 2009.

Temporal Trends in Aquatic Vegetation

The drought that began in Central Texas in 2007 provided a unique opportunity to assess aquatic vegetation over a long period of decreasing flows. To put these data in context, it is necessary to review and understand seasonal and yearly variation in aquatic vegetation within the San Marcos River. After ten years of data collection in the San Marcos River, we have mapped aquatic vegetation 31 times at the City Park and I-35 reaches, and after eight years of collection at the Spring Lake Dam reach we have mapped vegetation 25 times. These mapping efforts have included 2 winter samplings (1 at Spring Lake Dam Reach[SLD]), 9 spring (8 at SLD), 4 summers (3 at SLD), 10 falls (8 at SLD), 1 Critical Period high-flow event (0 at SLD), and 5 Critical Period low-flow events (5 at SLD). During these sampling efforts, flows have ranged from 92 to 319 cfs.

Temporal changes in coverage of aquatic vegetation are better understood by comparing the percent change at each reach (Table 7). When percent change is averaged across years, total vegetation area decreased by almost 7% between spring and fall (within the same year) at City Park and over 12% at Spring Lake Dam. An opposite but similar magnitude trend occurred from fall to spring (fall of the previous year to spring of the next year), with an average increase of over 8% at City Park and over 12% at Spring Lake Dam. Aquatic vegetation at I-35 displayed an opposite trend with an over 6% increase from spring to fall, and a more than 5% decrease from fall to spring. It is reasonable to assume a decrease in aquatic vegetation within years because flows tend to be lower during the summer months in the San Marcos River. Another facilitator of decreasing vegetation surface area is recreation, which is higher during the warmer months. The percent changes reflected during all years appear to support these trends. The City Park and Spring Lake Dam reaches support the largest numbers of recreationists during this time of year because they are located within the university campus and adjacent to a tubing rental business. The I-35 Reach is downstream of many of the parks on the river, and downstream of a barrier to tubing (Rio Vista Rapids), which is why it may be showing an overall average increase in aquatic vegetation area from spring to fall. Decreased recreation pressure from fall to spring every year is likely why overall vegetation area increased on average at the City Park and Spring Lake Dam reaches. However, a drop in recreation pressure did not result in increased vegetation coverage at the I-35 reach. Prior to the construction of Rio Vista Rapids in 2006 aquatic vegetation coverage increased at I-35 from fall to spring (7%). Since its construction, the channel morphology (increased sedimentation, shifting gravel bars/banks) has changed significantly in the upper portion of the reach. This may account for the overall decline in vegetation coverage during the lower traffic winter months for this reach.

When the Critical Period low-flow years (2006 and 2009) are looked at individually, the percent changes in aquatic vegetation are amplified (Table 7). In 2006, both the City Park and Spring Lake Dam reaches exhibited a larger decrease than the long term average for the spring to fall period. This was likely due to the decreased flows leaving some plants stranded coupled with increased recreation pressure. As in all years combined, vegetation at the I-35 reach increased over the year probably due to less recreation pressure (compared to the other reaches) and more areas of deep water that can withstand longer periods of low-flow. However, the prolonged drought in Central Texas that culminated in depressed flows in 2009 resulted in all reaches decreasing in aquatic vegetation from spring to fall. The City Park and Spring Lake Dam reaches decreased by more than 35%, which is outside the range of percent change for all years combined at both sites. Aquatic vegetation also decreased at the I-35 reach by nearly 3%.

These temporal trends observed across nine years of data provide us a better understanding of how aquatic vegetation reacts to seasonal and flow-related changes. Summers typically result in an overall decrease due to the combination of lower flows and increased recreation. This is amplified during longer periods of low flow such as 2009. Fragmenting of these stands can have deleterious effects on the endangered species found within the San Marcos River.

Table 7. The average percent change in aquatic vegetation between spring and fall within the three study reaches. The range of values is shown in parentheses. A negative indicates a decrease in percent change.

Time Period	Fall to Spring (range)	Spring to Fall (range)
City Park Reach		
All Years (2000-2009)	8.32 (-3.83 to 19.0)	-6.69 (-16.2 to 1.78)
2006	14.0	-9.74
2009	7.91	-37.5
I-35 Reach		
All Years (2000-2009)	-5.21 (-43.2 to 17.5)	6.06 (-17.2 to 34.9)
2006	17.5	30.7
2009	-3.2	-2.74
Spring Lake Dam Reach		
All Years (2000-2009)	12.3 (-16.4 to 33.8)	-12.2 (-25.5 to 12.9)
2006	1.33	-14.3
2009	4.53	-35.1

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. The extended drought provided a unique opportunity to monitor all of the Texas wild-rice plants in the river 3 times in 2009. Critical Period 1 allowed mapping these endangered plants during winter – a period that is not normally monitored. From summer 2008 to January 2009, Texas wild-rice coverage increased in the upper reaches of the San Marcos River (Maps 1 – 4 where > 95% of the Texas wild-rice is located, Table 8). Decreased recreation pressure and fewer vegetation mats during this time period allowed Texas wild-rice to flourish within these reaches. By early summer (Critical Period 3) however, total coverage of Texas wild-rice within the San Marcos River decreased by nearly 6% (4,277.2 m^2 to 4,034.4 m^2). When this mapping effort began (June 23, 2009), the discharge had been below 100 cfs for 47 consecutive days, and the lowest flow (83 cfs) recorded for the San Marcos River since the inception of this study occurred only a week before (June 16 and 17, 2009). Considering these factors, a drop of only 6% displays the resilience of this endangered plant. However, as flows continued to remain below 100 cfs and recreation pressure increased over summer, Texas wild-rice coverage declined more rapidly.

Table 8. Total areal coverage of Texas wild-rice (*Zizania texana*) within each study reach in 2008 - 2009.

Sampling Period	Map 1	Map 2	Map 3	Map 4	Map 5	Map 6	Map 7	Total Area (m^2)
Summer 2008	2,478.90	566.3	376.7	403.7	16.2	7.4	48.5	**3,897.7**
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**

By October, Texas wild-rice coverage had decreased by almost 17% in the entire river, with the majority of those losses occurring in the upper reaches of the study section (Maps 1 – 4). Note: although Texas wild-rice is not normally mapped in fall, it was decided that an additional effort was needed because springflow had been below 100 cfs for 157 consecutive days in 2009, but Texas wild-rice had not been mapped since June. Most of the decrease occurred here because of increased recreation pressure and stranding of individual Texas wild-rice stands due to minimal water depths. The large Texas wild-rice plant within Sewell Park continued to fragment during late summer (Figure 10). The increased rate of sedimentation coming out of Sessoms Creek has contributed to the expansion of BobDog Island just upstream of University Drive. 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. As a result, some Texas wild-rice plants became stranded in water barely 5 cm deep. Some of these plants were relocated to the deeper sections of this reach by the USFWS, but those that were not, died.

Another considerable loss of Texas wild-rice occurred within the City Park Reach (Map 2). Although decreased flows affected Texas wild-rice plants in the entire San Marcos River, plants in areas with high recreation pressure are affected more due to mechanical disturbances. As discussed above (Figure 6, City Park Reach), high recreation pressure led to a 14% decrease in overall Texas wild-rice coverage within the Map 2 Reach from Critical Period 3 (June) to Fall (October). The fragmenting of these plants occurred in areas that have adequate flow and depths, but are vulnerable to being pulled out by recreation activities. Within the Map 3 reach, Texas wild-rice coverage decreased by over 16% from June to October with nearly all of the losses occurring within a large plant that is adjacent to a heavily used park. Extended periods of low-flow appeared to be the driving factor behind losses in Texas wild-rice coverage within the Map 4 reach. This reach receives far less recreational pressure, however, from June to October Texas wild-rice still decreased by over 17%.

The continued drought in Central Texas in 2009 negatively affected Texas wild-rice within the San Marcos River by the end of the year. Although total coverage of the plant was at the highest ever recorded within this study in January (4,277.2 m^2), by October total coverage (3,350.9 m^2) was the lowest it had been since 2006.

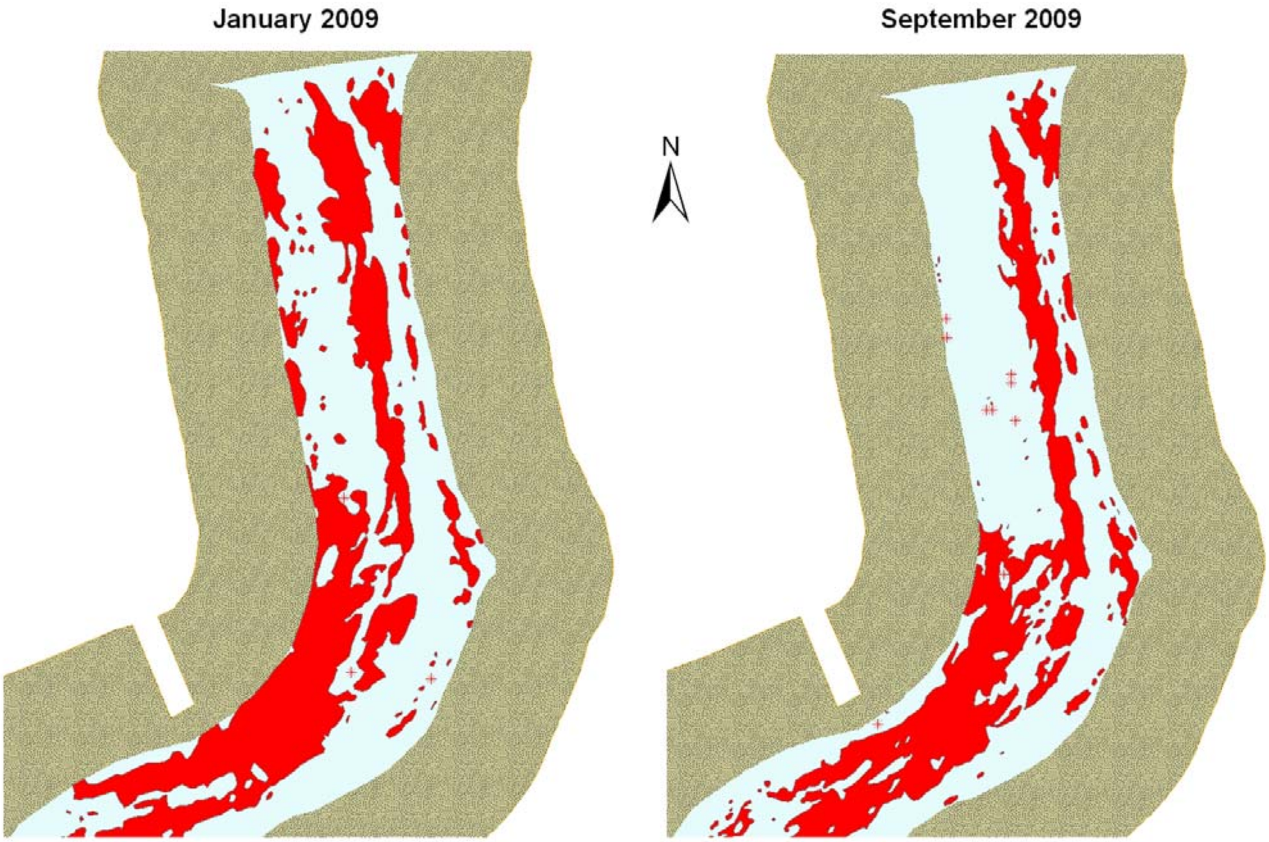


Figure 10. Changes in area of Texas wild-rice (*Zizania texana* [in red]) within Sewell Park (Map 1 Reach) from Critical Period 1 (January) to September 2009.

Texas Wild-Rice Physical Observations

Texas wild-rice observations were conducted 12 times during 2009. These observations were made during comprehensive sampling events (spring and fall) and also approximately every three weeks while average daily discharge in the San Marcos River was less than the 120 cfs trigger for Texas wild-rice observations (January - September 2009). The dates of these observations are presented chronologically with the number of the observation period and the corresponding average daily discharge value in Table 9. Observations were made on vulnerable stands within the Sewell Park reach (Figure 11), the I-35 reach (Figure 12), and an area downstream at Thompson's Island (Figure 13). The total coverage of Texas wild-rice observed during 2009 in each "vulnerable" stand in the San Marcos River is presented in Table 10, 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.

