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

Final 2010 ANNUAL REPORT

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EXECUTIVE SUMMARY

This annual summary report presents a synopsis of methodology used and an account of sampling activities conducted during three sampling events (two Comprehensive Monitoring efforts and one Critical Period high-flow effort) on the Comal Springs/River ecosystem in 2010. For ease of comparison, the data are reported here in an annual report format similar to previous reports (BIO-WEST 2001-2010).

In 2010, increased rainfall and subsequent aquifer recharge allowed central Texas to come out of the drought that it had experienced for the past couple of years. Flows were above the historic average in the Comal River to begin 2010, which was a trend that continued throughout the entire year. In early June, a major flood event occurred on the Comal River. The flows on June 9, 2010 peaked at 7,280 cubic feet per second (cfs), the highest daily average since 2002 (13,400 cfs). This Critical Period event was caused by an 18-hour rainfall total of 7 – 12 inches, with much of it centered over the City of New Braunfels. Extensive damage to areas adjacent to the Comal River occurred. Several construction trailers and other debris were stranded on and near Spring Island by flood waters rushing out of Blieder's Creek. Damage to two pedestrian bridges and the gazebo at Landa Park was caused by water rushing down Panther Canyon. In addition, substrate was scoured and piled up in several different areas within the Comal River (Spring Island and the Spring Runs most notably). After this event, rainfall lessened during the second half of 2010, but flows remained above the historic average. Springflows at all spring runs (Spring Runs 1-3) were higher in 2010 than in 2009. These higher flows and the flood event in June affected all aspects of the biota in the system.

Water temperature data from June 19 to October 29 were lost for all thermistor sites on the Comal River due to equipment/software malfunction. However, the higher flows (especially during the summer months) make it unlikely that temperatures ever exceeded 26 degrees Celsius (ºC). Input from Texas Master Naturalist monitoring continues to provide valuable insight into water quality and recreation use throughout the year. Data continued to show that carbon dioxide (CO_2) levels decrease and pH levels increase as you move downstream. These did not appear to be highly influenced by the flooding, but a major decline in the amount of recreation was observed immediately following the flood because much of the river was closed to the public.

Aquatic vegetation at the four study reaches were affected by increased spring flows and the flood event in 2010. The flooding in June changed the Upper Spring Run Reach the most because a lot of the flow came down Blieder's Creek, which enters the Comal River just upstream of this reach. Over 80% of the aquatic vegetation in this reach was removed by the high-flow event, and only strongly-rooted *Sagittaria* remained. By fall, *Hygrophila* and bryophytes had regained a toe-hold in the reach, but vegetation remained scarce. Of the reaches studied, the aquatic vegetation in the Landa Lake Reach was least affected by the flood probably because it is the least channelized of the reaches (much of the high flows could go overland at the golf course adjacent to the lake). Still, aquatic vegetation was scoured out along the river left section of the reach where most of the flow was concentrated. Since bryophytes are weakly rooted to the substrate, most of them were scoured out with only a small area remaining near the river right side of the lake. Other native vegetation (*Ludwigia*, *Sagittaria*, *Cabomba*) were reduced after the flood, but by fall they had reestablished in most areas where they were previously found. *Cabomba* is considered high quality fountain darter (*Etheostoma fonticola*) habitat in this reach, and the fact that it is found in relatively protected areas makes it a very important plant during flooding events. The Old Channel Reach is the most natural reach of the four, but it could not escape the effects of the flood. Filamentous algae and bryophytes were both scoured out of this reach in 2010, though their populations here had been relatively low in recent years. *Ludwigia* was reduced to only two small stands following the high-flow event, but by fall had increased to nearly half of what it was at the end of 2009. The New Channel Reach is similar to the Upper Spring Run Reach because they are both channelized with cement banks and have a creek upstream almost entirely fed by runoff. As a result, nearly all the aquatic vegetation in the New Channel Reach was lost following the June flood. *Cabomba* and *Hygrophila* managed to find a little protection due to slight curves in the wall along each side of the river. Re-growth in this section occurred rather rapidly, and by fall *Nuphar* had also established in this reach. Flooding effects on aquatic vegetation in the Comal River are important because fountain darter populations are closely tied to changes in areal coverage of submerged plants.

Aquatic vegetation is an important component of fountain darter habitat in the Comal River. Higher densities of these fish are consistently found in native vegetation like bryophytes, filamentous algae, *Ludwigia*, and *Cabomba*. Unfortunately, flooding in June decimated much of the bryophytes and filamentous algae which are most vulnerable to scouring in high flows. This resulted in the lowest normalized population estimate of fountain darters since the inception of the study. Impacts were most notable at the Old Channel and Upper Spring Run sites because much of the vegetation was removed in these reaches (filamentous algae and bryophytes were absent from both sites in June). Fountain darter populations began to recover by fall, and if previous high-flow events are any indication, they should continue to increase as aquatic vegetation grows back. This event underscores the importance of Landa Lake as a refuge for darter populations because it is less channelized, and therefore less susceptible to floods. The scouring of native vegetation also emphasizes the importance of more strongly rooted vegetation like *Vallisneria* and *Sagittaria* as refuges during high flows.

Size-class distribution of fountain darters captured during drop netting confirmed a reproductive peak in spring in most reaches, although some reproduction still takes place at other times of the year. Areas with native vegetation and high densities of fountain darter again yielded darters of all sizes throughout the year. Dip netting data suggest a drop in fountain darter populations following the June flood, and appear to correlate well with size-class distributions observed from drop netting. The hydrological conditions experienced in 2010 and resulting biological effects reiterated the importance and susceptibility of native vegetation, and how changes in its areal coverage can impact fountain darter populations.

Gill parasites in the Comal River were monitored throughout 2010. A specific study at three sites was conducted to compare overall gill parasite concentrations from 2010 to those observed during 2006. A significant decline in cercarial densities was observed from 2006 to 2010.

Comal Springs salamander (*Eurycea* sp.) populations decreased at all sites following the June flood except at the Spring Island East Outfall. At Spring Runs 1 and 3, the increased sedimentation from smaller diameter substrate (i.e. sand/silt) filled interstitial spaces leaving less space for salamanders to find refuge. As above average flows continued through the summer and fall, populations at Spring Run 1 increased and populations at Spring Run 3 held steady, possibly due to water pushing out the fine sediment and opening up those interstitial spaces that are habitat for salamanders. Similar to fountain darters, the highest concentrations of salamanders were found under rocks that were covered in bryophytes. The loss of and slow reestablishment of bryophytes following the flood may explain why salamander populations at the Spring Island Spring Run remained low in the fall.

Sampling of invertebrate populations is confined to areas near spring upwellings because these animals often are not observed until they are released or come out of the springs. As a result, these populations seemed less affected by the flooding than other aquatic organisms studied in the Comal River. Unfortunately, the flooding did affect the Comal Springs riffle beetle (*Heterelmis comalensis*) sampling effort because many of the lures (cotton rags) used to catch these invertebrates were washed away or buried by shifting substrates. In 2010, a new locality for the Comal Springs riffle beetle and Peck's

Cave amphipod (*Stygobromus pecki*) was chosen just downstream of the confluence of Spring Runs 1 and 2. As in previous years, populations were patchily distributed and abundance varied considerably in 2010.

The flood in June resulted in a myriad of effects on the biota in the system. Data from the past 10 years indicate that the Comal River/Springs ecosystem contains a highly resilient ecological community that is able to withstand these types of events. However, anthropogenic and natural stressors will likely continue to exacerbate the magnitude and frequency of high and low-flow events into the future. Therefore, continued monitoring and applied research will be vital to provide guidance on management strategies necessary for preserving this unique ecosystem.

METHODS

Study Location

Comal Springs, which consists of many spring openings, is the largest spring system in Texas. The clear, thermally constant water issues from the downthrown side of the Comal Springs Fault Block. The Comal River extends 5 kilometers to its confluence with the Guadalupe River (Figure 1). Although Comal Springs reportedly has the greatest discharge of any springs in the Southwest, the flows can diminish rapidly during drought conditions and the springs completely ceased to flow for several months in the summer and fall of 1956 during the drought of record. Despite this fact, Comal Springs is home to several extremely rare, listed species. This study includes monitoring and applied research efforts directed toward these species including one fish, the fountain darter, and three invertebrates, Comal Springs dryopid beetle (*Stygoparnus comalensis*), Comal Springs riffle beetle, and Peck's cave amphipod. One additional species that is monitored during this study is the undescribed Comal Springs salamander.

Two full comprehensive (spring and fall) and one Critical Period high-flow (June / July) sampling efforts were conducted in 2010. Additionally, Texas Master Naturalist volunteers assisted with weekly water quality measurements and recreational counts on the Comal system. A full comprehensive event includes the following sampling components and volunteer activities:

Water Quality
Thermistor Placement / Retrieval
Fixed Station Photographs
Weekly Standard Parameters (Volunteer)
Point Water Quality Measurements

Aquatic Vegetation Mapping

Fountain Darter Sampling
Drop Nets
Dip Nets
Visual Observations

Salamander Observations

Macroinvertebrate Sampling
Drift Nets
Comal Springs Riffle Beetle Surveys

Recreation Observations
Weekly Recreation Counts (Volunteer)

Comal Springflow

Total discharge data for the Comal River were acquired from United States Geological Survey (USGS) water resources division. The data are provisional as indicated in the disclaimer on the USGS website and, as such, may be subject to revision at a later date. According to the disclaimer, "recent data provided by the USGS in Texas – including stream discharge, water levels, precipitation, and components from water-quality monitors – are preliminary and have not received final approval" (USGS 2010). The discharge data for the Comal ecosystem were taken from USGS gage 08169000 from the Comal River at New Braunfels. This site represents the cumulative discharge of the springs that form this river system.

In addition to these cumulative discharge measurements, which are used to characterize the Comal Springs ecosystem during sampling, discharge was also measured in Spring Runs 1, 2, and 3, and in the Old Channel during each sampling effort. These data were used to estimate the contribution of each major Spring Run to total discharge in the river, and to estimate the relative proportion of water flowing in the Old and New Channels. Finally, spot water velocity measurements were taken during each drop net sampling event. All discharge and velocity measurements were taken using a SonTek® FlowTracker.

Low-Flow Sampling

There were no low-flow sampling events on the Comal Springs/River ecosystem in 2010.

High-Flow Sampling

A major rain event occurred on June 9, 2010 with a peak discharge of 7,280 cfs resulting in a subsequent high-flow Critical Period sampling event when conditions were suitable (clear water / safe riverine environment) for sampling.

Water Quality Sampling

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. However, two important components for maintenance of long-term baseline data, temperature loggers (thermistors) and fixed station photography were collected throughout 2010. 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.

Temperature Thermistors

Thermistors set to record water temperature every 10 minutes are placed in select water quality stations along the Comal River, and continue to be downloaded at regular intervals to provide continuous monitoring of water temperatures in these areas. Thermistors were also placed in deeper locations within Landa Lake using SCUBA. The thermistor locations will not be described in detail here to minimize the potential for thermistor tampering.

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

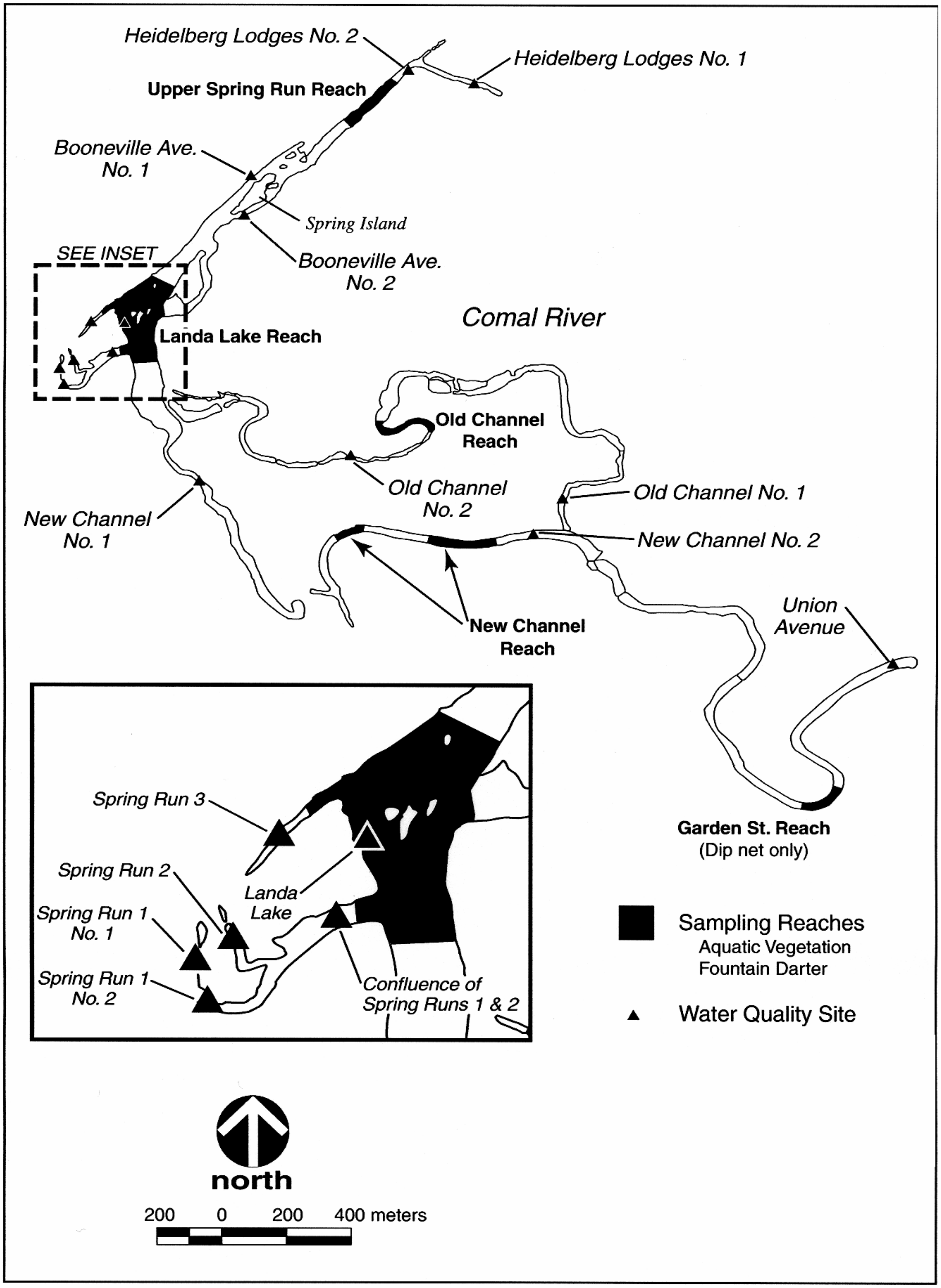


Figure 1. Comal River water quality and biological sampling areas.

Master Naturalist Monitoring

Volunteers with the Texas Master Naturalist program continued their monitoring efforts in 2010 at select locations along the Comal Springs/River ecosystem. The Texas Master Naturalist Program is a partnership among the Texas Cooperative Extension, Texas Parks and Wildlife Department (TPWD), and numerous local partners designed to provide natural resource education, outreach, and other services through volunteer efforts. To become a Master Naturalist, an individual must complete an approved training course and complete at least 40 hours of volunteer service per year. The program currently supports over 2,750 volunteers across the state of Texas (http://masternaturalist.tamu.edu).