The most notable observation of the extent of Texas wild-rice in vulnerable areas was the decrease in areal coverage of every stand that was observed from January to October 2009 (Table 10). Several new vulnerable Texas wild-rice stands were identified in 2009, and monitoring of these stands began with the spring 2009 sampling event (TWR-6 observation period). One of these stands, "Sewell Park-1" was broken out as a fragment of the previously grouped stands "Sewell Park 1-3". It was 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," were 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.

Table 9. The dates of Texas wild-rice observations conducted in 2009 and the corresponding average daily discharge in the San Marcos River.

Texas wild-rice observation period	Event Type	Date	Average Daily Discharge (cfs)
TWR 1	Critical Period 1	7 January 2009	98
TWR 2	<120 cfs Observation	29 January 2009	97
TWR 3	<120 cfs Observation	20 February 2009	100
TWR 4	<120 cfs Observation	23 March 2009	99
TWR 5	Critical Period 2	13 April 2009	96
TWR 6	Spring Comprehensive Sampling	18 May 2009	92
TWR 7	Critical Period 3	22 June 2009	94
TWR 8	<120 cfs Observation	17 July 2009	88
TWR 9	<120 cfs Observation	5 August 2009	87
TWR 10	<120 cfs Observation	19 August 2009	87
TWR 11	<120 cfs Observation	4 September 2009	87
TWR 12	Fall Comprehensive Sampling	19 October 2009	154

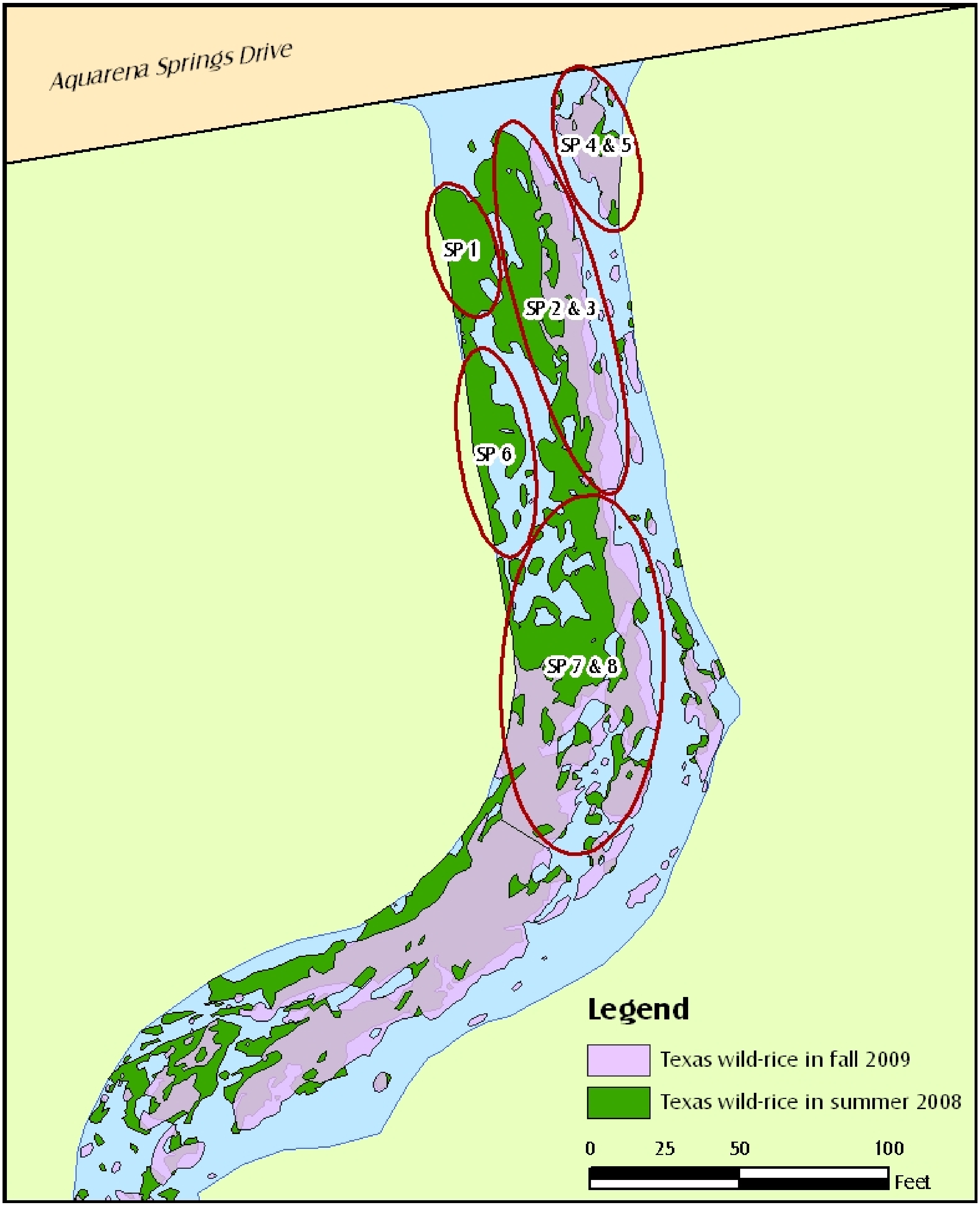


Figure 11. Map of vulnerable Texas wild-rice stands in the Sewell Park reach.

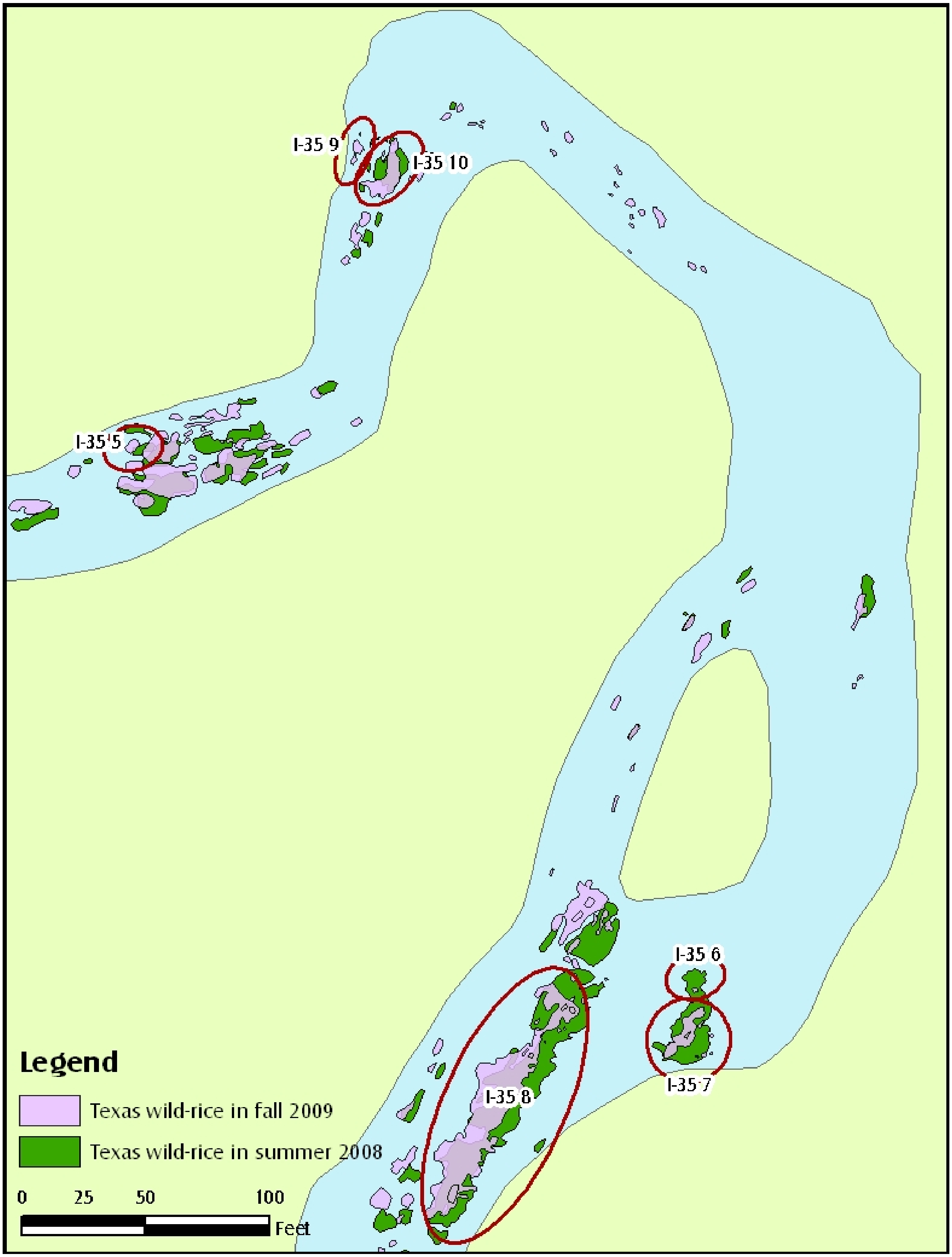


Figure 12. Map of vulnerable Texas wild-rice stands in the I-35 reach.

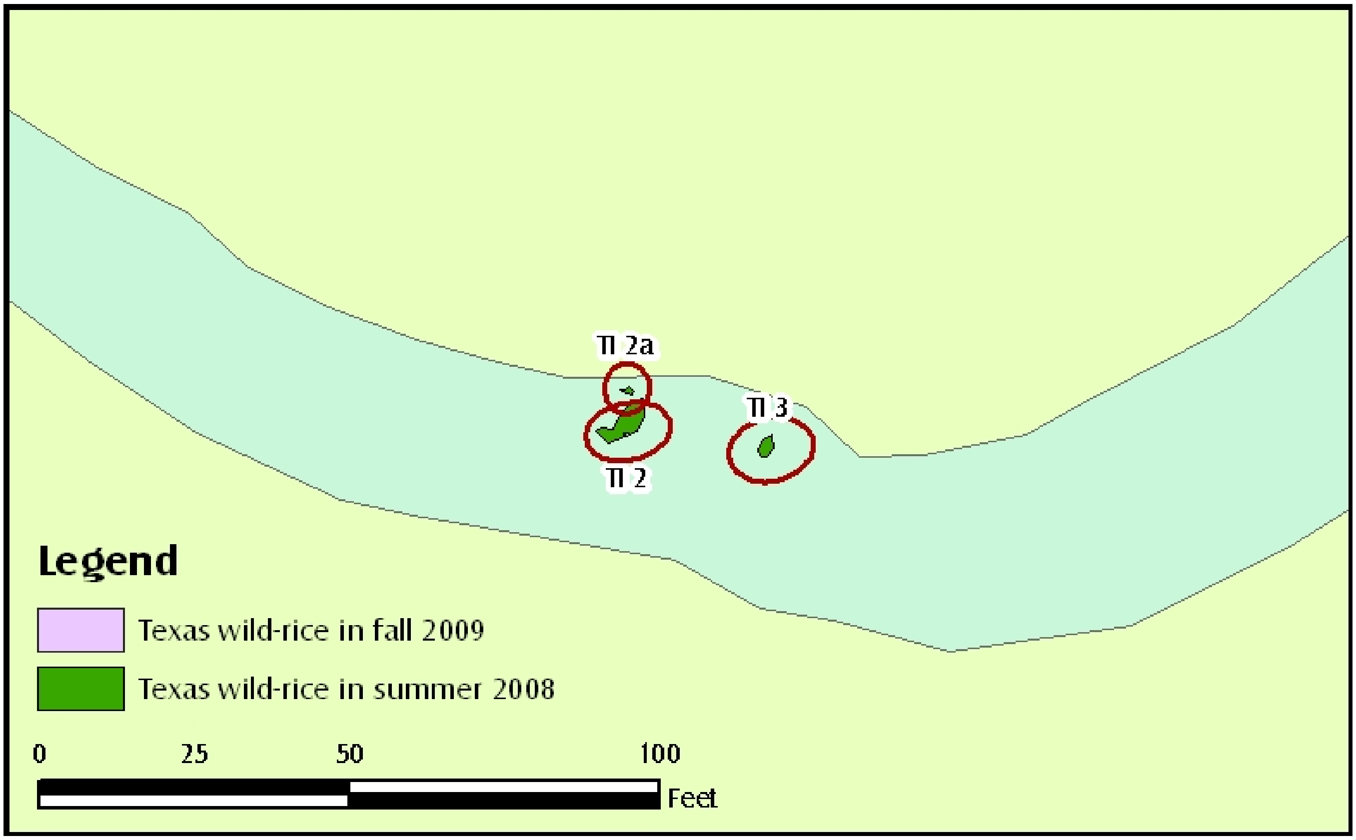


Figure 13. Map of vulnerable Texas wild-rice stands near Thompson's Island.