Since the summer of 2006, Master Naturalist volunteers have assisted BIO-WEST by collecting weekly water quality and recreation data on the Comal Springs/River ecosystem. Volunteers collected data at five sites (Figure 2) on a weekly basis (typically on a Friday afternoon). At each site, an Oakton Waterproof pHTestr 2 was used to assess pH, and a LaMotte Carbon Dioxide Test Kit was used to measure carbon dioxide concentrations in the water column. In addition to water quality measurements, recreational use data were collected at each site by counting the number of tubers, kayakers, anglers, etc. using the area at the time of sampling. Photos were taken at each site and any other notes on recreational use or condition of the river were recorded during each sampling event.

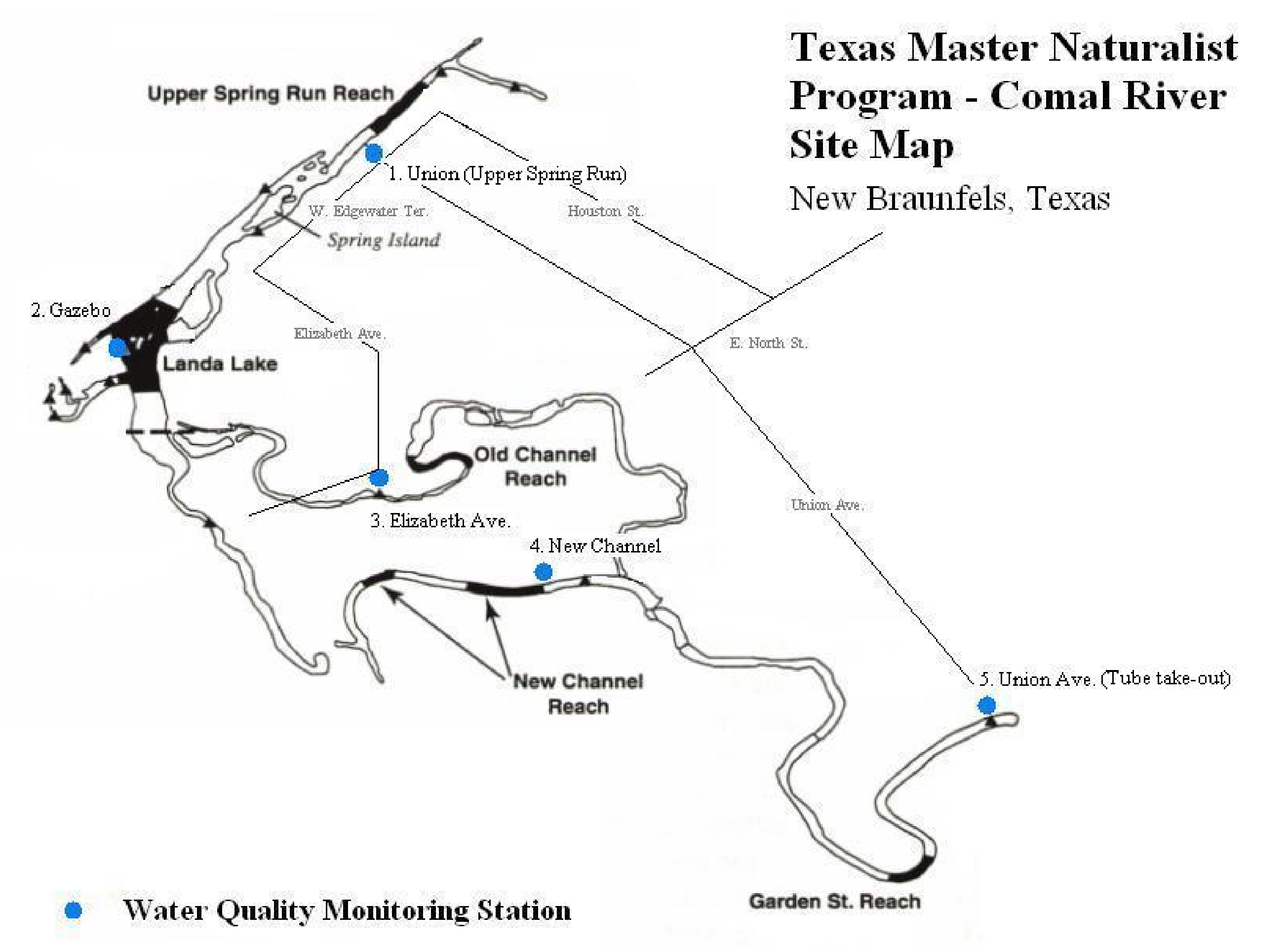


Figure 2. Weekly water quality / recreation monitoring sites on the Comal River used by Texas Master Naturalist volunteers.

Aquatic Vegetation Mapping

Aquatic vegetation mapping was conducted using a Trimble Pro-XH global positioning system (GPS) unit with real-time differential correction capable of submeter accuracy. The Pro-XH receiver was linked to a Trimble Recon Windows CE device (or similar device) with TerraSync software that displays field data in real time and improves efficiency and accuracy. The GPS unit was placed in a 10-foot (ft) Perception Swifty kayak with the GPS antenna mounted on the bow. The aquatic vegetation was identified and mapped by gathering coordinates (creating polygons) while maneuvering the kayak around the perimeter of each vegetation type at the water's surface. Vegetation stands that measured between 0.5 and 1.0 meter (m) in diameter were mapped by recording a single point. Vegetation stands less than 0.5 m in diameter were not mapped.

Filamentous algae (in the Old Channel) and bryophytes (*Riccia* and *Amblystegium*; primarily in the Upper Spring Run and Landa Lake) were included in all 2010 sampling events. Difficulties with mapping these vegetation types (patchiness, bryophytes were easily obscured by filamentous algae, etc.) precluded their inclusion during previous studies and early on in this project; however, these vegetation types were documented as important fountain darter habitat and have been included in all sample events since the summer of 2001.

Hygrophila (left) and algae growth within *Hygrophila* (right) in the Old Channel Reach

Fountain Darter Sampling Methods

Drop Nets

A drop net is a sampling device previously used by the United States Fish and Wildlife Service (USFWS) to sample fountain darters and other fish species. The design of the net is such that it encloses a known area (2 square meters [m^2]) and allows a thorough sample 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 drop net. For sampling during this study, a drop net was placed in randomly selected sites within specific aquatic vegetation types. The vegetation types used in each reach were defined at the beginning of the study as the dominant species found in that reach. Sampling sites were randomly selected per dominant vegetation type for each sampling event from a grid overlain on the most recent map (created with GPS-collected data during the previous week) of that reach.

At each location the vegetation type, height, and areal coverage were recorded, along with substrate type, mean column velocity, velocity at 15 centimeters (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 drop 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 for abundant species where only the first 25 individuals were measured. Fish species not readily identifiable in the field were preserved for identification in the laboratory. When collected, 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 (*Palaemonetes* sp.) was also recorded for each dip net sweep.

Drop Net Data Analysis

The fisheries data collected with drop nets were analyzed in several ways. Calculations of fountain darter density in the various vegetation types during 2000-2010 provide valuable data on species/habitat relationships. These average density values were also used with aquatic vegetation mapping data on total coverage of each vegetation type by sampling effort to create estimates of the population abundance in each reach (fountain darter density within a vegetation type x total coverage of that vegetation type in 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 is due to changes in environmental conditions (discharge, temperature, etc.) that had occurred since the last sample, but part is 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 Nets

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 each reach. Habitats thought to contain fountain darters, such as along the edge of, or within 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 presence of native and exotic snails was recorded per sweep.

To balance the effort expended across samples, a predetermined time constraint was used for each reach (Upper Spring Run - 0.5 hour, Spring Island area - 0.5 hour, Landa Lake - 1.0 hour, New Channel - 1.0 hour, Old Channel - 1.0 hour, Garden Street - 1.0 hour). The areas of fountain darter collection were marked on a base map of the reach. Although information regarding the density of fountain darters per vegetation type was not gathered with this method (as in drop net sampling), it did permit a more thorough exploration of various habitats within each reach. Also, spending a comparable length of time sampling the entirety of each reach allowed comparisons between 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). 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. Dip net data were analyzed by visually evaluating graphs of length-frequency distribution for each sample reach.

Presence/Absence Dip Netting

Presence/Absence dip netting was initiated on the Comal River during fall 2005. 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 extreme low-flow periods without harming critical habitat. During each sample, fifty sites were distributed among the four sample reaches based on total area, diversity of vegetation, previous fountain darter abundance estimates, and overall biological importance of each reach. Sites were randomly selected within the dominant vegetation types within each reach. Four dips were conducted at each site. 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.

Visual Observations

Visual surveys were conducted using SCUBA in Landa Lake to verify continued habitat use in deeper portions of the lake by both fountain darters and Comal Spring's salamanders. These time-constrained surveys were conducted in areas too deep for efficient drop netting or dip netting. Observations were conducted in the early afternoon. Since summer 2001, a specially-designed grid (0.6 m x 13.0 m) has been used to quantify the number of fountain darters using these deeper habitats. During each survey, all fountain darters within the grid were counted. A more labor-intensive effort would be required to develop an estimate of the true population size in the sample area, but these data are useful in providing an indication of fountain darter relative abundance in areas similar to those sampled. These data also provide insight into trends in population dynamics that may occur over time.

Gill Parasite Evaluations

In addition to routine monitoring, a specific gill parasite study was conducted in 2010 in conjunction with USFWS. Parasite monitoring was conducted in 2010 at the same three sites sampled during a special study in 2006 (Bolick 2007). Both collection periods were initiated during droughts. Two sites, Houston Street (HS) and Liberty Avenue (LA), were located in the shallow upstream reach of Landa Lake (Figure 3). Both of these sites are located within 300 m of one of the springs that feed the upper portion of Landa Lake. The third site, Elizabeth Avenue (EA), is located downstream in the Old Channel, approximately 500 m from the spillway of Landa Lake (Figure 3). At each of the three sites, a transect was established across the river perpendicular to flow. At each transect six points were established where two 5 liter (L) samples of water, one at approximately 10 cm from the bottom and one at 60% depth from the surface were collected. Each water sample was pumped through a flexible acrylic tube (6.4 mm internal diameter) into a 10 L bucket via a battery-operated submersible pump, which was positioned at the desired depth on an adjustable 1.5-m rod before pumping was initiated.

Immediately following collection, 5 milliliters (mL) of formalin were added to each water sample to fix the cercariae. Each sample was filtered using an apparatus described in Theron (1979) and Prentice (1984), but using modifications developed by Cantu (2003). Each sample was passed through three successive mesh filters with pore sizes of 220 micrometers (µm), 86 µm, and 30 µm, respectively. After each sample was filtered, the 30 µm filter was placed in a Petri dish and covered with 3 mL of a 10% formalin solution. The cercariae on the filters were subsequently stained in a 10% Rose Bengal solution. All filters were taken to the laboratory for analysis. All *Centrocestus formosanus* cercariae present were counted using a dissecting microscope (100 X). The number of cercariae/L was calculated by dividing the total number of cercariae counted on a filter by the total volume of the water sample (5 L).

Following cercariae collection, depth and stream velocity were measured at 20 equidistant points along the site transect using methods adapted from Buchanan and Somers (1969). Stream temperature and dissolved oxygen were also measured at each site. Cercarial abundance (*C. formosanus* cercariae/L) at each site was regressed against wading discharge (collected locally) and against total stream discharge (collected from the USGS gage station) to determine if stream discharge affects the density of *C. formosanus* cercariae drifting in the water column. The Ryan-Joiner test was used to screen data for non-normality and the Grubbs test to remove outlying values. An independent *t*-test ($\alpha = 0.05$) was used to determine if significant differences existed in wading discharge data, total stream discharge data, or cercarial count data collected during the two sampling periods. One-way ANOVA with Tukey's post hoc testing was used to determine if significant differences existed between cercarial densities at the three sites.

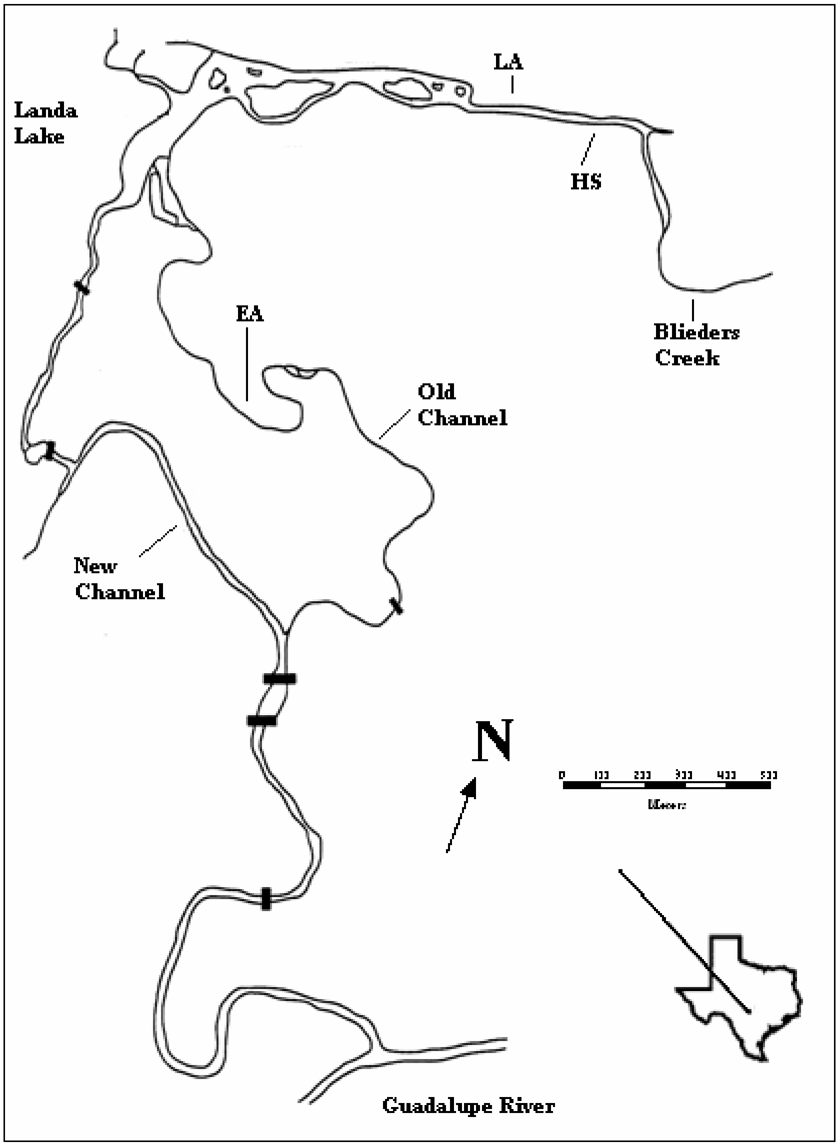


Figure 3. Gill parasite collection sites (HS, LA, and EA) in the Comal River in 2010.

Comal Springs Salamander Visual Observations

In addition to visual observations made in deeper portions of Landa Lake for fountain darters and Comal Springs salamanders, the BIO-WEST project team performed presence/absence surveys for the Comal Springs salamanders in the spring reaches located at the head of the Comal River during all 2010 sampling events. These two-person surveys were conducted in Spring Run 1, Spring Run 3 (next page), and the Spring Island area (Figure 1).

Each survey began at the downstream-most edge of the sampling area and involved turning over rocks located on the substrate surface while moving upstream toward the main spring orifice. A dive mask and snorkel were utilized when depth permitted. Salamander locations were noted, along with time, water depth, and presence/absence of vegetation species. To maintain consistency between samples, all surveys were initiated in the morning and terminated by early afternoon.

Within Spring Run 1, surveys were conducted from the Landa Park Drive Bridge upstream to 9-m below the head spring orifice. Spring Run 3 was surveyed from the pedestrian bridge closest to Landa Lake upstream to 9-m below the head spring orifice. In the Spring Island area, surveys were conducted within the entire spring reach including an approximately 15-m radius from each Spring Run outfall. These two areas include the spring outfall on the east side of Spring Island (closest to Edgewater Drive) and the area on the north side of Spring Island (upstream).

Macroinvertebrate Sampling

In 2010, drift nets were placed in spring openings during the spring and fall comprehensive sampling efforts. Drift nets were placed over the openings of Comal Spring Runs 1 and 3 and a moderate-sized spring upwelling along the western shoreline of Landa Lake. The nets were anchored into the substrate directly over the spring opening, with the net face perpendicular to the direction of flow of water. The nets had a 0.45-m by 0.30-m rectangular opening and mesh size of 350 µm. The tail of the net was connected to a detachable 0.28-m long cylindrical bucket (300-µm mesh). The buckets were removed at 4-hour intervals, and the cup contents were sorted in the field. Except for voucher specimens of Comal Springs riffle beetle, Peck's cave amphipod, and Comal Springs dryopid beetle, all organisms of these three species were identified and returned to their spring of origin. Voucher specimens included fewer than 20 living specimens (identifiable in the field) of each species. All other invertebrates were preserved in 70% ethanol for later identification. Water quality measurements (temperature, pH, conductivity, dissolved oxygen, and current velocity) were taken at each drift net site using a Hydrolab multiprobe and DataSonde (model 2) and a Marsh McBirney portable water current meter (model 201D).

In addition to drift nets placed over spring openings, surveys for Comal Springs riffle beetles were conducted in the two comprehensive sampling efforts in 2010 (May/June and November/December). These samples were conducted in Spring Run 3, along the western shoreline of Landa Lake, and near Spring Island in locations that were previously identified (BIO-WEST 2002a) to have high densities of Comal Springs riffle beetles. Samples were collected using the same "cotton lure" methodology as in previous years. Bed sheets (60% cotton, 40% polyester) were cut into 15-cm x 15-cm squares which were placed in spring openings with rocks loosely stacked on top to keep them in place. Approximately four weeks later, squares were removed, and depth and current velocity measurements were taken. Beetles were identified, counted, and returned to their spring of origin. Other spring invertebrates collected on the lures were also noted. At each of the three study sites, 10 springs were sampled using this method.

OBSERVATIONS

The BIO-WEST project team conducted 2010 sampling on the dates shown in Table 1.

Table 1. Study components and sampling dates of the 2010 sampling events.

EVENT	DATES
Spring	
Vegetation Mapping	April 23 - 28
Fountain Darter Sampling	May 3 - 6
Comal Salamander Observations	May 5
Macroinvertebrate Sampling	May 27 - 28
Critical Period 1	
Vegetation Mapping	June 23 – 28
Fountain Darter Sampling	June 28 – July 8
Comal Salamander Observations	June 30
Fall	
Vegetation Mapping	October 22 - 26
Fountain Darter Sampling	October 29 – November 4
Comal Salamander Observations	October 29
Macroinvertebrate Sampling	November 11 - 12

Comal Springflow

Near the conclusion of 2009 precipitation in the region led to a subsequent increase in flows, drawing the region out of the prolonged drought that began in 2007. Average monthly flows in 2010 were above the historic monthly average and well above 2009's average until October when flows decreased nearer to the historic average (Figure 4). A major storm event on June 9 centered over the Guadalupe River and the City of New Braunfels resulted in a slug of water peaking at 7,280 cfs in the Comal River which subsequently triggered a high-flow Critical Period sampling event. Much of the impact occurred at the Upper Spring Run and Landa Lake sampling sites where several trailers from a construction site were washed into the river and deposited near Spring Island (Figure 5). Storm flows also impacted Landa Lake Park damaging the gazebo and two pedestrian bridges (Figure 6).

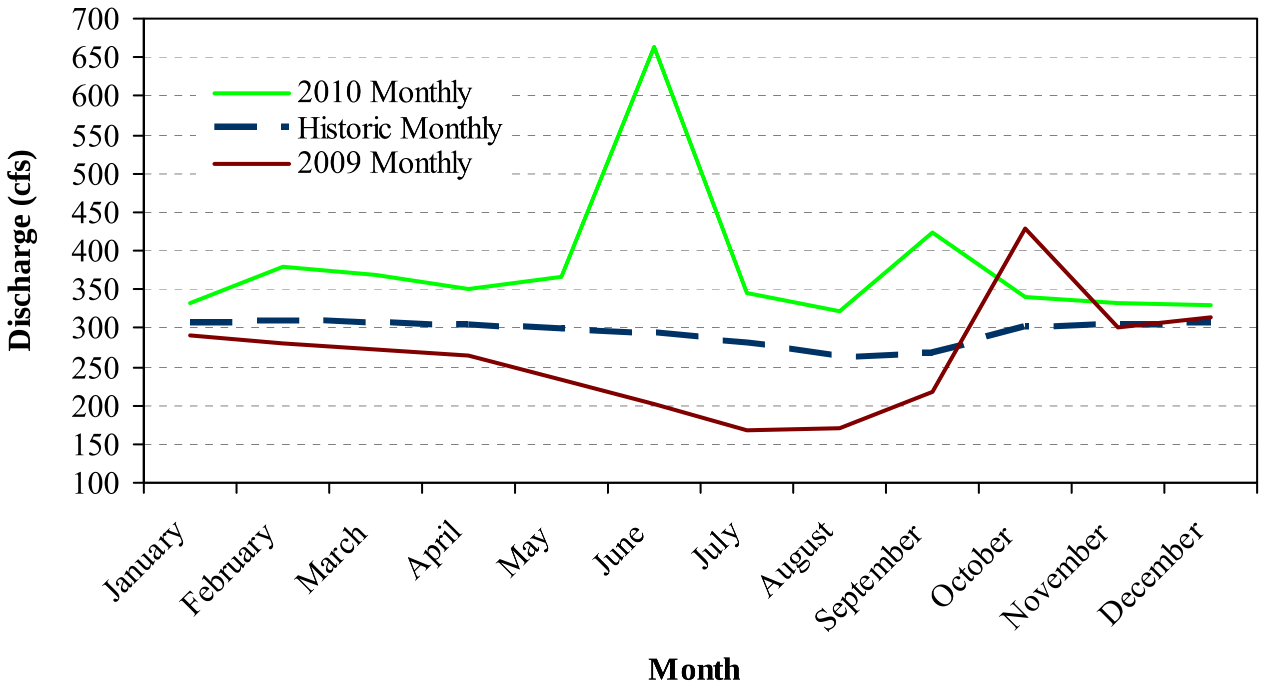


Figure 4. Mean monthly discharge (cfs) in the Comal River during the 1934 – 2010 period of record.

Figure 5. Trailer washed into the Comal River near Spring Island, June 2010.

Figure 6. Damage to the gazebo at Landa Lake Park after flood, June 2010.

Figure 7. Damage to the Hinman Island Dr. bridge at the Old Channel, June 2010.

Figure 8. Flooding at the New Channel Reach, June 2010.

Table 2. Lowest discharge during each year of the study (2000-2010) and the date on which it occurred.

Year	Discharge	Date
2000	138	Sept. 7
2001	243	Aug. 25
2002	247	Jun. 27
2003	351	Aug. 29
2004	335	May 28
2005	349	July 14
2006	202	Aug. 25
2007	251	Mar. 8-10
2008	260	June 30
2009	158	July 2
2010	305	Aug. 26, 30

The destructive properties of the flood were also observed downstream in the Old Channel (Figure 7) and the New Channel (Figure 8). After the flood, typical summer conditions in central Texas resulted in decreased flows and the lowest average daily discharge of 305 cfs in late August (Table 2). This was the highest minimum average daily flow since 2005 underscoring the recent drought in this region. Another rain event in September resulted in a maximum daily flow of 2,110 cfs, but no extensive damage was observed from this event. The remainder of 2010 was exemplified by few rainfall events and decreasing flows.

Higher flows during the first half of 2010 resulted in higher total flows at each Spring Run during the spring sampling effort (Table 3). However, measurements during the Critical Period high-flow sampling indicated a decrease in flow at Spring Runs 1 and 2 (and marginal increases at Spring Run 3) even though discharge in the river had increased. Flow conditions were closer to average in October, and discharge decreased at all sites from June except at Spring Run 2. Slight measurement error may have occurred at this site due to large rocks (washed into the Spring Run from the June flooding event) confounding flow measurements.

Increased flows from 2009 to 2010 were reflected in the increase in the proportion of water from each Spring Run (Table 4). During spring 2010, the proportion of water traveling down the Old Channel decreased slightly, but remained fairly constant due to the culvert regulating flow going into the Old Channel from Landa Lake. The relative proportions changed little after the high-flow event, except for a 7% increase at the Old Channel. These proportions decreased at all sites by fall (except for Spring Run 2), but were still higher than the same time in 2009.

Table 3. Total discharge in the Comal River (USGS data) and discharge estimates for Spring Runs 1, 2, 3, and Old Channel reach during fall 2009 and all sampling efforts in 2010.

Location	Discharge (cfs)			
	Fall 2009	Spring 2010	Critical Period 2010	Fall 2010
Total Discharge Comal River (USGS)	286	345	361	331
Spring Run 1	24.9	35.9	35.8	33.9
Spring Run 2	3.8	6.1	5.9	7.6
Spring Run 3 (upstream)	8.9	16.6	17.9	14.0
Spring Run 3 (downstream)	31.8	42.1	43.0	40.9
Old Channel	49.7	54.9	86.1	72.5

Table 4. Percentage of total discharge in the Comal River (USGS data) that each Spring Run contributed and percentage that traveled down the Old Channel during fall 2009 and all sampling efforts in 2010.

Location	Percentage of Total Discharge			
	Fall 2009	Spring 2010	Critical Period 2010	Fall 2010
Spring Run 1	7.1 %	8.5 %	8.4 %	8.0 %
Spring Run 2	1.1 %	1.4 %	1.4 %	1.8 %
Spring Run 3 (upstream)	2.5 %	3.9 %	4.2 %	3.3 %
Spring Run 3 (downstream)	9.1 %	9.9 %	10.1 %	9.7 %
Old Channel	14.2 %	13.0 %	20.3 %	17.1 %

Water Quality Results

Temperature Thermistors

The continuously recorded water temperature data (Appendix B) have provided a good view of the thermal conditions throughout the Comal Springs ecosystem from 2000-2010. Gaps in readings present on some graphs are indications of theft or thermistor failure, and in the latter case, these readings were excluded because they may not be entirely accurate. Water temperatures are most constant at or near the spring inputs and become more variable downstream as other factors (runoff, precipitation, and ambient temperature) become more influential. At times, precipitation can have acute impacts (cold winter rainfall) in some locations resulting in large temperature spikes. However, these are generally short-lived, and the overall relationship at these sites is more directly associated with ambient air temperature (air temperatures also strongly influence precipitation temperatures). Due to equipment malfunction, all temperature data from April 19 to October 29, 2010 were lost for all sites on the Comal River.

As a result of the loss of data it is difficult to assess the variation in temperatures for each site, but some generalizations can still be made. The thermistor data for the New Channel sites are presented in Figure 9, and graphs for all other reaches can be found in Appendix B. Several precipitation events in early 2010 contributed to several large temperature drops at the downstream New Channel site. This site is downstream of where Dry Comal Creek enters the Comal River and more prone to temperature fluctuations because Dry Comal Creek is a flashy stream draining an urban area. Similar to this stream, Blieder's Creek is also prone to temperature deviations because it is situated within an urban area. In summer, temperatures often exceed 26.7 ºC (Texas Commission on Environmental Quality [TCEQ] water quality standard) in Blieder's Creek, but due to data loss we do not know if this occurred in 2010. Water temperatures did not exceed the TCEQ standard at any site in 2010. Temperatures in the Spring Runs varied little as most of the water comes from the near constant temperatures of the Edward's Aquifer. Areas near Landa Lake typically exhibit relatively little variation, whereas the Old Channel exhibits stronger seasonal temperature fluctuations due to its distance from spring inputs (Appendix B).

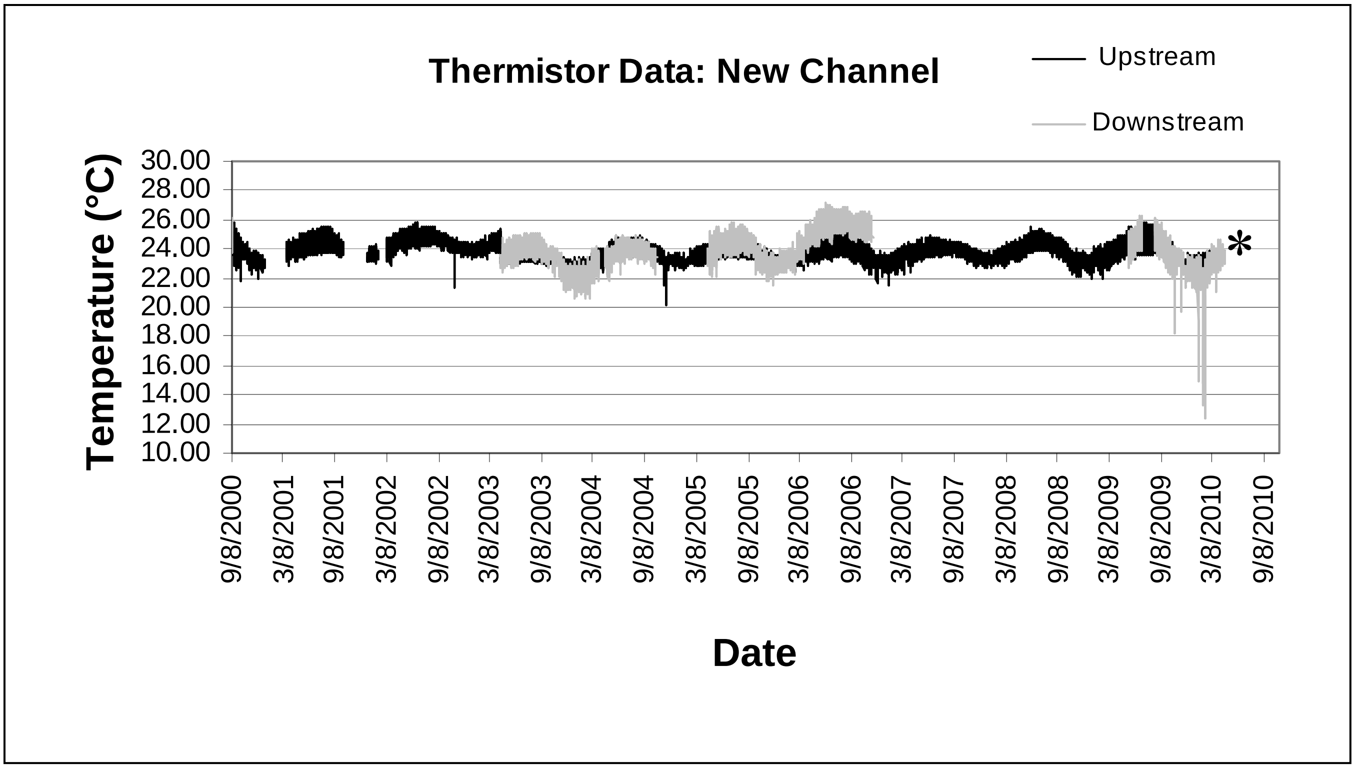


Figure 9. Temperature (°C) data at the New Channel from 2000 – 2010. *Data from 4/19/10 on lost due to retrieval malfunction.