Table 10. Areal coverage (m^2) of Texas wild-rice vulnerable stands during each sampling period in 2009.

REACH-STAND NO.[a]	TWR 1	TWR 3	TWR 5	TWR 6	TWR 7	TWR 8	TWR 9	TWR 10	TWR 11	TWR 12
Sewell Park - 1				14.8	11.8	4.8	0.4	0.4	0	0
Sewell Park - 2	193.1	166.6	166.7	156.0	153.4	152.2	152.2	161.4	161.3	113.6
Sewell Park – 3										
Sewell Park - 4 & 5	46.6	47.3	47.5	47.8	47.6	48.1	44.2	43.7	43.1	41.6
Sewell Park - 6	32.7	16.4	16.0	17.7	12.9	4.6	2.0	2.2	0.8	0.4
Sewell Park - 7 & 8	263.6	326.0	327.9	310.8	324.6	266.6	149.9	225.8	226.1	219.8
Total Area	**535.9**	**556.2**	**558.1**	**547.1**	**550.4**	**476.4**	**348.7**	**433.5**	**431.4**	**375.4**
I-35 - 5	2.9	1.3	nm	0.9	1.9	0.8	0.7	0.6	0.7	0.5
I-35 - 6	7.5	4.7	5.7	5.6	2.6	2.9	2.0	0.8	0.8	0.3
I-35 - 7	32.1	26.0	30.3	30.1	24.4	23.6	21.1	17.4	17.4	11.0
I-35 - 8	236.0	192.9	191.8	190.7	165.4	165.3	160.9	153.6	156.5	134.6
I-35 – 9[c]	nm	nm	nm	2.7	2.9	2.4	2.0	2.2	2.8	3.0
I-35 – 10[c]	nm	nm	nm	17.9	22.9	15.0	14.9	15.4	14.8	12.2
Total Area	**278.5**	**224.9**	**nm**	**247.9**	**220.1**	**210.0**	**201.6**	**190.0**	**193.0**	**161.6**
Thompson's Island - 2	1.4	1.7	1.3	0.6	0.2	0.1	0.1	0.04	0.1	*Gone*
Thompson's Island - 3	0.02	0.03	0.07	0.01	*Gone*	-	-	-	-	-
Total Area	**1.42**	**1.73**	**1.37**	**0.61**	**0.2**	**0.1**	**0.1**	**0.04**	**0.1**	***Gone***

[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.

[c] New stands measured beginning in spring 2009.

"nm" indicates a stand was not measured during a particular sampling event.

Sewell Park Reach

Of the three reaches sampled, Sewell Park has the highest mapped area of "vulnerable" Texas wild-rice stands (Table 10). The vulnerable stands in this reach began 2009 with the lowest areal coverage since 2002, and decreased by another 30% in area between the January (539.5 m^2) and the fall (375.4 m^2) 2009 sampling. Low water levels, as a result of lower flows in the San Marcos River, have allowed the growth of grasses and watercress in shallow areas at the upstream end of the reach. This has, in turn, led to a decrease in flow within the center and river-right side of the channel and increased deposition of silt in these areas. A photo series illustrating the changing water levels and vegetation in this reach is presented in Figure 11. Throughout 2009, these Texas wild-rice stands have become more fragmented and subject to being covered by vegetation mats. The newly-monitored (as of spring 2009) plant SP-1 was fragmented from the previously grouped stand SP-1,2,3 and was ultimately lost by fall 2009.

During the first seven low-flow observation events (January to June), fewer than 10% of the vulnerable Texas wild-rice stands in this reach were found in water less than 0.5 feet in depth. In July, this amount increased to 31%, and then increased to over 50% in August and September (TWR-9 to TWR-11). The amount of emergent Texas wild-rice plants also increased from less than 36% in January and February, to 41-49% in March-June, and to 53-62% in July-September. Due to concern over the survival of these plants in extremely shallow water during the summer, the USFWS relocated Texas wild-rice plants that were in areas with less than 0.2-foot in depth to areas greater than 0.5-foot depth within the same reach.

Average root exposure of vulnerable stands remained above a 2.0 throughout 2009, reaching a maximum of 4.5 during the fall sampling event (TWR-12). The main areas of concern for root exposure were located at stand SP-4,5 on river-left in a sand/gravel area that has been experiencing scouring for several years. Following widespread siltation that occurred in this reach in 2009, root exposure was also a concern at all stands following increased flows in September and October that removed the silt layer around many plants. Herbivory was also a concern with so many of the plants emergent and more accessible to potential grazers such as waterfowl and *Nutria*. Herbivory measurements remained above 3.0 beginning in spring (TWR-6) throughout the summer, reaching a maximum of 5.2 in August. Following increased water levels in fall, herbivory estimates declined to 2.3 (TWR-12). Vegetation mat coverage was fairly consistent throughout the year, ranging from 15-38% through September, and decreased in fall to less than 2% due to recent precipitation events. Fewer flowering and seeding plants were observed in 2009 than in 2008, although these measurements may be masked by the effects of herbivory on the emergent plants.

Recreation continued to have a significant impact by fragmenting Texas wild-rice in this area. A small dam built with large river rocks was observed in the middle of plant SP-7,8 during the summer.

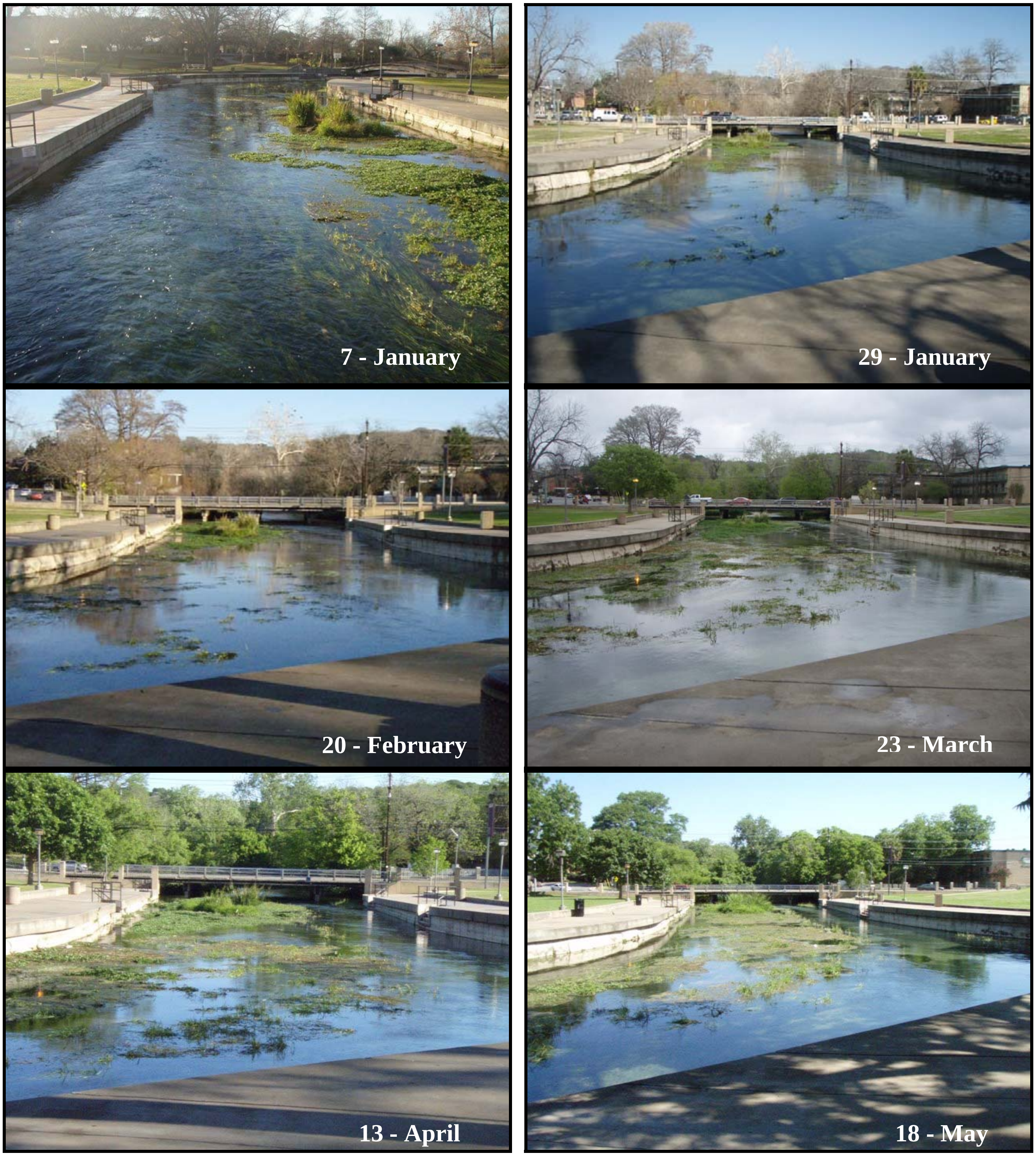


Figure 14. Water level conditions near vulnerable Texas wild-rice stands in the Sewell Park Reach in 2009.