Master Naturalist Monitoring

Water quality data collected by Master Naturalist volunteers in 2010 showed that CO_2 concentrations continue to be highest near springs (Houston Street [Upper Spring Run Reach], Gazebo [Landa Lake/ Spring Run 3], Figure 10), while pH increased going downstream (Figure 11). At all sites, CO_2 concentrations were similar between years (2006-2010). The high flows in June did not appear to have any significant effect on CO_2 or pH concentrations in the Comal River.

To compare recreational use at the various sites, weekly counts of recreation users were converted to monthly averages and plotted over the survey period (Figures 12 - 16). In previous years, recreation use at Elizabeth Street has been very low, but there was a large increase in users in August (Figure 12). The annual summer increase in recreation at the Upper Spring Run is likely a result of more people staying at the Heidelberg Lodges (Figure 13). The Landa Lake park gazebo area is used for recreation regularly during all months of the year, but is typically busiest during the spring with a slight dropoff by summer. However, the high-flow event in June damaged the gazebo and much of Landa Lake Park resulting in its closure to all users for a period of time, and all vehicles as of the last sampling period. The closure resulted in a decline in users at this location (Figure 14). The New Channel site is the most heavily recreated site, with recreation concentrated from March until September (Figure 15). Tubing is the dominant recreational activity at this site, especially between May and September. This is not surprising since it is both within a park setting and is heavily used by tubers as a launching point. As at the Gazebo Site, the high-flow event resulted in a decrease in recreation immediately following the flood, but unlike other sites this decrease was minimal. The Union Avenue site is the second most heavily used of the recreation sites, because it is an exit station for tubers during the summer months (Figure 16), and similar to the New Channel Site, there was a decrease in recreation immediately following the high-flow event. Compared to previous years, 2010 had similar numbers of people engaged in recreational activities. The only places that appeared to be negatively impacted from the higher flows were Landa Park and the New Channel.

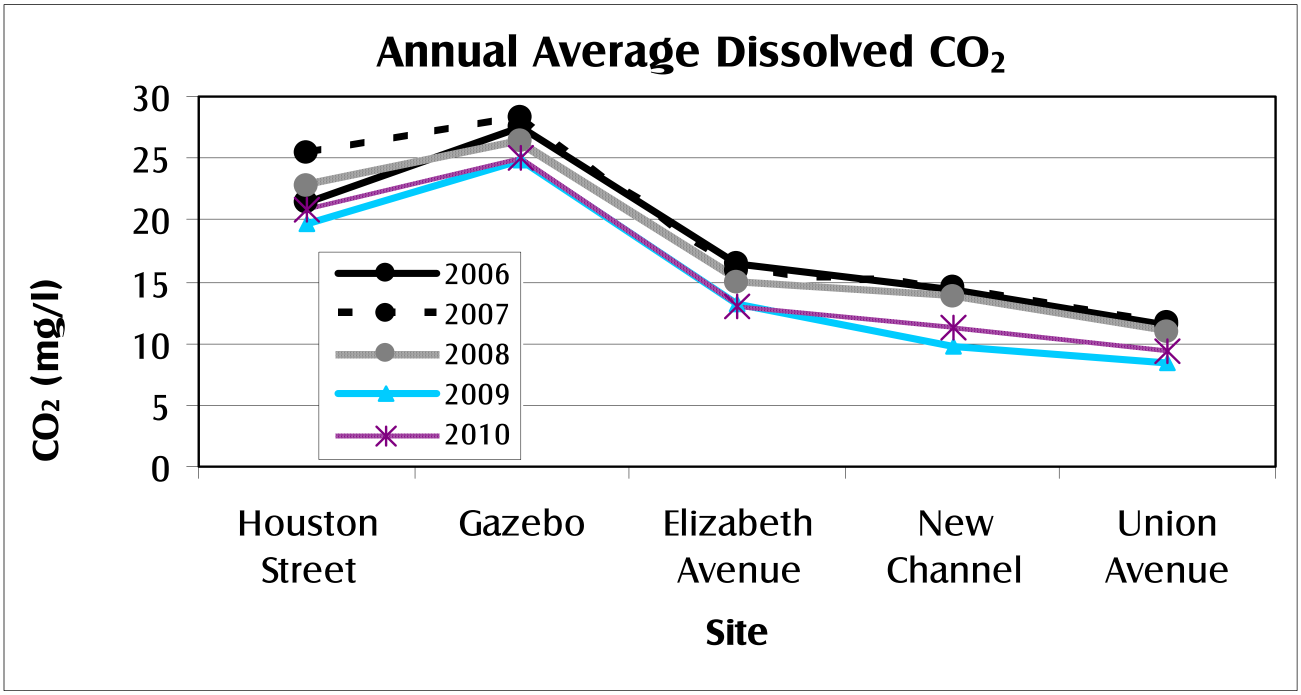


Figure 10. Annual average dissolved carbon dioxide (CO_2) concentrations at five sites on the Comal River system (2006-2010).

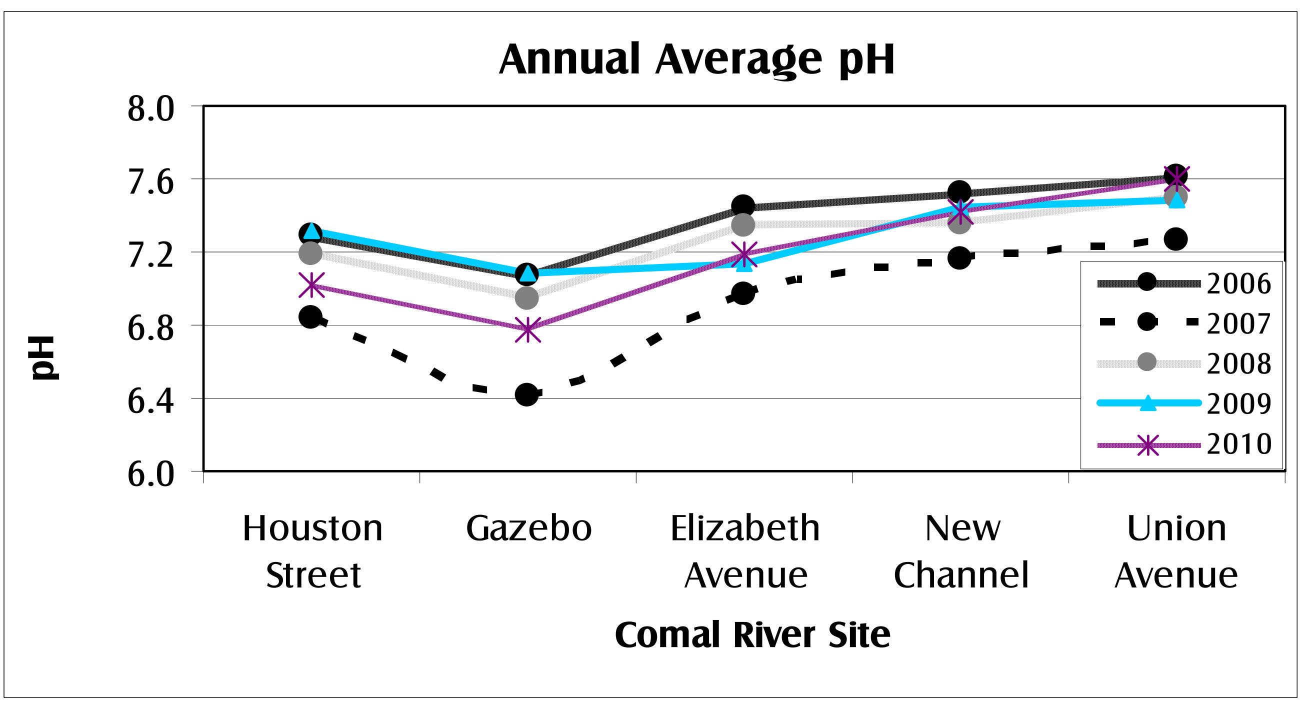


Figure 11. Annual average pH values at five sites on the Comal River system (2006-2010).

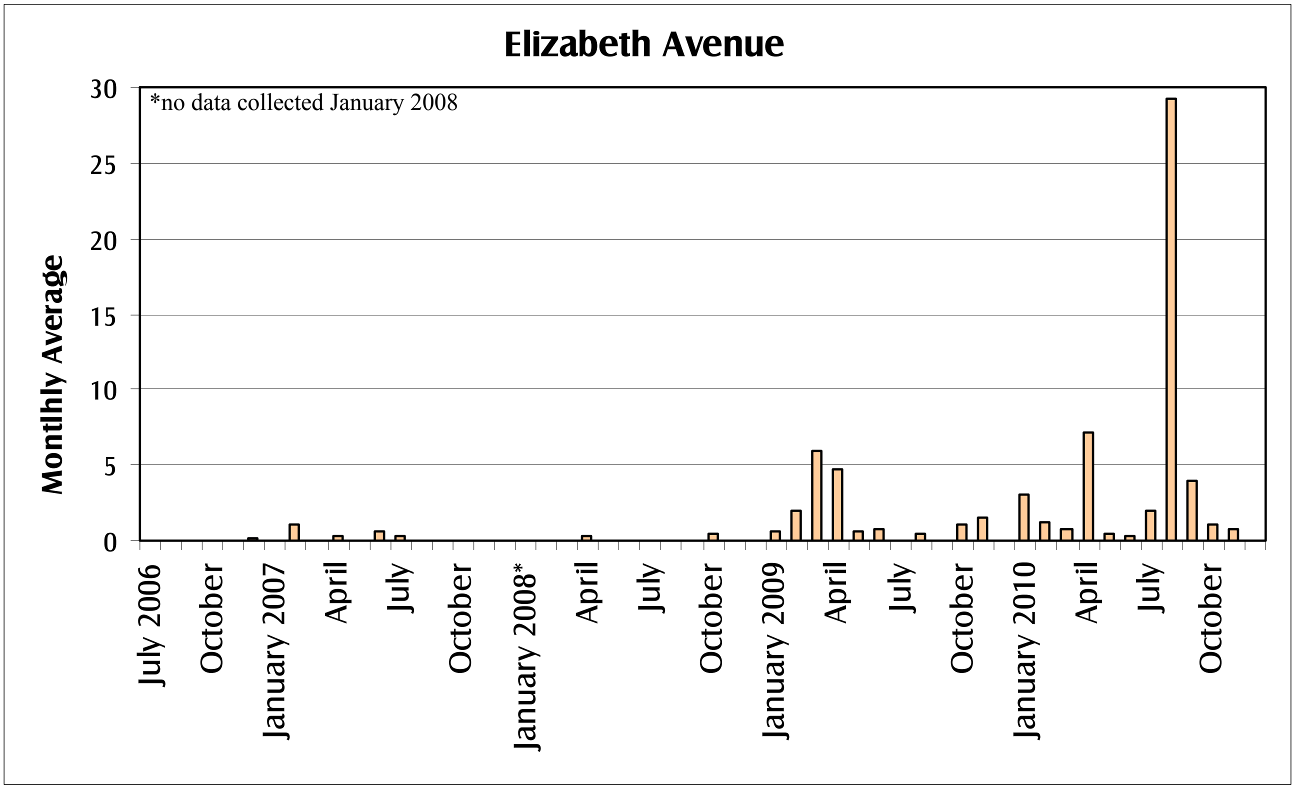


Figure 12. Average recreational use counts at the Elizabeth Avenue site (2006-2010).

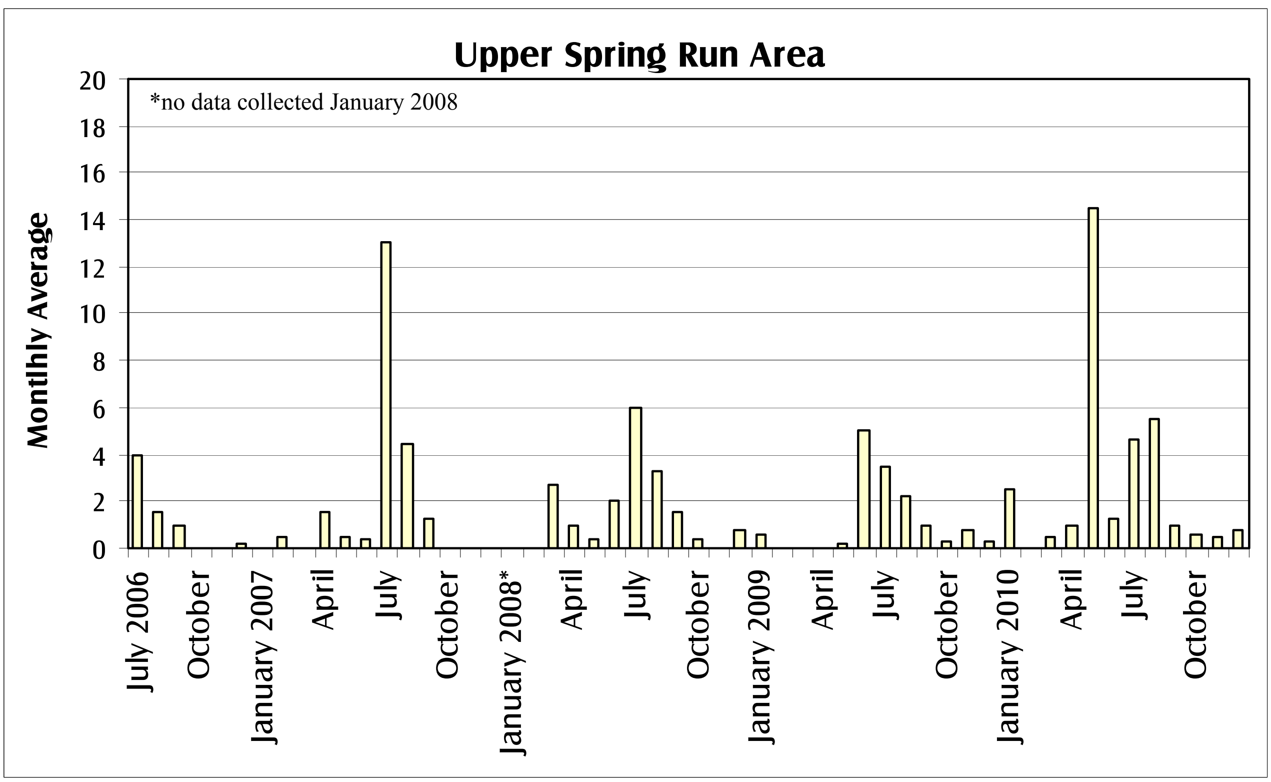


Figure 13. Average recreational use counts at the Upper Spring Run area (2006-2010).

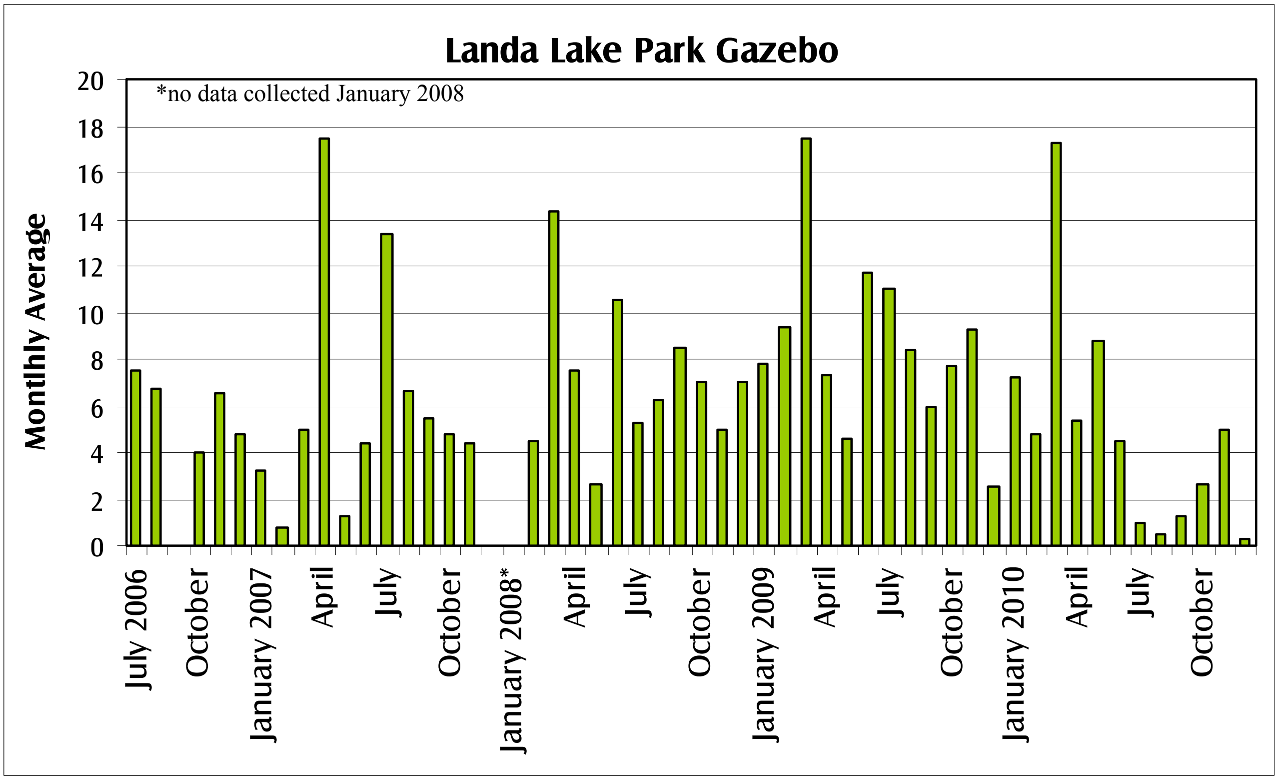


Figure 14. Average recreational use counts at the Landa Lake Park Gazebo site (2006-2010).

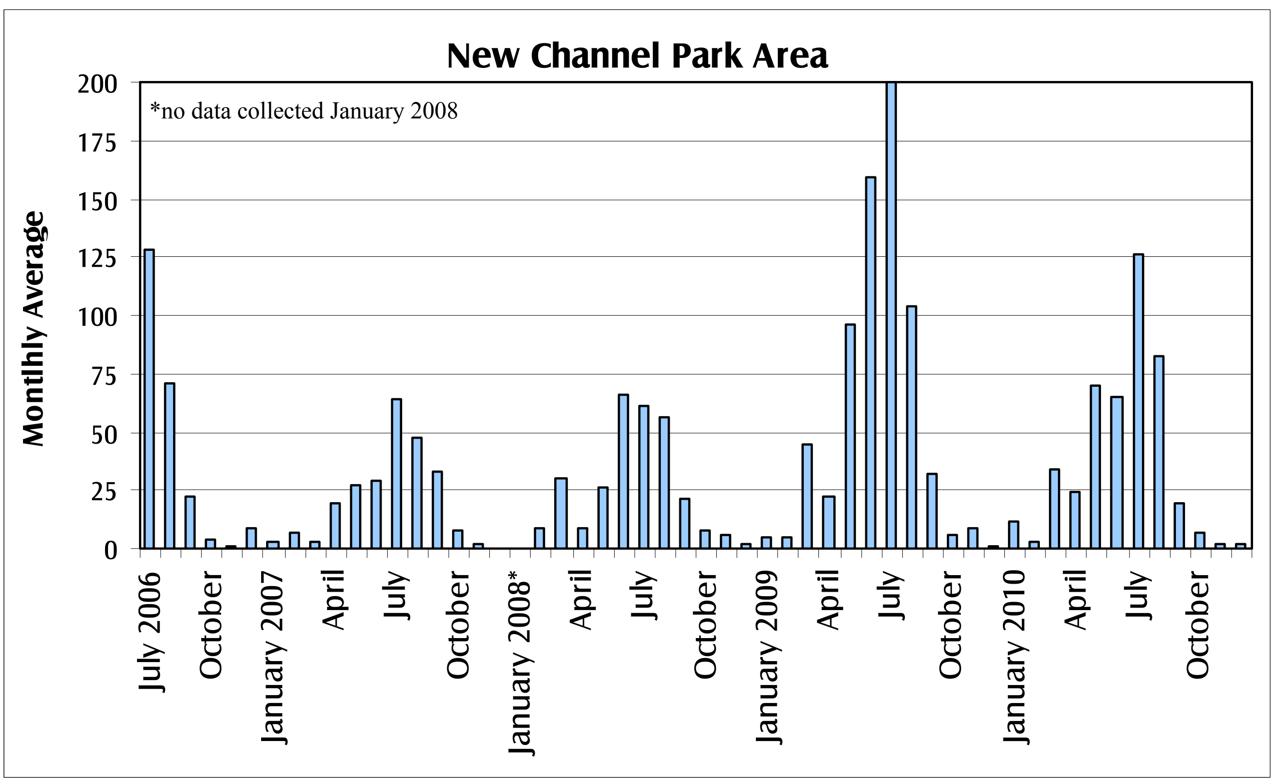


Figure 15. Average recreational use counts at the New Channel site (2006-2010).

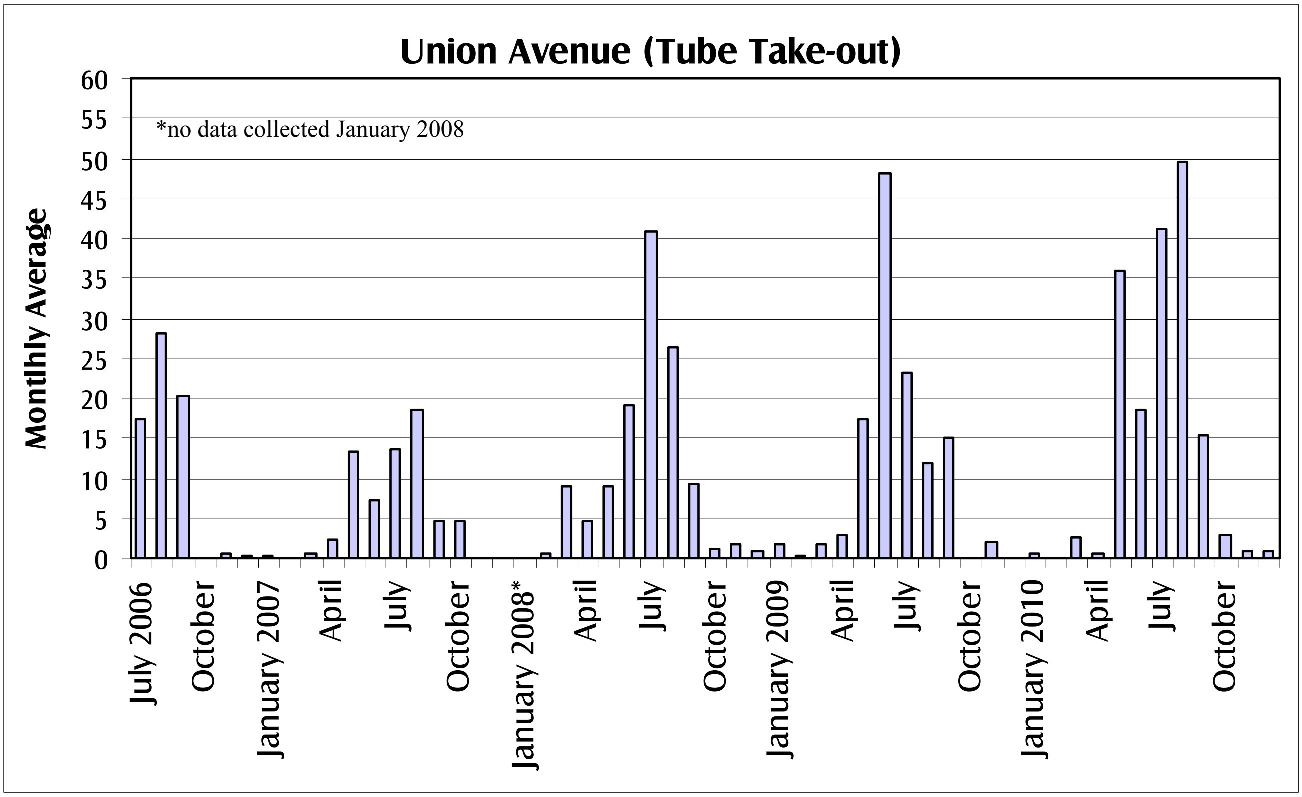


Figure 16. Recreational use counts at the Union Avenue site (2006-2010).

Aquatic Vegetation Mapping

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

Upper Spring Run Reach

At the conclusion of 2009, the two year drought in central Texas began to abate as flows in the Comal River increased above the historic monthly average (Figure 4). The relatively constant (though elevated) flows over winter contributed to aquatic vegetation growth during the spring at the Upper Spring Run Reach. All types of vegetation increased from fall 2009 to spring 2010 in this reach, except for *Sagittaria* which decreased slightly (8.0 m^2 loss). This native plants' ability to establish firm roots in the substrate underscores its importance as habitat in this reach. Bryophytes continued their yearly boom/bust cycle with a more than two-fold increase in areal coverage over winter. Although this reach supports a relatively stable population of aquatic vegetation, its urban setting resulting in channelization makes it vulnerable to flooding events.

The intense rain event in June impacted the Upper Spring Run Reach the most because much of the flow came down Blieder's Creek (where several trailers were washed into the river from a nearby construction site). With the entirety of this reach having cement banks and few flow breaks (due to the river being nearly straight here), almost all of the vegetation was removed by the June 9 flood event. The only remaining vegetation was the well-rooted *Sagittaria*. This was the first time in over a decade that this reach was reduced to a mono-specific vegetation community. Although this species' coverage was reduced over 200 m^2, it was still present in each area where it has been since the inception of the study. Slight variations in this channelized section creating velocity breaks probably contributed to this species holding on during the high-flow. All *Hygrophila*, bryophytes, and *Ludwigia* were displaced during the flood event. While fountain darter density is typically not high in *Sagittaria* due to its simple leaf structure, this native vegetation was likely an important refuge for these fish during and after this flood. In addition, much of this reach seemed to get shallower due to a large amount of gravel being washed into the reach likely from Blieder's Creek and overland flow (a very steep hill characterizes the river-right riparian area in this reach).

By fall, other vegetation began to reestablish in the Upper Spring Run Reach and *Sagittaria* decreased slightly in areal coverage. *Hygrophila* found a small foothold along river left near the bottom of the reach (14.4 m^2), and bryophytes (15.6 m^2) began to establish as flows stabilized. With large sections of this reach absent of vegetation, green algae blooms were common during the summer and early fall months. Algae covered nearly 450 m^2 mostly in the central and lower sections of the reach.

Native plants are an important habitat for fountain darters in the Comal River. The highest densities of fountain darters are found in *Cabomba*, *Ludwigia*, and bryophytes. However, *Cabomba* and *Ludwigia* are no longer present in this reach. Although *Sagittaria* is abundant in this reach and clearly resistant to flood events, it harbors fewer fountain darters than most other native plants. Overall, the non-native *Hygrophila* contains fewer darters than similar native vegetation, but it does appear to be of some importance to fish within the Upper Spring Run Reach. Although native plants appear to be declining in this reach (*Cabomba*, *Ludwigia*), bryophytes continue to provide important fountain darter habitat because of the structure they offer throughout the reach.

Landa Lake Reach

Compared to fall 2009, there was an increase in areal coverage for all species of aquatic vegetation including a four-fold increase in bryophytes when measured in spring 2010. This exceptional bryophyte growth was likely stimulated by constant and higher flow conditions coupled with the spring growing season, again following the typical boom/bust cycle these plants display during the year. Another native vegetation type, *Ludwigia*, remained patchily distributed while increasing slightly from 2009 (17.8 m^2 to 29.0 m^2).

The flood event of June 2010 had minimal impacts on the aquatic vegetation in the Landa Lake Reach. The prevalence of velocity breaks from islands, a wider channel, and more sinuous banks resulted in less scouring of aquatic vegetation and provided lower-velocity refuges for all organisms. Although the western shoreline is characterized by a very steep riparian area (as in the Upper Spring Run Reach), the wide flat golf course along the eastern shoreline allows water to flow overland during a flooding event reducing the impact at Landa Lake. The native plants *Ludwigia*, *Cabomba*, and *Sagittaria* were all reduced after the flood, but were still higher than during the final sampling trip in 2009. The most severe impact occurred to bryophytes because they are not firmly rooted to the substrate like other plants in this reach. Most of this reduction occurred along river-left in the upper portions of the reach where velocities were likely the greatest. However, small patches remained in the river-right areas providing refuges for fountain darters and other organisms. The other area of impact in the Landa Lake Reach occurred where the combined Spring Run 1 and 2 channel enters the lake. High flows significantly damaged the pedestrian bridge (Figure 17), and reduced the coverage of *Vallisneria* in this area. Following the flooding, two small patches of *Ludwigia* established in this arm of the lake which was likely a result of being washed down from larger patches present upstream in Spring Run 1.

Ludwigia, *Cabomba*, and *Sagittaria* all increased in areal coverage from the high-flow event to fall likely aided by reduced flows and longer daylight hours. Bryophytes also increased as patches along the river-right bank that were spared from the flood grew together. Non-native *Hygrophila* also increased in areal coverage from summer to fall (367.1 m^2 to 411.6 m^2), after becoming more patchy post-flood.

As in the Upper Spring Run Reach, native plants are important to the populations of fountain darters found in Landa Lake. Similarly, *Cabomba* and bryophytes yield high numbers of these fish, but unlike the Upper Spring Run Reach *Cabomba* is perennially found in several patches within the lake. These *Cabomba* patches are located in relatively protected areas making their continued presence extremely important as refuges to fishes during high-flow events like June 2010. Bryophytes are also an important habitat for darters, as confirmed by drop net density data. *Vallisneria* is the most common native plant in this reach, but it yields low numbers of fountain darters because of its simple leaf structure. A diverse community of native vegetation in Landa Lake will continue to be invaluable to fountain darter populations in the Comal River.

Figure 17. Damage to a pedestrian bridge at Landa Park, June 2010.