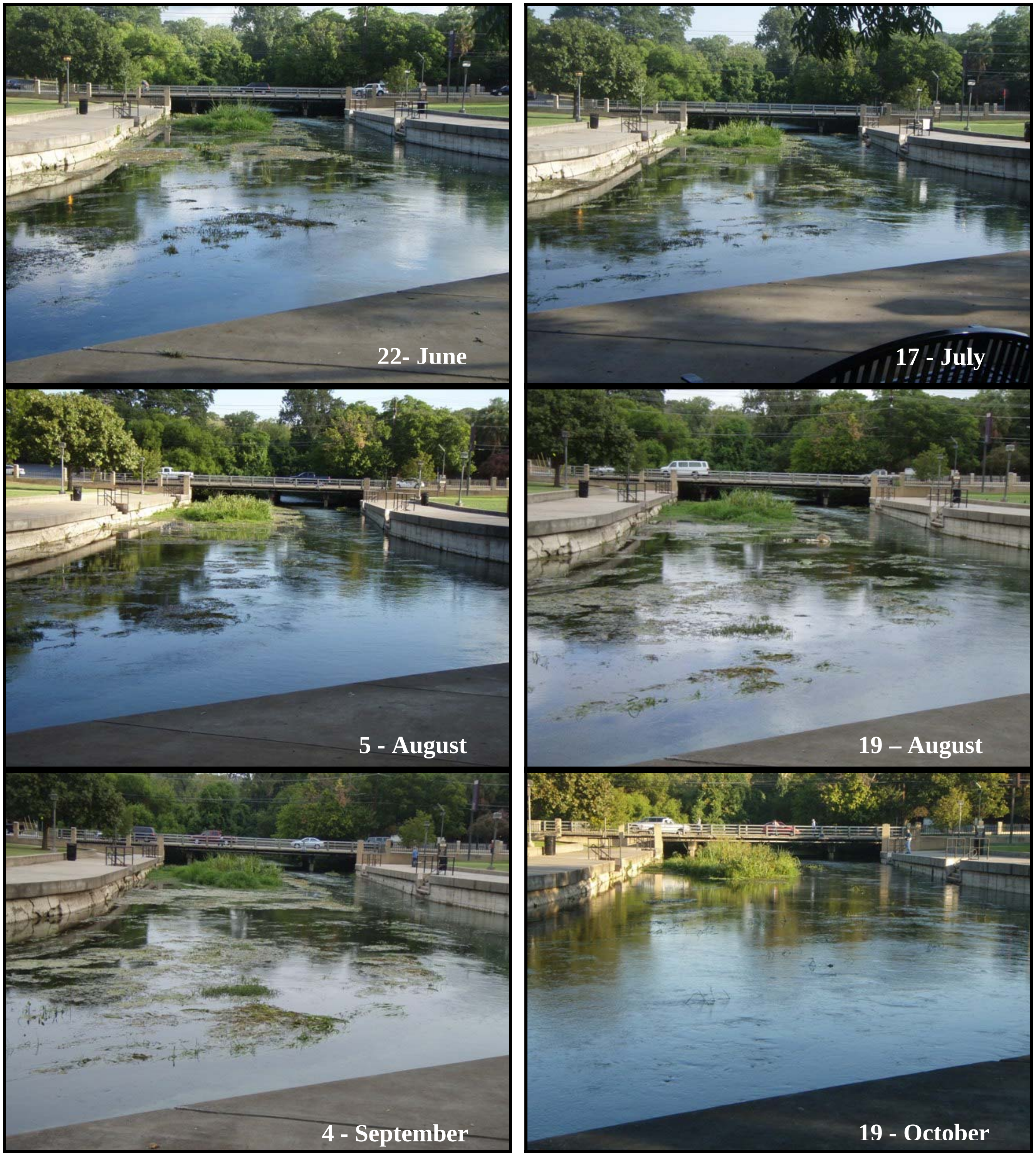


Figure 14 continued. Water level conditions near vulnerable Texas wild-rice stands in the Sewell Park Reach in 2009.

I-35 Reach

Areal coverage of "vulnerable" Texas wild-rice stands in the I-35 reach increased from fall 2008 (197.7 m^2) to January 2009 (278.5 m^2; TWR-1), resulting in the highest amount mapped in this reach since 2002. Between 2008 and January 2009, the plant I-35-9 (Table 10) connected to a larger plant upstream and was included in the 2009 area calculations (but not fall 2008). This new area of plant was 29.5 m^2 in area and can explain part of this increase, while the rest of the difference may be due to dislodged Texas wild-rice plants from upstream areas becoming rooted in this reach. Subsequently, 42% of this total area was lost from January to the fall 2009 sampling event (TWR-12). Approximately, 30-49% of the stands were in areas less than 0.5-foot in depth through spring 2009 (TWR-6), increasing to a maximum of 70% of the stands in August (TWR-9) and decreasing to zero in fall 2009 after several recent precipitation events increased discharge in the river. The amount of emergent plants in this reach was above 20% throughout the year, reaching a maximum of 61% in September (TWR-11). As in the Sewell Park reach, plants in very shallow water (<0.2-foot depth) in the I-35 reach were transplanted during the summer by USFWS to deeper areas within the reach. Most of plant I-35-6 was relocated to within the I-35-8 stand area, along with several plants from I-35-7 and shallow plants of I-35-8. This transplanting effort should be considered while comparing the measured area of these stands, especially since most of plant I-35-6 was relocated, and not lost due to environmental conditions. The amount of flowering and seeding plants was higher in summer (12-35%) than in winter (5-24%), spring (1.5-10%), or fall (13%), reaching a peak in September (35%).

Plants in this reach were less affected by recreation because this reach is farther away from recreational areas (e.g., City Park, Sewell Park). However, kayakers and occasional fishermen do utilize this reach, and tend to float over Texas wild-rice plants in the center of the channel (I-35-8 stand). Herbivory in this reach fluctuated throughout 2009 (1.8-3.5) and was highest in late January (3.5; TWR-2) (Appendix B). Most of the herbivory was concentrated at plants 6 and 7, as well as newly-monitored plant 9, because these stands are found in shallower waters more easily accessed by grazers. Root exposure also fluctuated throughout the year (1.7-3.3), and was highest in March (3.3; Appendix B).

Under the low-flow conditions that were persistent throughout the spring and summer, water levels and flow measurements at plants I-35-6, 7, 8 and 9 were very low compared to previous years, and silt deposition was observed in front of and within plants I-35-6, 7 and 8. While we know that several plants within the I-35-6 stand were transplanted, the stands I-35-7 and 8 also became increasingly fragmented throughout the year. Only 34% of plant I-35-7 remained in fall 2009 from the beginning of the year, and only 57% of plant I-35-8 remained.

Thompson's Island Reach (Natural)

The areal coverage of vulnerable Texas wild-rice stands within Thompson's Island reach has been slowly decreasing since fall 2007. A long-term cross-section of the river just upstream of plant "Thompson's Island - 2" has shown erosion of the center of the channel and deposition of sand and gravel at the river-left side of the channel. This deposition along with decreasing water levels caused the two vulnerable stands in this reach to become emergent and fragment between fall 2008 and spring 2009. Herbivory measurements were also high during this period (2.5 to 5.5; Appendix B). One of the two stands, "Thompson's Island - 3," had only two small stems of Texas wild-rice remaining in spring 2008 (TWR-6), and was completely gone following that sampling event. The other vulnerable stand, "Thompson's Island - 2," also continued to decrease in area and became increasingly emergent until March (TWR-4), when portions of the emergent plants began to disappear. Root exposure estimates of the plant were highest in spring (4.5; Appendix B) and by June, only a portion of the submerged area of the plant remained. For the remainder of the summer, the stand was not emergent, did not flower or seed, or have any vegetation mats covering it. Root exposure was moderate (2.0 to 3.0) until September (TWR-11) when it increased to a level of 5. This plant was gone by fall 2009 (TWR-12). Currently, there are no longer any mapped Texas wild-rice plants in this reach, but the river channel cross section will continue to be monitored in the event that new plants become established in the future.

Fountain Darter Sampling Results

Drop Net Results

In addition to the typical spring (May 11-12) and fall sampling (Oct. 15-16), drop netting was conducted during three low-flow Critical Period trips in 2009 (Jan. 12-13, Apr. 6-7, and June 25-26). The number of drop net sites and vegetation types sampled per reach is presented in Table 11. 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 11. Vegetation types sampled within each reach in the San Marcos Springs/River ecosystem in 2009.

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 Sites	**Total = 8 Sites**

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 (0.0/m^2) versus vegetated habitats (5.4-7.8/m^2) (Figure 15). However, fountain darter density varies considerably between vegetation types, demonstrating that some vegetation types provide more suitable habitat than others. For example, fountain darter densities calculated from drop netting data are rather high in the native vegetation type *Cabomba* (7.8/m^2), yet considerably lower in non-native *Hygrophila* (5.4/m^2) (Figure 15). Fountain darter densities in non-native *Hydrilla* (6.0/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. In the Comal, certain vegetation types such as filamentous algae and bryophytes exhibit extremely high densities (23-24 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 data confirms a high abundance of darters in Spring Lake.

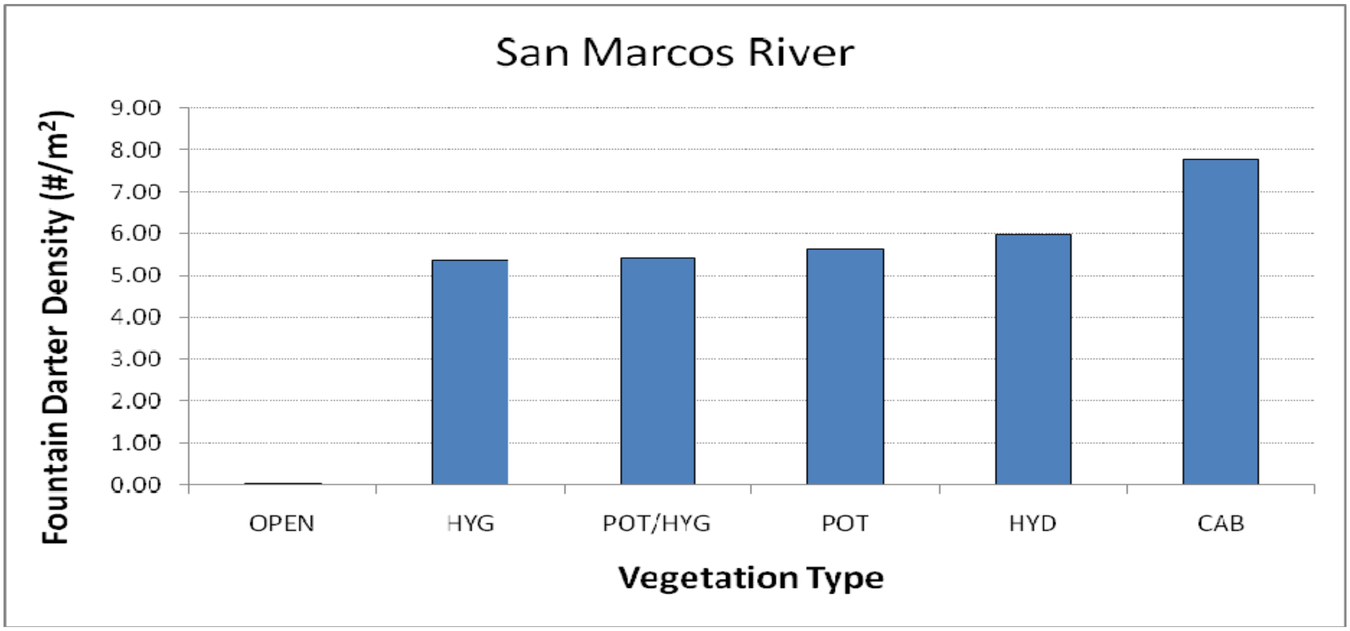
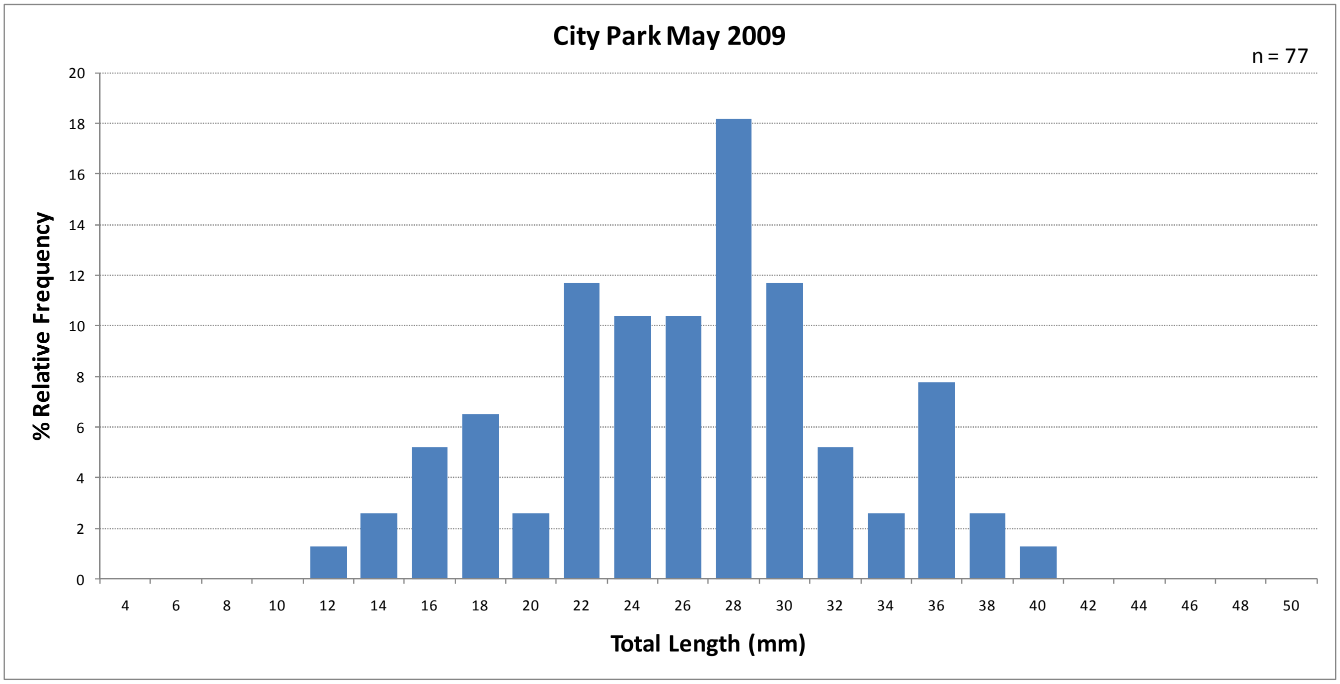


Figure 15. Average density of fountain darters collected by vegetation type in the San Marcos Springs/River ecosystem (2000-2009). HYG – *Hygrophila*, POT - *Potamogeton* POT/HYG – *Potamogeton / Hygrophila*, HYD – *Hydrilla*, CAB – *Cabomba*.

The size-class distribution for fountain darters collected by drop net from the San Marcos Springs/River ecosystem during all sampling events combined in 2009 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 16 and 17) the size-class distributions reveal trends similar to those observed in the Comal Springs/River ecosystem (BIO-WEST 2010). 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, at the City Park Reach, this trend is not as evident. Some reproduction seems to be occurring in the late summer/fall at this location. Similarly, length frequency data from areas of high habitat quality in Landa Lake and Spring Lake suggest year-round reproduction (see dip net results).



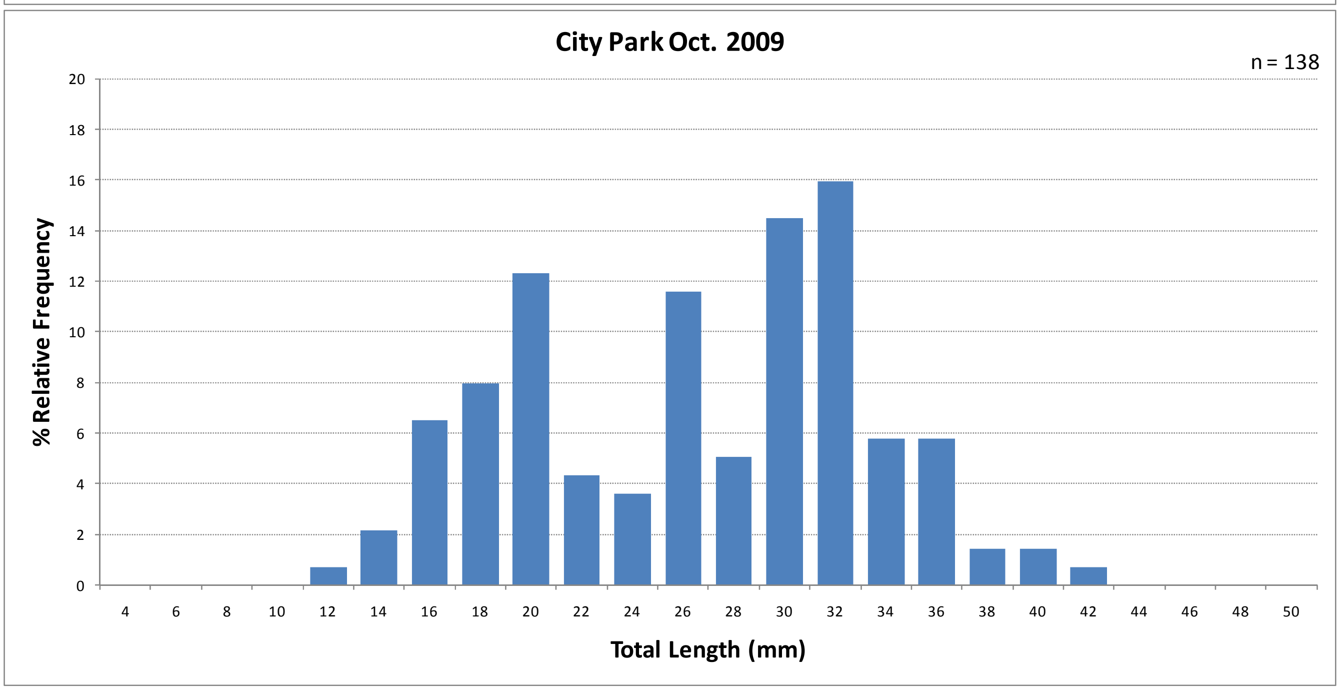


Figure 16. Length frequency distributions of fountain darters collected from the City Park Reach in spring and fall 2009.

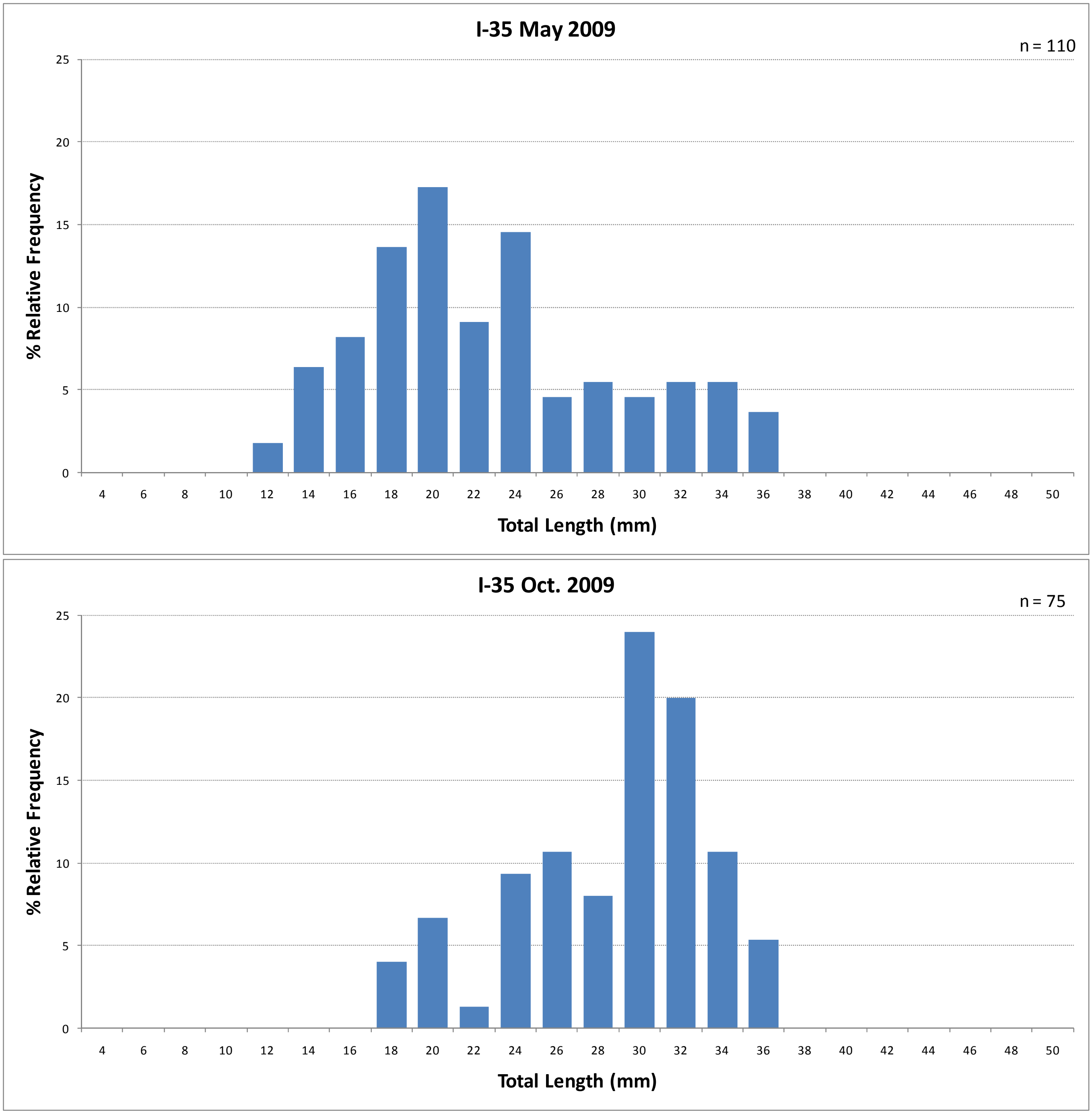


Figure 17. Length frequency distributions of fountain darters collected from the I-35 Reach in spring and fall 2009.

Estimates of fountain darter population abundance are based on changes in vegetation composition and abundance and average density of fountain darters found in each, 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 little variation in the average density of fountain darters found among vegetation types in the San Marcos River. Therefore, changes in coverage of various vegetation types 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 18). As in the Comal River, previous high-flows have resulted in scouring of vegetation, and thus, lower population estimates. Changes to the vegetation community as a result of low flows and recreational impacts in 2009 also influenced population estimates, as described below.

Long-term population estimates exhibit a slightly declining trend in the City Park Reach. This is a result of changes in vegetation coverage within this reach, and is most evident in recent samples from spring to fall 2009. During the low flows observed in 2009, the City Park Reach was much shallower than in previous years. High recreational traffic (swimmers and tubers) in the area uprooted much of the submerged vegetation in the middle portion of this reach (mainly *Hydrilla*), resulting in a sharp decline in the fountain darter population estimate for this reach. In fact, fall 2009 exhibited the lowest population estimate of the study period.

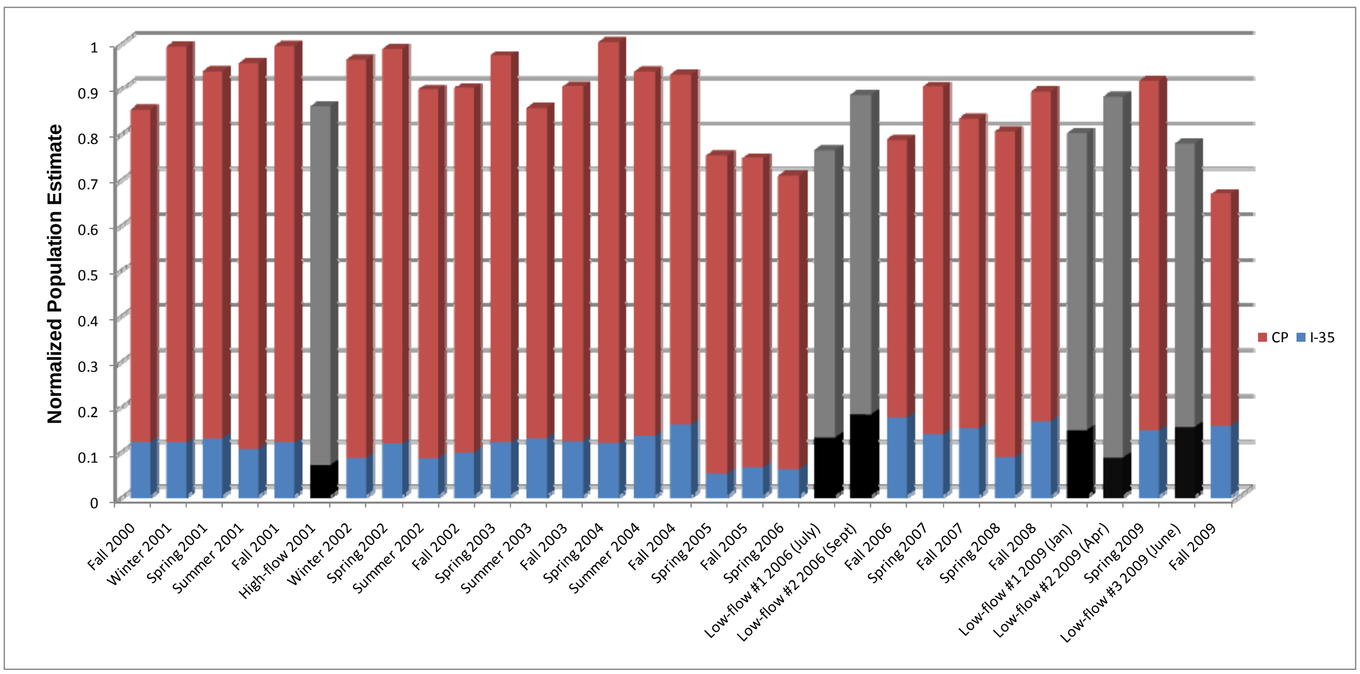


Figure 18. Population estimates of fountain darters in the San Marcos River; values are normalized to a proportion of the maximum observed in any single sample. Black and gray columns represent critical period sampling events.