Old Channel Reach

Although the Old Channel Reach is a sinuous stretch of the Comal River, the aquatic vegetation here was also impacted by the high-flow event in June 2010. From 2009 to 2010 there was little change in the overall coverage of aquatic vegetation (1,890.1 m^2 – fall 2009, 1,861.0 m^2– spring 2010), however, *Ludwigia* decreased to below 10 m^2. This important native plant is entirely confined to the shallower upstream end of the reach, and more susceptible to changes in flow. *Hygrophila* remained the dominant vegetation here increasing to 1,587.0 m^2. As in other reaches the vegetation was significantly affected by the high discharge in June (Figure 18). As a result of a debris dam created by the high flows, there was considerable scouring in the middle of the reach resulting in a 2/3 decrease in the total amount of *Hygrophila* (498.1 m^2). *Ludwigia* decreased to less than 2.0 m^2 with only two small stands remaining. Lightly-rooted native vegetation like filamentous algae and bryophytes were displaced from this reach with bryophytes not seen again in 2010. *Ceratopteris* (an introduced plant) was severely denuded and by fall was no longer present in the reach.

As in other reaches in the Comal River, the summer growing season contributed to a recovery in the plant population here with *Hygrophila* and *Ludwigia* continuing to be the most common plants. Filamentous algae also reestablished in this reach (7.0 m^2). The regulated flow in this reach allows a unique opportunity to monitor the interaction between native (filamentous algae, bryophytes, *Ludwigia*, *Nuphar*) and non-native (*Hygrophila*, *Ceratopteris*) plants in a relatively non-flashy channel (compared to the Upper Spring Run and New Channel Reaches). Although the amount of native plants recovered slightly by October 2010, they have still decreased substantially since the inception of this study. Close monitoring is necessary to understand the interactions between native and non-native plants in this reach and how they affect fountain darter populations.

Figure 18. Debris dam created by high-flows in the Old Channel Reach, June 2010.

New Channel Reach

The most vulnerable reach to flood events due its channelized structure and cement banks is the New Channel Reach. Since a high-flow event in 2004 (BIO-WEST 2005) when discharge reached 3,150 cfs in the river, aquatic vegetation has never flourished in this reach. Only *Hygrophila*, *Ludwigia*, *Cabomba*, and bryophytes have managed to gain a foothold in this susceptible section of the river. By spring 2010, vegetation had begun to recover from flows in excess of 4,000 cfs during fall of 2009. *Cabomba* increased to 108.6 m^2 and *Hygrophila* to 113.3 m^2. A patch of *Ludwigia* also managed to grow over winter. However, another high-flow event (7,280 cfs) in June 2010 decimated this reach with a single *Cabomba* stand and *Hygrophila* plant left as the only remaining vegetation. These plants likely survived because of the slight protection from high-velocities due to slight curves in the river bank. After the flooding event only 26.3 m^2 of vegetation remained in the New Channel Reach. This is the lowest areal coverage of aquatic vegetation in this reach since the inception of this study (2000). Dry Comal Creek contributed 3,050 cfs (USGS gage 08168797) just upstream of this reach, and combined with flows in the Comal River, very high velocities were likely present over a short period of time.

By fall, vegetation in the reach began to recover with *Hygrophila* reaching nearly 200 m^2. *Cabomba* also recovered, albeit at a slower pace (51.5 m^2). Interestingly, several patches of *Nuphar* were found along the river-left bank in fall 2010. These had a different growing habit compared to other reaches where it's found (Landa Lake, Old Channel), with all of the terminal leaves several inches to several feet below the water line. Although the total calculated areal coverage was likely overestimated (131.0 m^2 - difficult to map each area because they were so patchily distributed), all plants appeared to be rooted to the substrate. While this may not have much bearing on fountain darter populations (we don't currently sample this vegetation), it may contribute to stabilizing the substrate and enabling other plants to root firmly.

Fountain Darter Sampling Results

Drop Nets

A total of 64 drop net samples were conducted during 2010 in the Comal Springs/River ecosystem. Due to changes in the aquatic vegetation community in some reaches, the number of samples taken from each vegetation type in each reach has been modified several times over the course of the study. For example, filamentous algae were once a dominant vegetation type in the Old Channel Reach, but have been sparse and patchy since 2004. Therefore, filamentous algae were not sampled in 2010. Similarly, the vegetation community in the Upper Spring Run Reach was drastically impacted by high flows from the June 2010 flood event. As a result, modifications were made during the high-flow Critical Period sampling effort in June and during the fall 2010 sampling event. Table 5 shows the number of drop net samples taken from each vegetation type in each reach during 2010 sampling events.

Table 5. Number of drop net samples collected in each vegetation type per reach during 2010 sampling events.

Vegetation Type	Spring			June High-Flow Critical Period			Fall		
	Upper Spring Run	*Landa Lake*	*Old Channel*	*Upper Spring Run*	*Landa Lake*	*Old Channel*	*Upper Spring Run*	*Landa Lake*	*Old Channel*
Filamentous Algae									
Bryophytes	2	2			2			2	
Ludwigia		2	1		2			2	3
Hygrophila	2	2	5		2	4	2	2	3
Sagittaria	2			3			3		
Vallisneria		2			2			2	
Cabomba		2			2			2	
Open				3			1		
TOTAL	**6**	**10**	**6**	**6**	**10**	**4**	**6**	**10**	**6**

The number of fountain darters captured in each drop netting-event in 2010 varied from a high of 655 in spring to a low of 482 in fall. Excluding collections from the New Channel Reach since it is no longer sampled; the number captured during each event over the course of the study has varied from 224 to 901. Figure 19 reflects the number of fountain darters collected in each drop net event overlaid on a hydrograph showing mean daily discharge. Due to the extremely variable nature of the discharge data, discharge-abundance relationships are difficult to discern from this analysis. Additionally, it is important to remember that the number of drop net samples taken in each vegetation type has been modified slightly as vegetation communities have changed throughout the study. However, even across sampling events with exactly equal effort, Figure 19 shows that fountain darter abundance varies considerably. A linear trendline suggests a rather dynamic but stable population throughout the study period with no long-term trend.

Drop net data collected from 2000-2010 show that average densities of fountain darters in the various vegetation types ranged from 3.6/m^2 in *Ceratopteris* to 26.4/m^2 in bryophytes (Figure 20). Open substrate with no aquatic vegetation contains few fountain darters (0.9/ m^2). Native vegetation types which provide thick cover at or near the substrate (i.e., bryophytes and filamentous algae [23.5/ m^2]) tend to have the highest fountain darter densities. Filamentous algae and bryophytes also contain high numbers of amphipods, a common food item for fountain darters. In contrast, exotic vegetation (*Ceratopteris* and *Hygrophila* [7.1/m^2]), and native vegetation with simple leaf structures (*Vallisneria* [5.0/m^2] and *Sagittaria* [4.9/m^2]) which provide little cover near the substrate tend to have fewer darters. In the Comal River, the native vegetation types *Cabomba* and *Ludwigia* exhibit intermediate fountain darter densities (10.4 and 13.4/ m^2, respectively).

Filamentous algae and bryophytes, which provide the best fountain darter habitat, are also the most susceptible to scouring during high-flow events and have shown considerable fluctuation in coverage over the study period. Filamentous algae were once the dominant vegetation type in the Old Channel Reach; however, it has been replaced in recent years by *Hygrophila* and *Ludwigia*. This has resulted in an overall decrease in the abundance of fountain darters in this reach (see dip net data). Bryophytes are a key habitat component because they occupy large areas of the Upper Spring Run and Landa Lake reaches, and thus make up a significant portion of the available habitat. *Cabomba* and *Ludwigia* are also relatively common, and therefore, provide substantial amounts of fountain darter habitat. Although fountain darter densities are relatively low in *Hygrophila*, it is an important habitat component because it is abundant in all sample reaches.

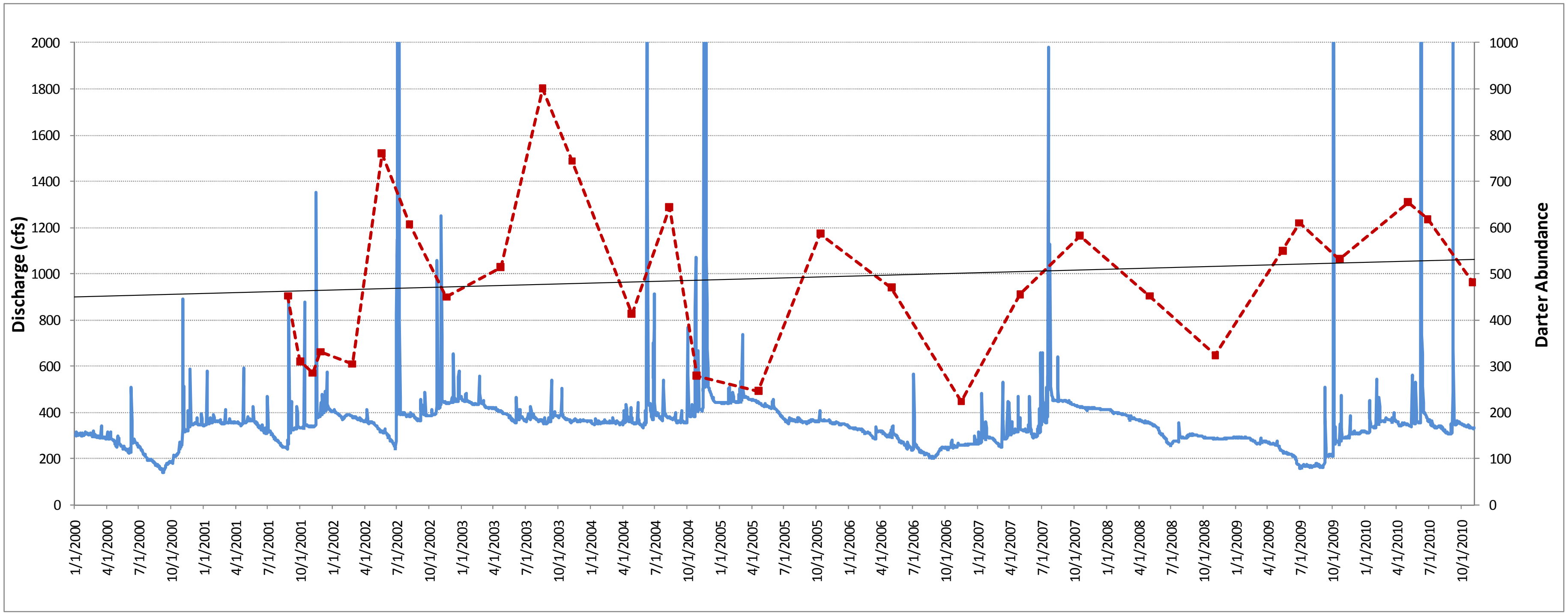


Figure 19. Abundance of fountain darters from each drop net sampling event (red dashed line) plotted over a hydrograph of mean daily discharge from the USGS gage on the Comal River at New Braunfels (blue line).

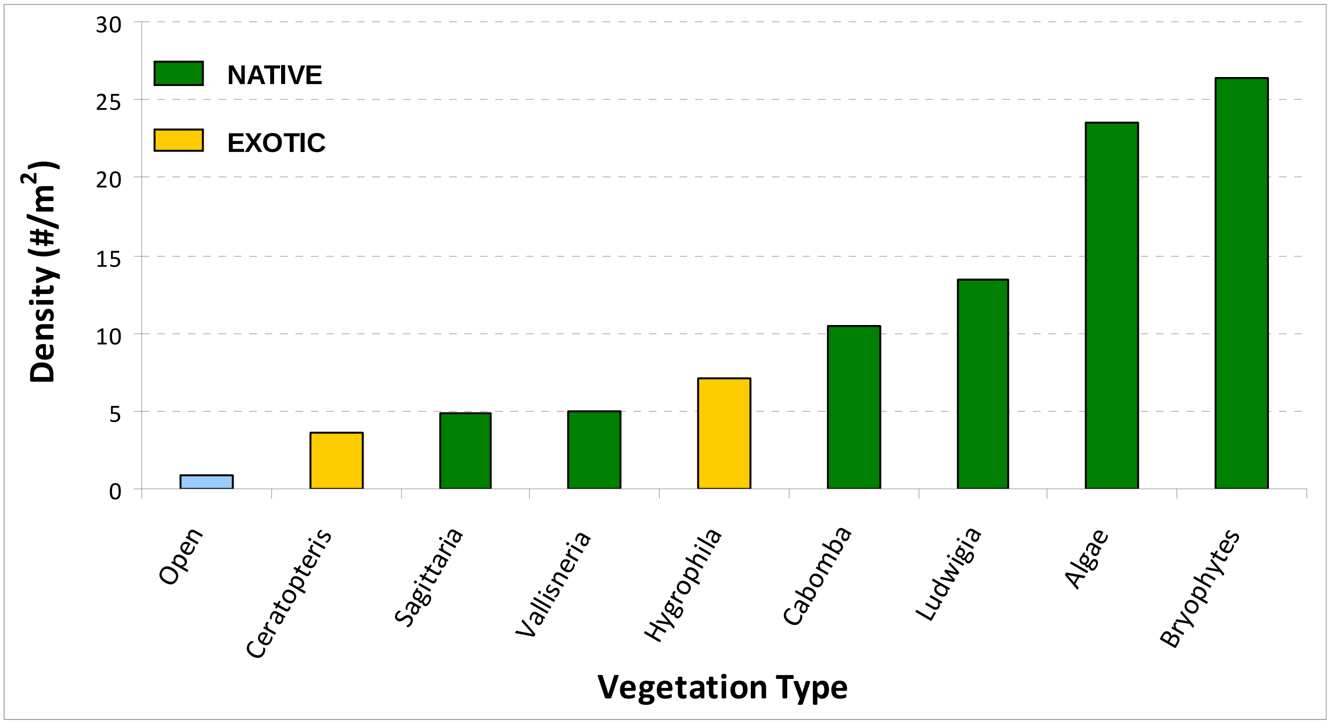


Figure 20. Density of fountain darters collected by vegation type in the Comal Springs/River ecosystem in 2000-2010.

Estimates of fountain darter population abundance in all reaches (Figure 21) were based on the changes in vegetation composition and abundance and the average density of fountain darters found in each, as described in the methods section. The vegetation type that had the greatest influence on these estimates was the bryophytes. This is due to the size of the Landa Lake Reach (where most of the bryophytes were mapped) and the density of fountain darters found there. Thus, as coverage of bryophytes in this reach fluctuate, so do fountain darter population estimates. Estimates of population abundance were highest in spring 2003 when coverage of bryophytes peaked (4,190 m^2) in Landa Lake (Figure 21). Population estimates in fall 2000, winter 2001, and spring 2001 are low because mapping at the time did not include filamentous algae in the Old Channel Reach or bryophytes in the Landa Lake Reach. All high-flow Critical Period samples during the study period showed a decrease in population estimate relative to the previous sample. This is most pronounced in the high-flow Critical Period sample collected in June 2010, which followed the second largest flood event witnessed during the study period. This sample exhibited the lowest overall fountain darter population estimate recorded during the 10 year study. This low population estimate is due to the intense scouring of vegetation in the Upper Spring Run and Old Channel Reach. Flood waters moving down Bleider's Creek resulted in removal of nearly all submerged vegetation in the Upper Spring Run Reach, except for a few small patches of strongly-rooted *Sagittaria* (Appendix A). Intensive scouring also occurred in the Old Channel Reach during this time. The resulting loss of habitat displaced fountain darters which are typically abundant in the bryophytes of the Upper Spring Run Reach, and thus, caused a considerable reduction in the overall population estimate (as calculated by this method). By November 2010, when fall sampling was conducted, the vegetation in the Old Channel Reach had recovered but vegetation in the Upper Spring Run Reach was still extremely limited. Despite this, previous less-intense flood events have shown that the system recovers relatively quickly, and the vegetation in the Upper Spring Run Reach is expected to recover in the coming months.

Drop netting efforts in 2010 resulted in collection of 1,755 fountain darters in the Comal Springs/River ecosystem. The size-class distribution for fountain darters collected by drop nets from the Comal ecosystem during spring and fall 2010 is presented in Figure 22 (all data collected in previous years is presented in Appendix B). As in previous years, small fountain darters are more abundant in the spring sample suggesting a peak in reproduction during this time. However, at least some reproduction seems to occur year-round as evidenced by the presence of a few small darters in fall samples.

In addition to fountain darters, 124,730 specimens representing at least 24 other fish taxa have been collected by drop netting from the Comal Springs/River ecosystem during the study period. Of these, seven are considered exotic or introduced (Table 6). Although several of these species are potential predators of fountain darters, previous data collected during this study suggested that predation by both native and introduced predators is minimal during average discharge conditions. The impact of predation is to be further evaluated under extremely low discharge.

Other potential impacts of exotic fish species include negative effects of herbivorous species such as the armadillo del rio (*Hypostomus plecostomus*) on algae and vegetation communities that serve as fountain darter habitat. Although these fish are rarely captured in drop nets, based on visual observations they are abundant in the system. This species has the potential to affect the vegetation community and thus impact important fountain darter habitats and food supplies.

Another exotic species which has had considerable impact on the vegetation community in the Comal Springs/River ecosystem in the past is the giant ramshorn snail. In the early 1990s, giant ramshorn snails became very dense and caused substantial destruction to the vegetation community and at one time numbered between 2 and 12 million in the Comal Springs/Landa Lake area (Arsuffi 1993).. However, numbers have since declined. Early in the study period giant ramshorn snails were relatively abundant - 142 snails were collected in 2001. However, from 2005 through 2008, no giant ramshorn snails were collected while drop netting in the Comal River. In 2009 and 2010, three snails were collected each year. Although giant ramshorn snail density is down, since this exotic species can have considerable impacts at higher densities, close monitoring of their population will continue.

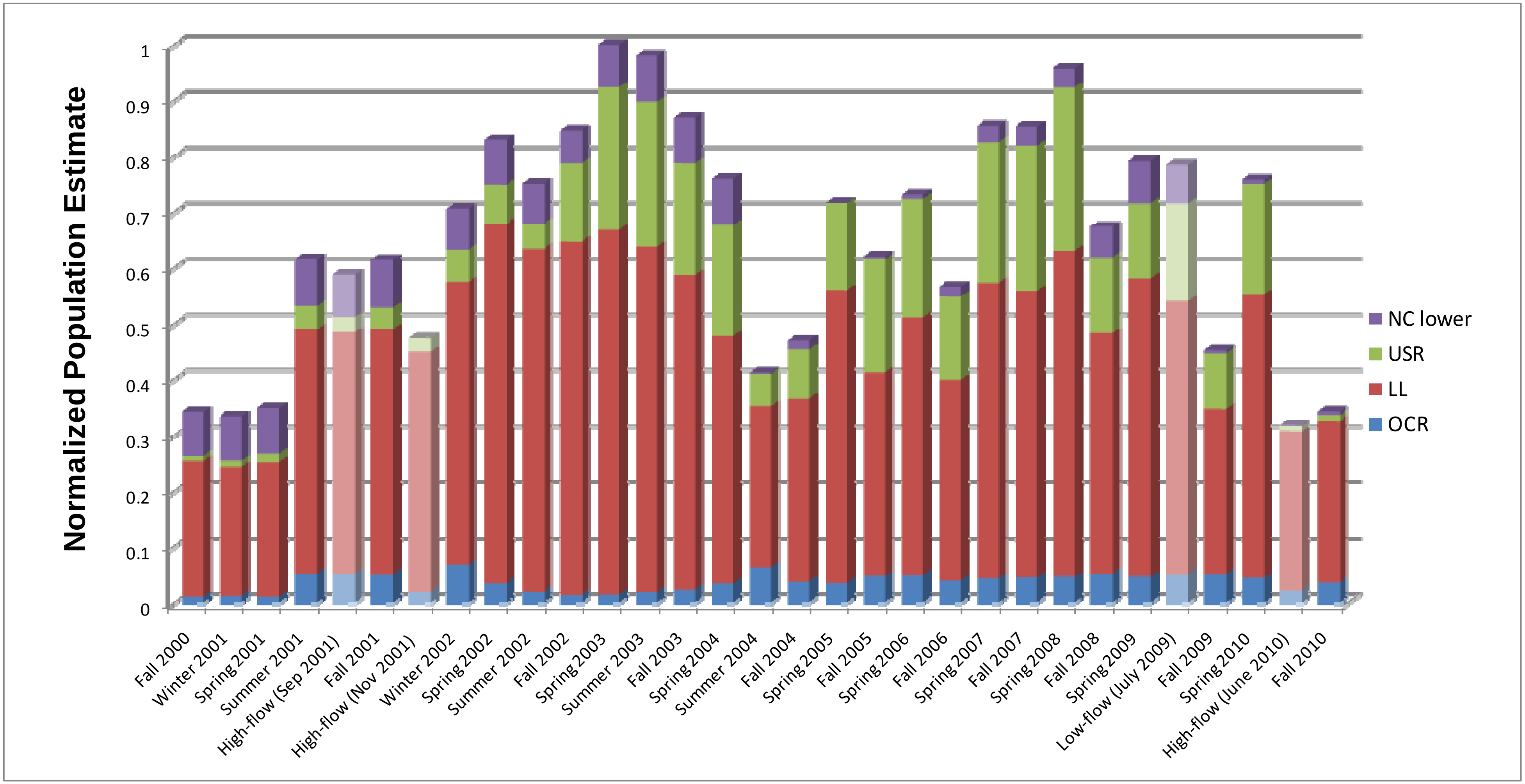
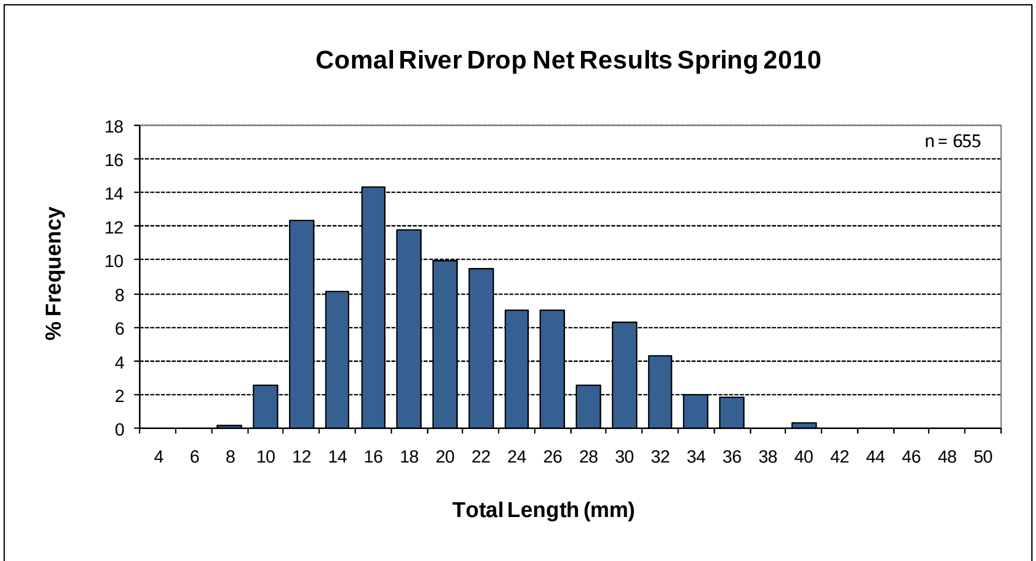
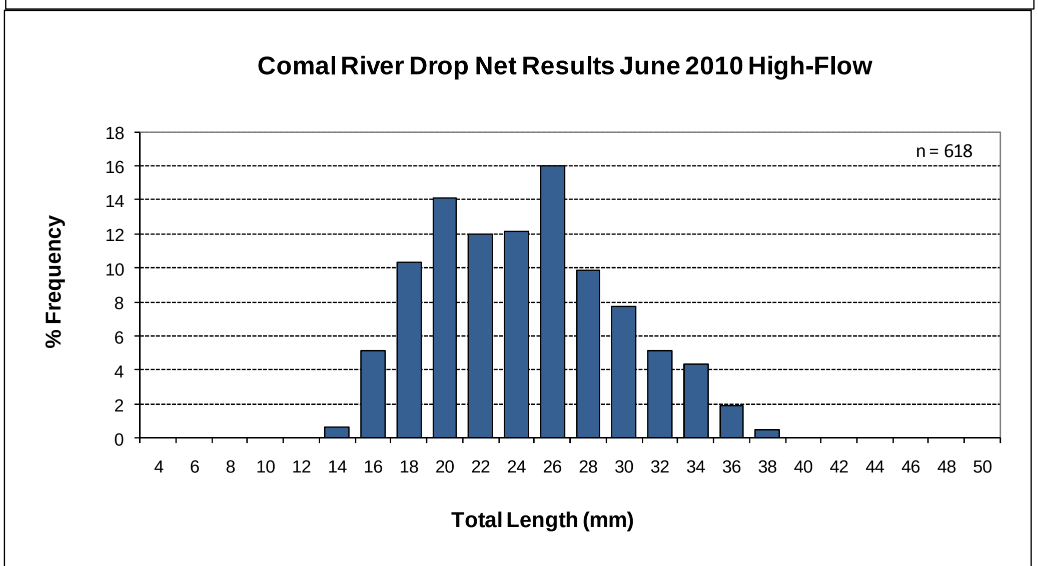


Figure 21. Population estimates of fountain darters in all four sample reaches combined (2000-2010). Values are normalized to the maximum sample. Lighter colors represent critical period sampling events. NC lower – New Channel Lower, USR – Upper Spring Run, LL – Landa Lake, OCR – Old Channel Reach.





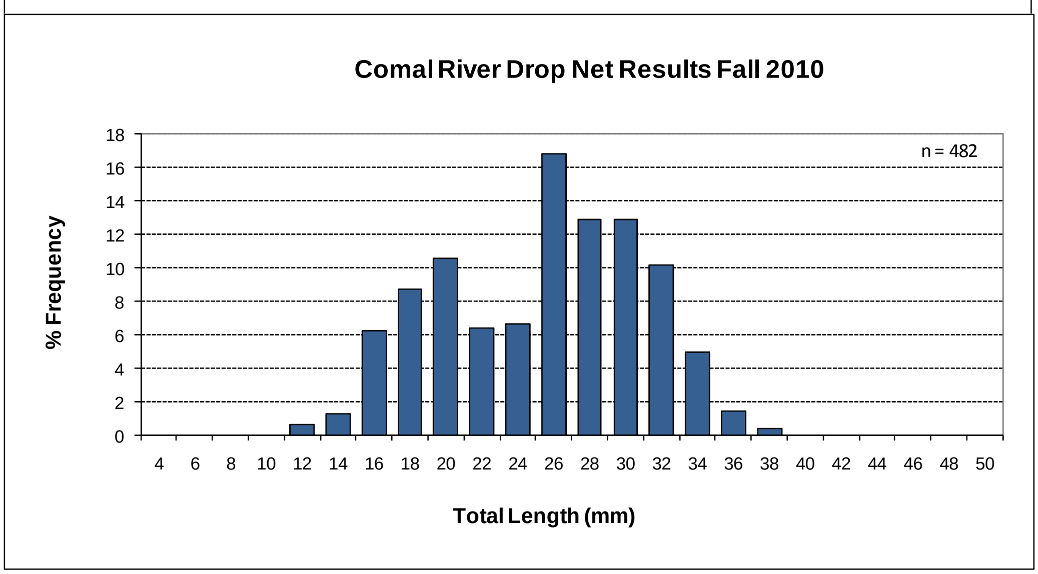


Figure 22. Length frequency distribution of fountain darters collected from the Comal River by drop netting in 2010.

Table 6. Fish taxa and the number of each collected during drop net sampling.

Family	Scientific Name	Common Name	Status	2010	2000-2010
Cyprinidae	*Campostoma anomalum*	Central stoneroller	Native	0	1
	Dionda nigrotaeniata	Guadalupe roundnose minnow	Native	338	842
	Notropis amabilis	Texas shiner	Native	6	217
	Notropis volucellus	Mimic shiner	Native	0	31
	Pimephales vigilax	Bullhead minnow	Native	0	4
Characidae	*Astyanax mexicanus*	Mexican tetra	Introduced	12	385
Ictaluridae	*Ameiurus melas*	Black bullhead	Native	0	1
	Ameiurus natalis	Yellow bullhead	Native	6	105
Loricariidae	*Hypostomus plecostomus*	Armadillo del rio	Introduced	1	57
Poeciliidae	*Gambusia* sp.	Mosquitofish	Native	7,861	114,605
	Poecilia latipinna	Sailfin molly	Introduced	132	4,561
Centrarchidae	*Ambloplites rupestris*	Rock bass	Introduced	0	24
	Lepomis auritus	Redbreast sunfish	Introduced	0	136
	Lepomis cyanellus	Green sunfish	Native	0	10
	Lepomis gulosus	Warmouth	Native	0	32
	Lepomis macrochirus	Bluegill	Native	0	213
	Lepomis megalotis	Longear sunfish	Native	0	250
	Lepomis microlophus	Redear sunfish	Native	0	2
	Lepomis miniatus	Redspotted sunfish	Native	196	1,695
	Lepomis sp.	Sunfish	Native/Introduced	9	726
	Micropterus punctulatus	Spotted bass	Native	0	3
	Micropterus salmoides	Largemouth bass	Native	12	140
Percidae	*Etheostoma fonticola*	Fountain darter	Native	1,755	15,351
	Etheostoma lepidum	Greenthroat darter	Native	1	36
Cichlidae	*Cichlasoma cyanoguttatum*	Rio Grande cichlid	Introduced	51	605
	Oreochromis aureus	Blue tilapia	Introduced	0	49
Total				10,380	140,081

Dip Nets

Data gathered using dip nets are graphically represented in Figure 23 for the Old Channel Reach and in Appendix B for all other reaches. The boundaries for each section of the dip net collection efforts are depicted in Figure 24.