Population estimates provided above are based on the average density for each vegetation type calculated from the entire drop net dataset (2000-2009). Since the density in each vegetation type is held constant across events, the fluctuations in fountain darter populations observed are directly related to changes in coverage of aquatic vegetation within the sample reaches. Therefore, these population estimates are not directly tied to the abundance of darters in each sample period, but instead provide an estimate of habitat quality based on long-term average density data within each vegetation type.

To further explore fountain darter population dynamics, the density of fountain darters in each vegetation type was calculated per sample event. As evident from Figure 19, the density within vegetation types in the I-35 Reach varies considerably between sample events. In fact, fountain darter density within *Cabomba* varies from a low of less than 1 darter/m^2 in summer 2004 to over 24/m^2 in spring 2008. Even greater variability is present in data from the City Park Reach, where the density in *Hydrilla* for each event varies from 0.6 to 93.7/m^2. When density is averaged across events for each vegetation type, *Hydrilla* exhibits the highest average density of all vegetation types in City Park (8.9/m^2 vs. 4.6/m^2 in *Hygrophila* and 5.2/m^2 in *Potamogeton*/*Hygrophila*) and the lowest average density of all vegetation types in I-35 (2.2/m^2 vs. 6.4/m^2 in *Hygrophila* and 7.7/m^2 in *Cabomba*). This is probably a result of depth and velocity profiles in each reach. At City Park, the majority of the *Hydrilla* grows in deeper slow-moving areas, whereas most *Hydrilla* in the I-35 Reach is found in shallow swift water that typically holds fewer fountain darters, and greater numbers of Guadalupe darters (*Percina apristis*).

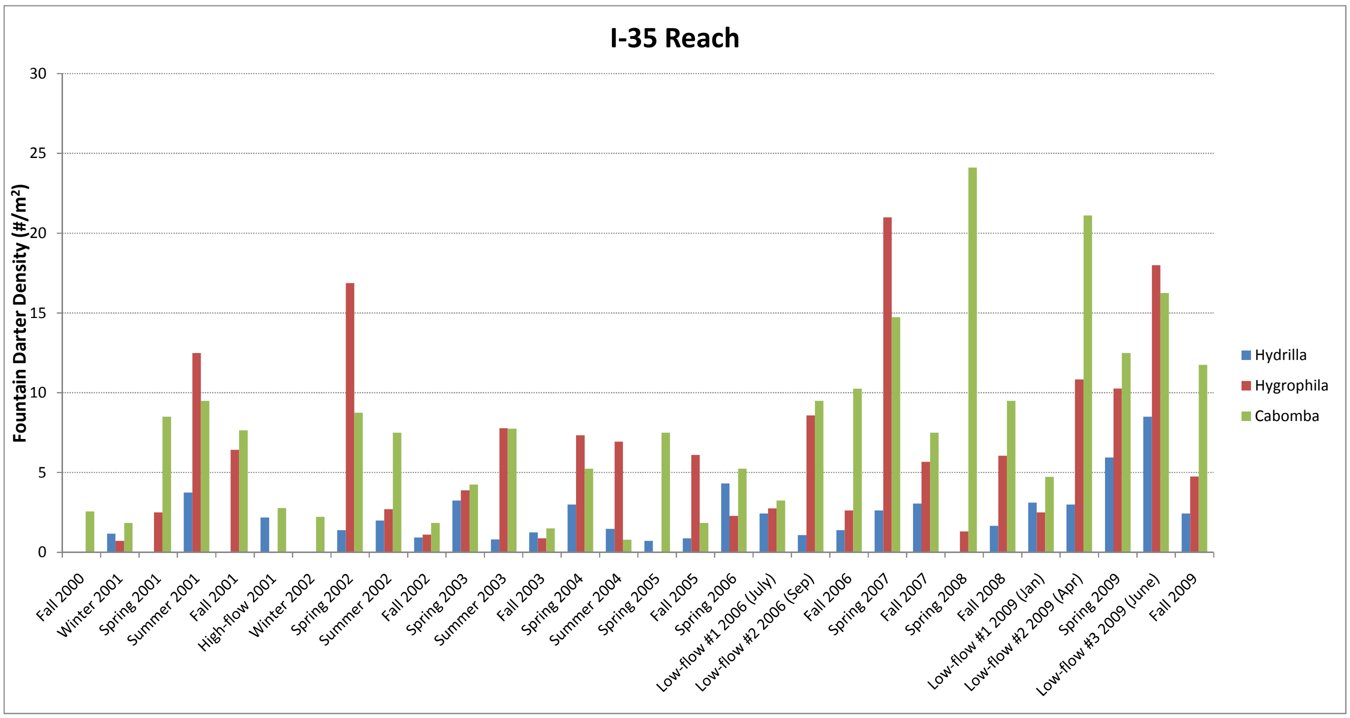


Figure 19. Density of fountain darters by vegetation type during each drop net sampling event conducted within the I-35 Reach from Fall 2000 through Fall 2009.

To examine the relationship between low flows and fountain darter density each sample event was grouped into one of two categories – those conducted under low flow conditions (discharge ≤ 110 cfs), and those conducted under all other flow conditions (discharge > 110 cfs). Based on these criteria eight events were considered low flow (July 2006 – fall 2006, and fall 2008 – June 2009), and were compared to the remaining 22 events using two-sample t-tests.

At City Park, no significant difference in average density was found between the two groups (α=0.05, df=28, p=0.435). Similarly, no difference was found in each of the vegetation types at City Park. In contrast, the average density was found to be higher at I-35 under low flow conditions (α = 0.05, df=28, p=0.035). This was a result of higher densities in *Hydrilla* under low flow conditions (α=0.05, df=26, p=0.032). Densities in *Cabomba* (α =0.05, df=28, p=0.07) and *Hygrophila* (α =0.05, df=25, p=0.432) were not significantly different between the two groups.

Higher densities of fountain darters in *Hydrilla* within the I-35 Reach under low-flow conditions may be due to the decrease in velocities within this area. As flows decline, velocities within this rather shallow section of the river decrease, perhaps allowing (or forcing, due to drying of edge habitats) movement of darters into *Hydrilla* patches which previously were too swift.

Additionally, it is important to note that average density increased under low-flow conditions in all comparisons (although it was only significant for I-35 *Hydrilla* and I-35 overall). Linear regression demonstrates a significant negative association between average event density and discharge in both reaches (Figure 20). Therefore, increases in density under low-flow conditions may simply be a result of a reduction in wetted area causing concentration of darters, and is likely also influenced by increased sampling efficiency under lower flows.

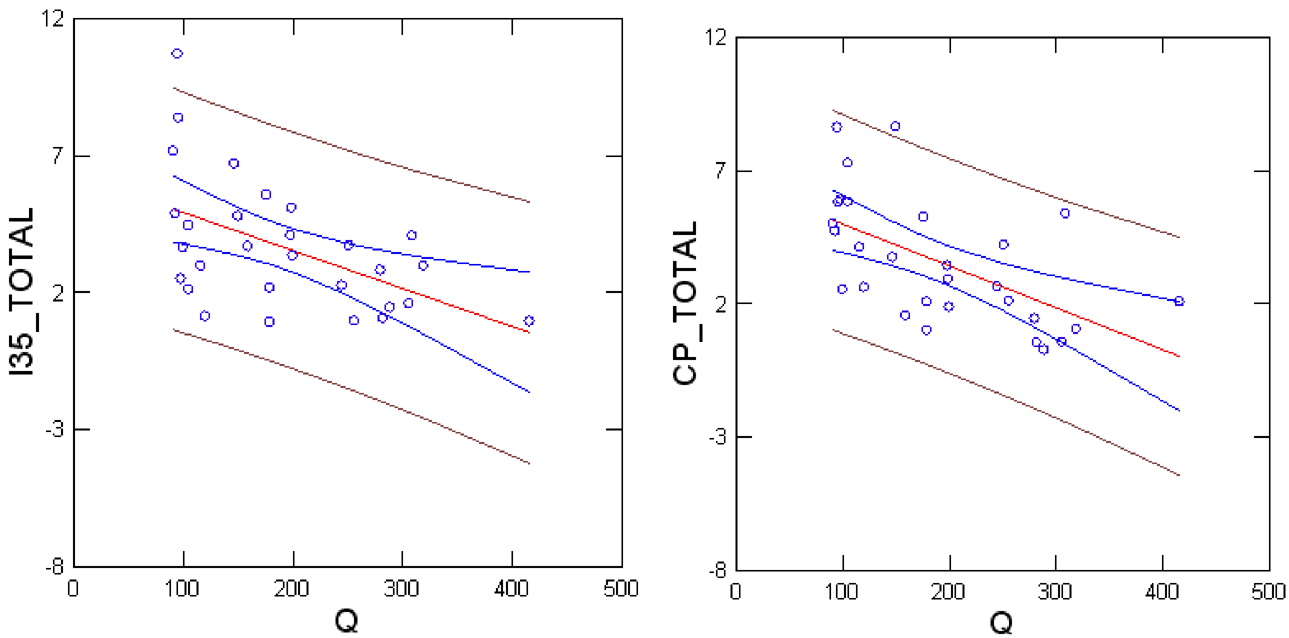


Figure 20. Least-squares linear regression of average fountain darter density versus discharge (Q) in two reaches of the San Marcos River (I-35 and City Park).

Another way to explore relationships between fountain darter populations and discharge is to examine raw abundance data. The number of darters captured during each event in 2009 ranged from 129 in January to slightly over 300 in June. 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 a hydrograph of mean daily discharge throughout the study period (Figure 21). Due to the extremely variable daily discharge data no discharge-abundance relationships are obvious from this comparison. However, the abundance of fountain darters in drop net samples seems to have increased over the study period.

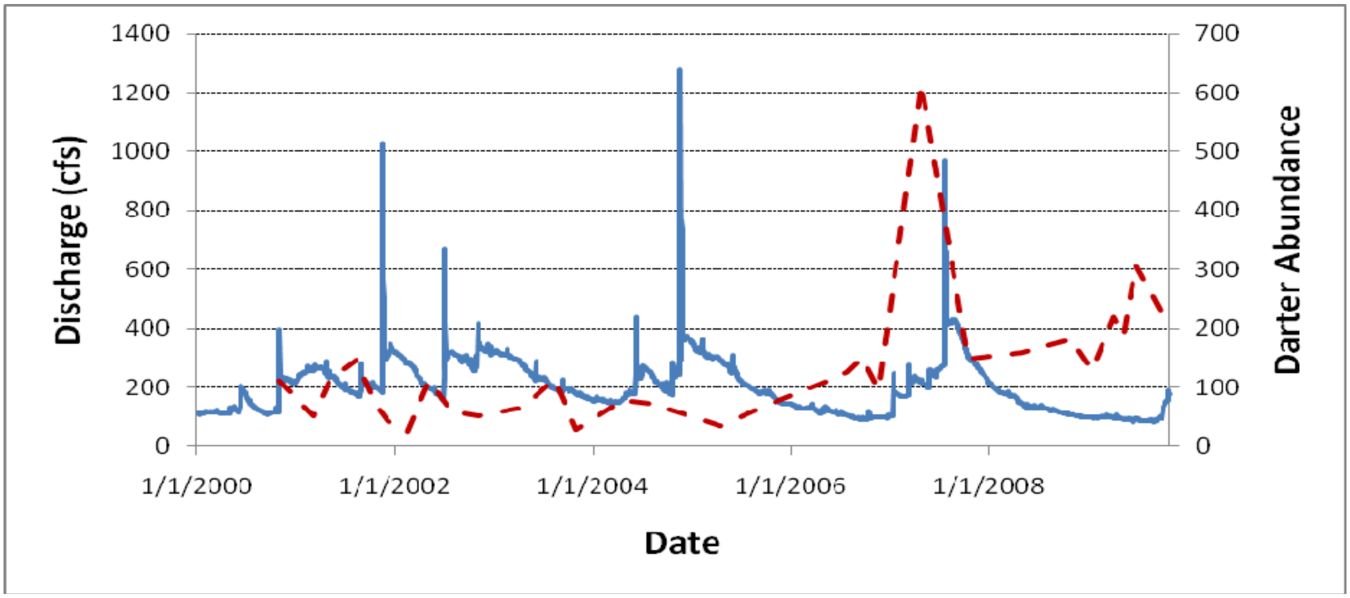


Figure 21. Mean daily discharge (blue line) and fountain darter abundance in drop net samples (red dotted line) over the study period.

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 22). Similar to density-discharge results in Figure 20, Figure 22 demonstrates that as discharge increases, the number of fountain darters captured in each drop net event decreases. Again, this trend is most likely a result of decreased drop net efficiency under higher flow conditions, and may also be influenced by concentration of darters into limited habitat areas under low flows.

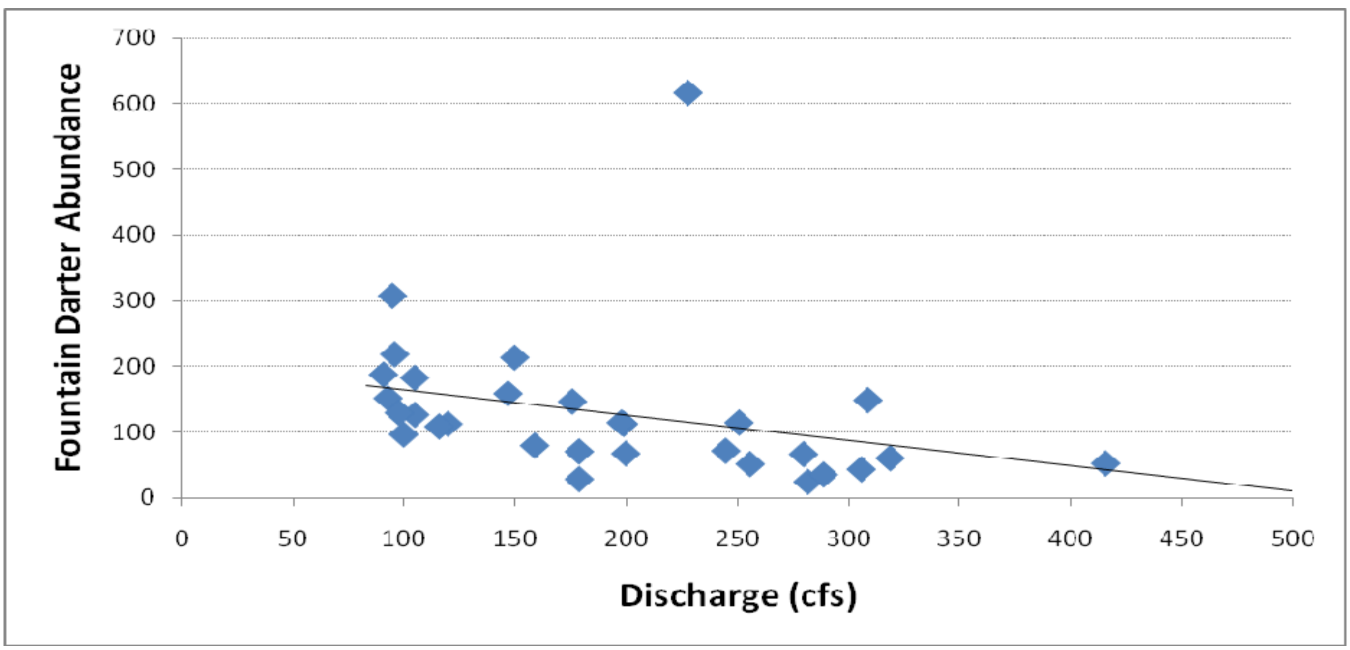


Figure 22. Scatterplot of fountain darter abundance in drop net samples versus daily mean discharge on each sample date.

In addition to fountain darters, there have been 34,131 fishes representing at least 27 other taxa collected by drop netting since 2000 (Table 12). Of these, 7 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 suckermouth catfish or armadillo del rio (*Hypostomus plecostomus.*). 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 critical fountain darter habitats and food supplies.

Table 12. Fish species and the number of each collected during drop-net sampling in the San Marcos Springs/River ecosystem from 2000-2009.

Family	Scientific Name	Common Name	Status	Number Collected	
				2009	2000-2009
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	Native	0	1
Cyprinidae	*Cyprinella venusta*	Blacktail shiner	Native	0	6
	Dionda nigrotaeniata	Guadalupe roundnose minnow	Native	1	42
	Notropis amabilis	Texas shiner	Native	48	65
	Notropis chalybaeus	Ironcolor shiner	Native	30	85
	Notropis sp.	Unknown shiner	Native	0	4
Catostomidae	*Moxostoma congestum*	Gray redhorse	Native	0	2
Characidae	*Astyanax mexicanus*	Mexican tetra	Introduced	5	26
Ictaluridae	*Ameiurus melas*	Black bullhead	Native	0	1
	Ameiurus natalis	Yellow bullhead	Native	17	93
	Noturus gyrinus	Tadpole madtom	Native	0	4
Loricariidae	*Hypostomus plecostomus*	Armadillo del rio	Introduced	5	32
Poeciliidae	*Gambusia* sp.	Mosquitofish	Native	9058	31882
	Poecilia latipinna	Sailfin molly	Introduced	9	132
Centrarchidae	*Ambloplites rupestris*	Rock bass	Introduced	55	429
	Lepomis auritus	Redbreast sunfish	Introduced	11	55
	Lepomis cyanellus	Green sunfish	Native	2	8
	Lepomis gulosus	Warmouth	Native	0	23
	Lepomis macrochirus	Bluegill	Native	0	72
	Lepomis megalotis	Longear sunfish	Native	0	18
	Lepomis microlophus	Redear sunfish	Native	0	1
	Lepomis miniatus	Redspotted sunfish	Native	161	842
	Lepomis sp.	Sunfish	Native/Introduced	11	153
	Micropterus salmoides	Largemouth bass	Native	1	46
Percidae	*Etheostoma fonticola*	Fountain darter	Native	1054	3883
	Percina apristis	Guadalupe darter	Native	0	10
	Percina carbonaria	Texas logperch	Native	0	1
Cichlidae	*Cichlasoma cyanoguttatum*	Rio Grande cichlid	Introduced	23	82
	Oreochromis aureus	Blue tilapia	Introduced	12	16
Total				10503	38014

Impacts of exotic species are not limited to introduced fishes. Among invertebrate exotic species, the giant ramshorn snail (*Marisa cornuarietis*) also elicits concern because of its recent impacts (early 1990s) on aquatic vegetation in the Comal River. Figure 23 shows the number of giant ramshorn snails captured during drop net sampling in each year since the study began in 2000. Data suggests that current giant ramshorn snail numbers are extremely low, but close monitoring should continue because of the impact that this exotic species can have on the vegetation community under heavier densities.

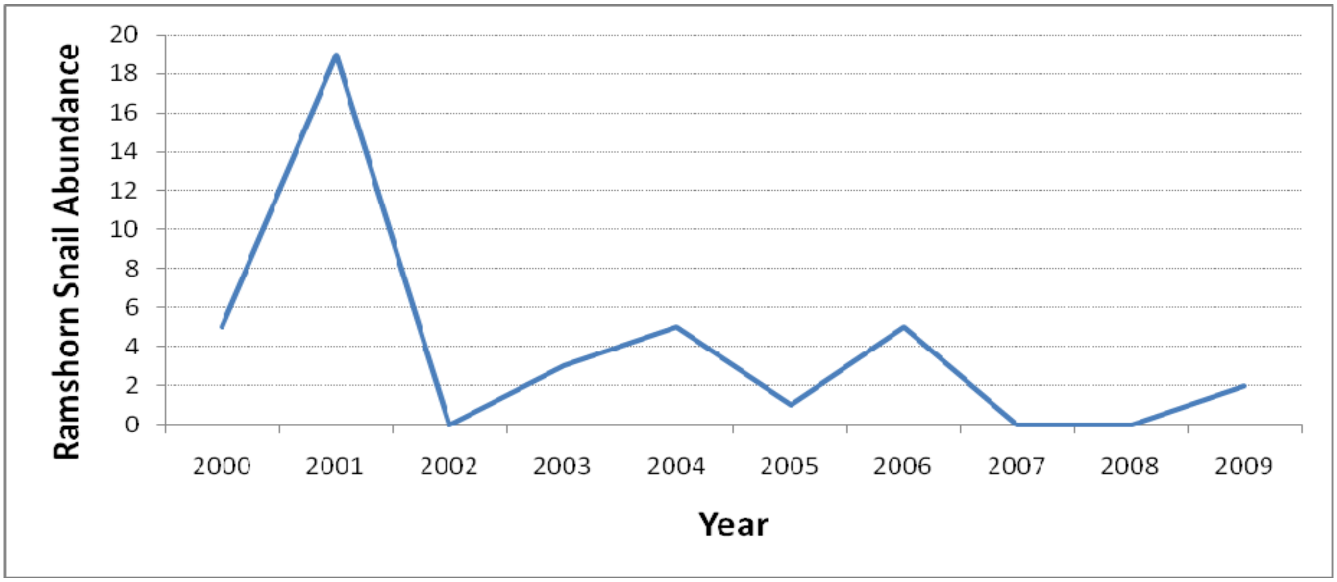


Figure 23. Number of giant ramshorn snails collected during each year of drop net sampling on the San Marcos Springs/River ecosystem.

Dip Net Results

The boundary for each section where dip net collections were conducted is depicted on Figure 24. Section numbers are included to be consistent with the USFWS classification system for the San Marcos River. In fall 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 Hotel Reach at Spring Lake are presented in Figure 25, and data from City Park and I-35 are graphically represented in Appendix B. Since only one sample has been collected from the new site on the lower river (Section 12), a graph was not generated. Seven fountain darters were collected from this reach during October 2009.

The number of fountain darters per unit time collected in the Hotel Reach by dip nets is much greater than that found in the other 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 (5-15 mm). 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 sites 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.

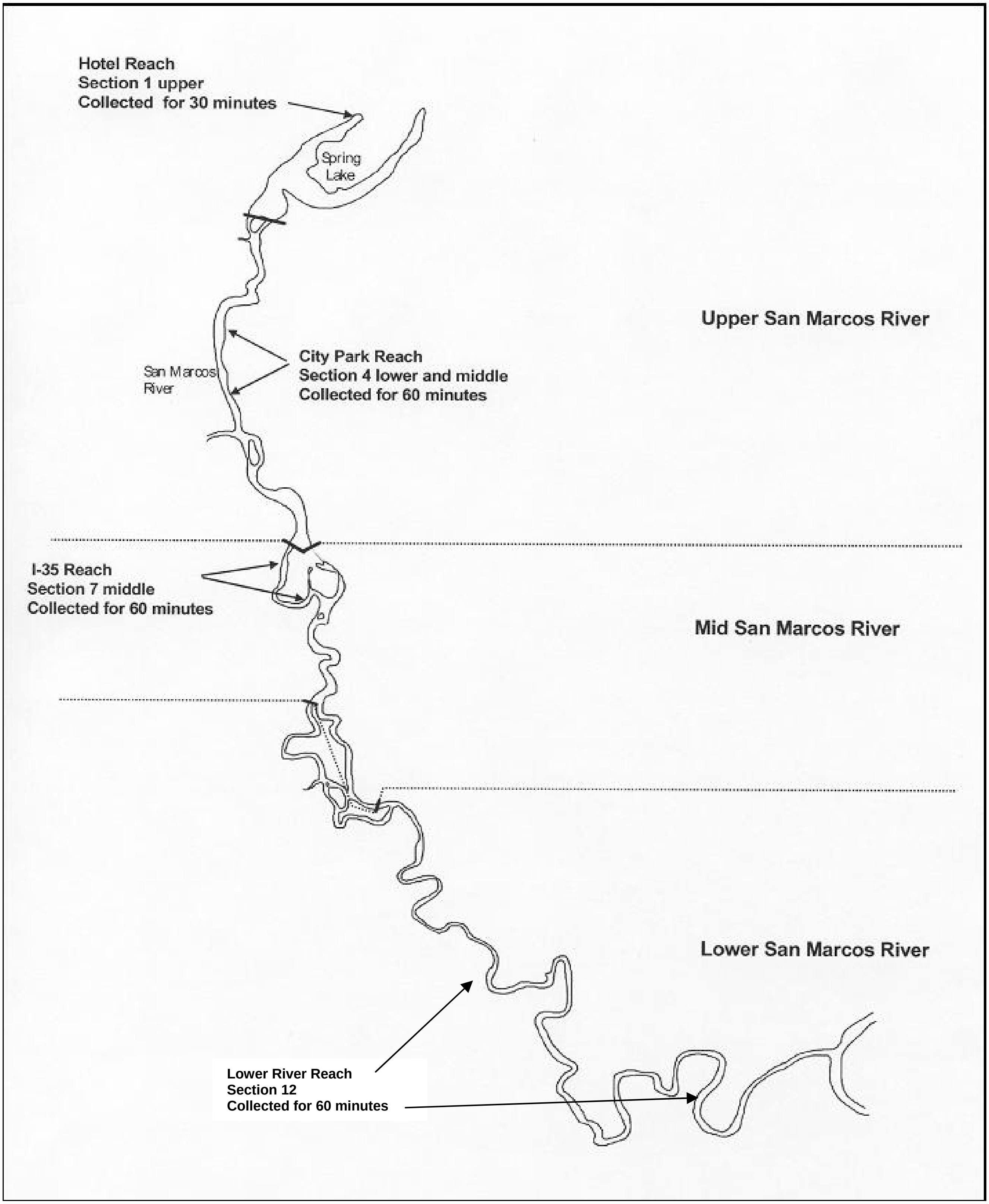


Figure 24. Areas where fountain darters were collected with dip nets in the San Marcos River in 2009.

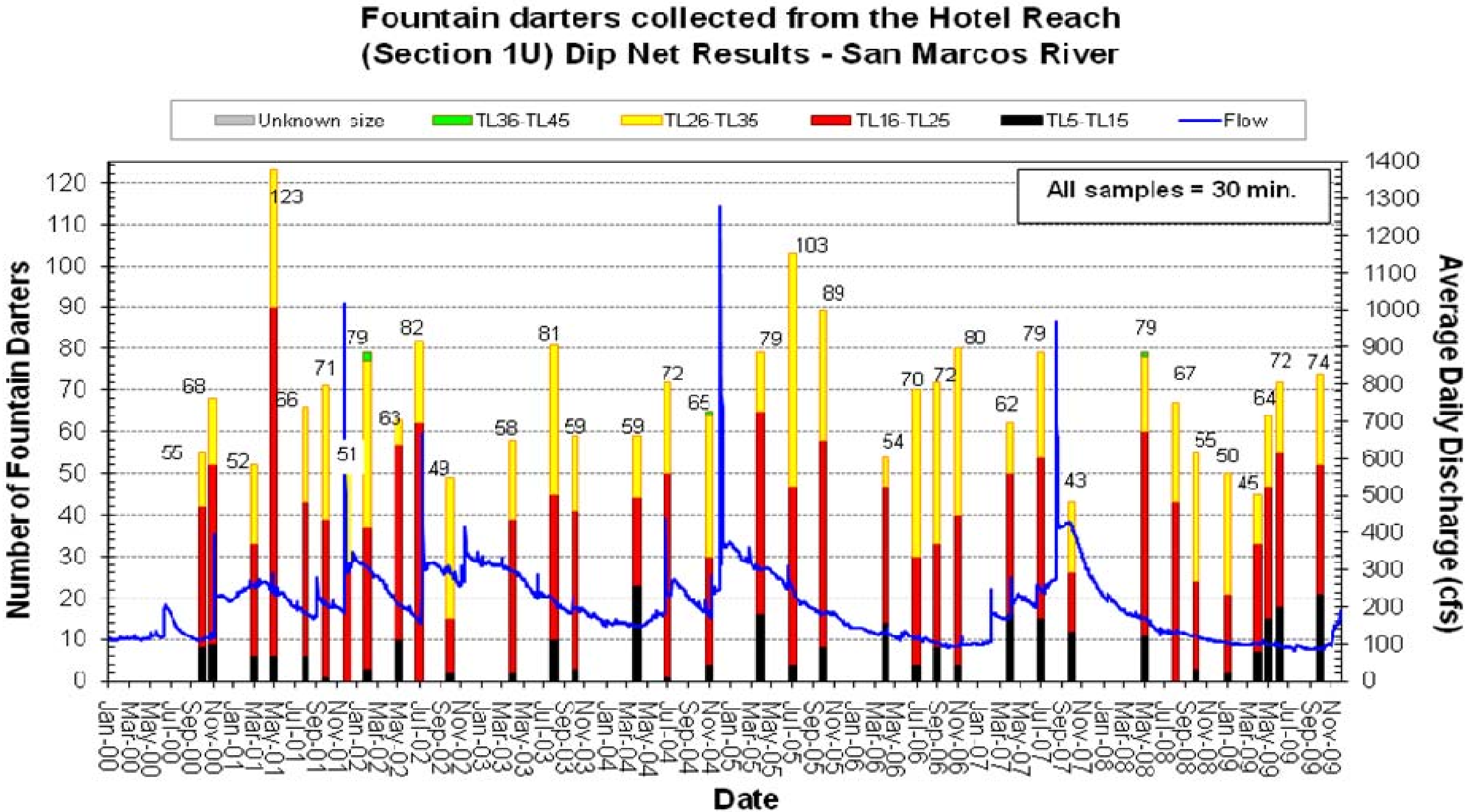


Figure 25. Number of fountain darters collected from the Hotel Reach (section 1 upper) of the San Marcos Springs/River ecosystem using dip nets.

Presence/Absence Dipnetting

In 2009, presence/absence dip netting was conducted on the San Marcos River five times. This included low-flow critical period sampling trips in January, April, and June, as well as the usual spring and fall sampling in May and October, respectively.

The percentage of sites in which fountain darters were present during each sample is presented in Figure 26. In April 2009, 60% of sites contained fountain darters. This represents the highest percentage observed since initiation of this technique in spring 2006. However, the percentage of sites with darters decreased by May and June and fell to a low of 36% by October 2009. This is the lowest percentage observed during the study period, and may represent impacts from sustained low flows which occurred throughout 2009. However, it is important to note that flows increased immediately before the October 2009 dip net sample was conducted. Therefore, the decline observed may be a result of darters spreading out as more habitats became available. A slight drop in this indicator was also noticed in fall 2006 after a period of extended low flows. However, when higher flows returned in spring 2007, the percentage of sites containing darters increased. Continued sampling is necessary to determine if such a rebound will occur with the higher flows witnessed since October 2009.

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.

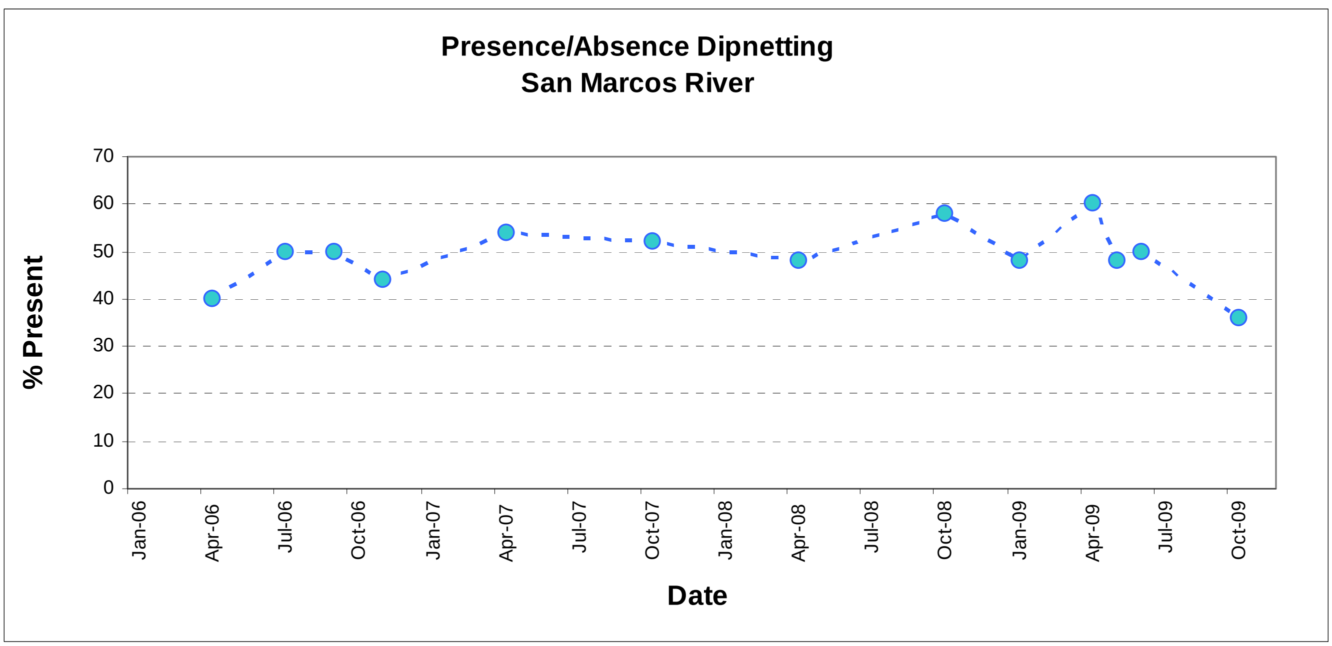


Figure 26. Percentage of sites (N = 50) in which fountain darters were present during presence/absence dip netting.

San Marcos Salamander Visual Observations

Salamander populations varied widely in 2009, but were similar to the numbers observed in previous years (Table 13). The highest density observed in the study took place during the Critical Period 2 sampling effort at the Hotel Reach (Sample Area 2). The greatest variability in salamander densities was observed at Sample Area 21 (upper section of the Spring Lake Dam Reach) where the highest density was 11.4 salamanders/m^2 in the summer (Critical Period 3), followed by the lowest density of 4.8 salamanders/m^2 in fall. Since this is the only area where salamander observations are performed that is open to the public, there is often variability in the number of fist-sized rocks due to people moving them around during the year. Densities at Sample Area 14 were within the variability observed since the fall of 2000 when observations began.

Table 13. 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	9.0	13.7	2.8
Fall 2007	9.2	8.1	9.1
Spring 2008	16.8	12.3	6.0
Fall 2008	15.1	11.7	8.6
Critical Period 1 2009	11.9	15.3	5.7
Critical Period 2 2009	25.2	11.0	10.5
Spring 2009	13.7	12.1	7.4
Critical Period 3 2009	18.2	8.5	11.4
Fall 2009	15.3	15.9	4.8

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