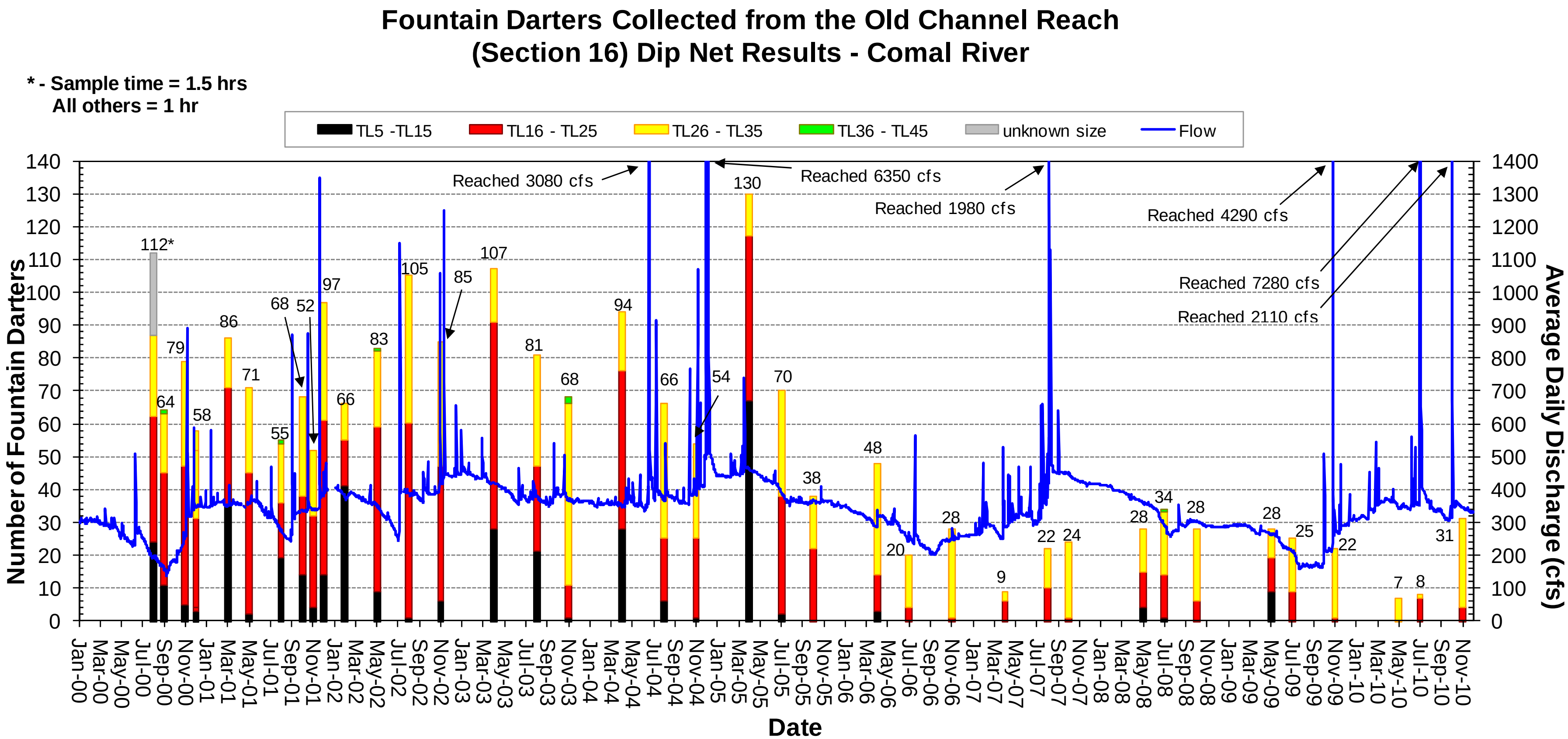


Figure 23. Number of fountain darters, by sample date and size class, collected from the Old Channel Reach (section 16) using dip nets.

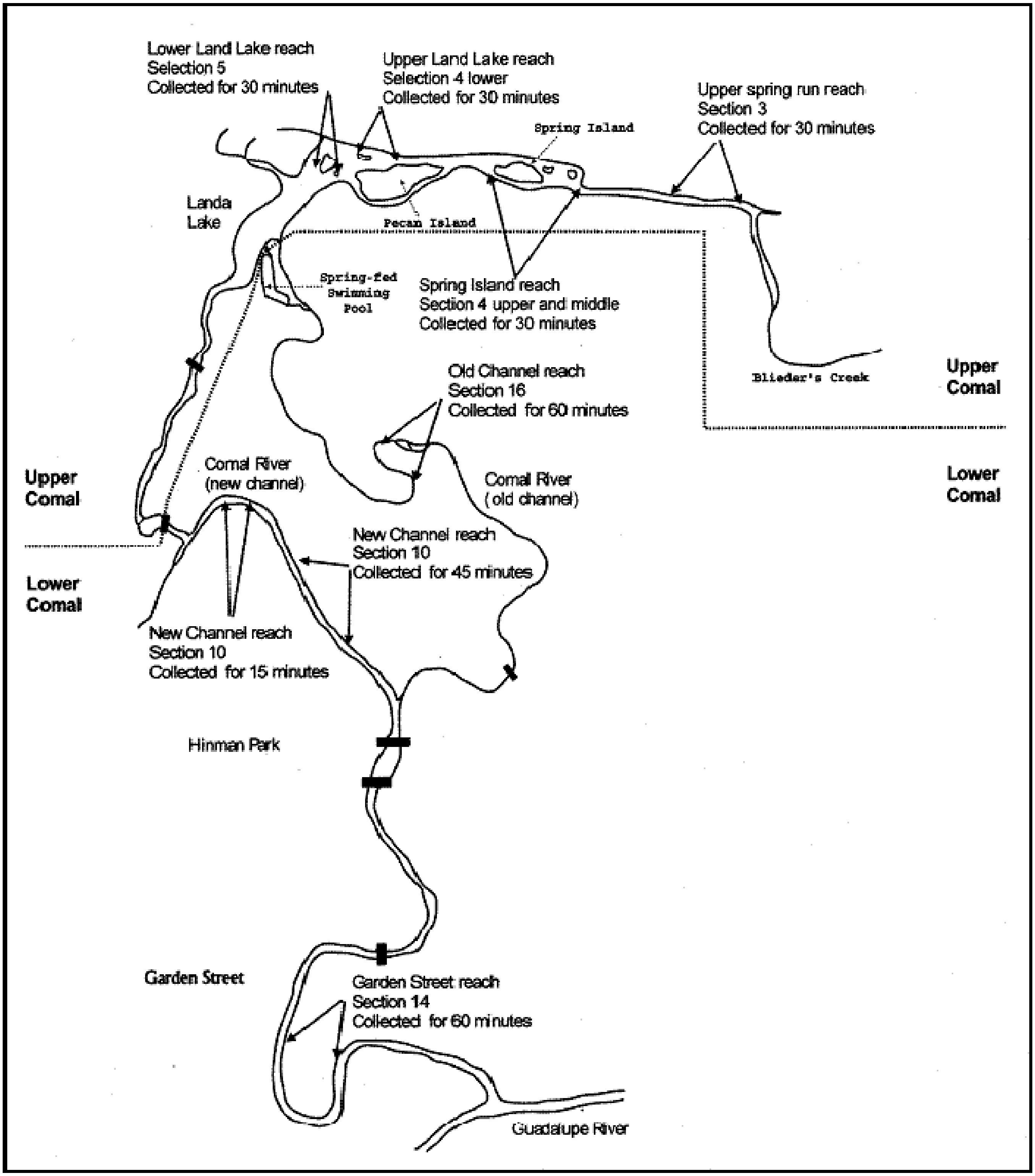


Figure 24. Areas where fountain darter were collected with dip nets, measured, and released in the Comal River.

Figure 23 provides a good example of how changes in vegetation community can affect fountain darter population dynamics. In 2005 the vegetation community of the Old Channel Reach switched from having a good amount of high-quality filamentous algae to one dominated by *Hygrophila*. This switch resulted in a corresponding change in the fountain darter population. Before 2005, the number of darters collected per sample ranged from 54 to 130 and all samples contained small darters (<15 mm) indicating year-round reproduction. Since this change in vegetation, total number of darters per sample has ranged from 9 to 48 and small darters are typically only collected in spring months. However, prior to the June 2010 flood event, bryophytes had begun to establish in the Old Channel. If bryophytes become widespread in the Old Channel, it would likely lead to a rebound in the number of fountain darters collected in this reach.

Overall, size class distributions of fountain darters from dip netting correlate well with those of drop netting: small fountain darters most abundant in the spring, and larger darters dominating fall samples (Appendix B). However, small fountain darters are occasionally captured in summer, winter, and fall sample periods as well. This indicates that there is some reproduction occurring year-round, although perhaps on a limited basis and only in areas like Landa Lake and Spring Island. These areas which exhibit year-round reproduction are relatively close to spring upwellings and contain large amounts of filamentous algae and bryophytes, which provide high-quality fountain darter habitat according to drop net density estimates.

Variability in the total number of fountain darters collected by dip netting makes any inference into overall population trends difficult with this method. However, noticeable changes in numbers and size distributions of fountain darters have been observed in several sample reaches and are well correlated with changes in the vegetation community. For example, there was a substantial increase in the number of darters collected from the Upper Spring Run Reach in 2003 which corresponded with an increase in bryophytes in this reach at approximately the same time. Similarly, vegetation shifts in the Old Channel Reach described above seem to have resulted in a decrease in the overall numbers of darters collected there since summer 2005.

Presence/Absence Dip Netting

In 2010, presence/absence dip netting was conducted on the Comal River during the typical spring (May 6) and fall (October 29) sampling events, as well as one high-flow Critical Period sampling effort in the summer (June 24). The percentage of sites with fountain darters during 2010 varied from 76% in May to 62% in October (Figure 25). This is up slightly from values observed in fall 2008 through fall 2009 (52-58%), but is similar to data collected from fall 2005 to spring 2008 (60-70%).

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 provides a good baseline for comparison in future critical period events.

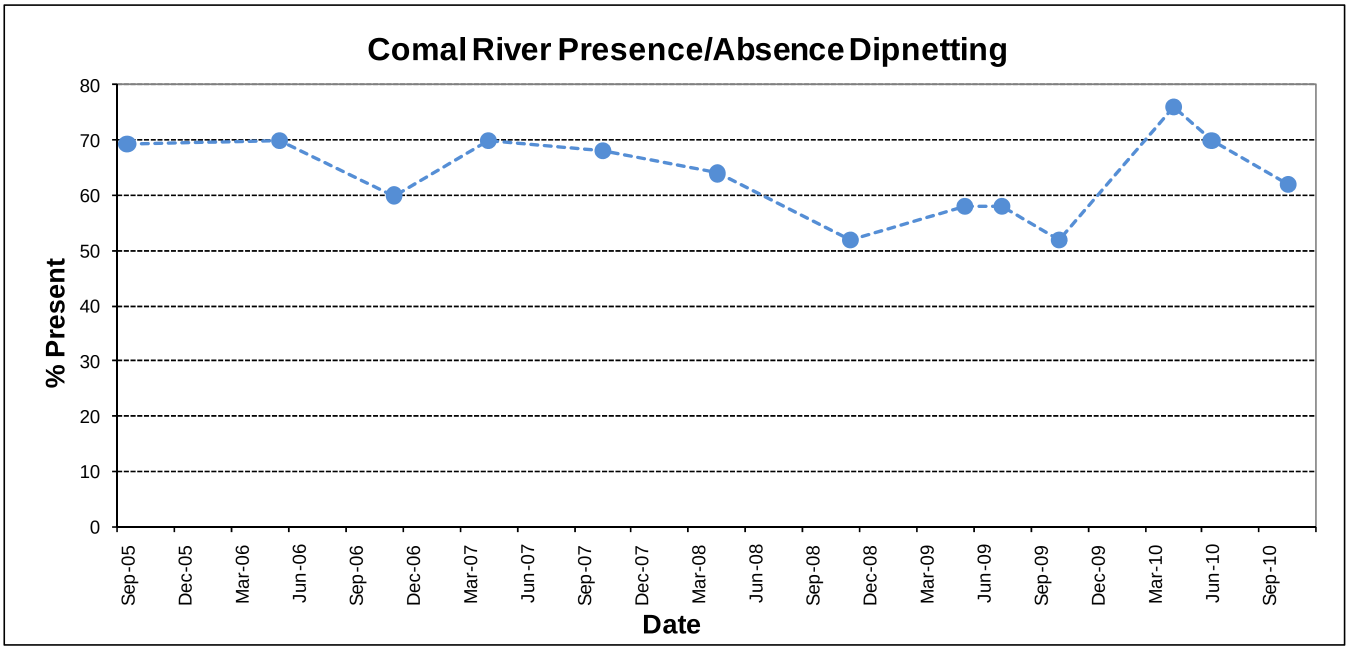


Figure 25. Percentage of sites (N = 50) in which fountain darters were present during 2005-2010.

Visual Observations

Fountain darters were observed in the deepest portions of Landa Lake (depths greater than 2 m) during each sampling event in 2010. This is consistent with each SCUBA sampling effort in Landa Lake conducted since the adoption of this methodology in summer 2001. Excluding the 2002 and 2004 high-flow sampling events, average vegetation coverage in the sample grid has been approximately 75% with an average of approximately 50 darters per sample. The spring 2010 sample effort was consistent with those averages. During the June 2010 flood, the designated sample area was completely denuded of all vegetation and considerable sedimentation was observed along the western shoreline and deeper areas of the lake, presumably washed in from upstream and from the adjacent hillside. Over the past decade of SCUBA sampling, this was the most severe disturbance observed in this area. Subsequently, there was no aquatic vegetation in the sample grid and only 2 darters were counted within the sample grid on open substrate during that sample event. In comparison, following the 2002 flood event, aquatic vegetation was reduced to 40% and 21 darters observed, and following the 2004 flood event, aquatic vegetation was reduced to 15% with 12 darters observed. During the fall 2010 sampling, aquatic vegetation including bryophytes was recovering slowly in this reach (20% coverage within sample grid) and darter abundances also appeared to be rebounding (22 darters within sample grid).

Gill Parasite Evaluations

During each drop netting and dip netting effort, fountain darter gills are visually examined for gill parasite load. In 2009/2010, a special study was conducted to 1) evaluate gill parasite concentrations in the water column following an extended drought, and 2) to compare back to a similar study completed in 2006/2007 to evaluate gill parasite trends in the Comal system over time. For comparison purposes, the first sampling period occurred from June 2006 to June 2007, during which samples were collected every two weeks (Bolick 2007). The second period of sampling occurred between July 2009 and July 2010 during which samples were collected every two weeks for the first three months and then monthly thereafter. The sampling frequency was reduced to monthly because by October 2009 drought conditions had subsided and regional precipitation had returned to near-normal conditions.

In general, during both sample periods, the most upstream site (HS) had the lowest densities of the parasite, while the most downstream site (EA) had the highest (Figure 3). One-way ANOVA test determined that significant differences ($p < 0.05$) exist between the cercarial densities of all three sites during both sampling periods. Additionally, a significant decline from July 2006 to July 2010 was observed in the Comal River. In all cases, differences between cercerial densities were significantly less during the 2009/2010 sample period. None of the abiotic factors measured in the study (temperature, DO, pH) correlated with changes in cercarial densities between July 2006 (Bolick 2007) and July 2010. Although the Comal River experienced several flooding events during this study, it is unlikely that they caused the overall decline of cercarial density. Individual sites show temporary declines in cercarial density after floods, but densities rebound relatively quickly following each event. It is speculated that the observed decline in population followed a period of exponential growth, which Sakai et al. (2001) indicates as common for invasive species after they spread into new habitats. Following its introduction to Texas in the 1960's, *Melanoides tuberculata* could have potentially experienced a period of exponential population growth as it spread into suitable habitats throughout the Comal River. By the time the parasite was introduced in the 1980's, it had an existing snail population to infect which aided in its invasion of the system. *Centrocestus formosanus* potentially then displayed the same population growth pattern observed in other invasive species, leading to high levels of *C. formosanus* cercariae. When researchers first observed the parasite infecting the gill tissues of the fountain darter (Mitchell et al. 2000), it is possible that C. *formosanus* was either approaching or at its peak, and the parasite has been in slow decline since this time. Unfortunately, there are no parasite monitoring data available from 1996 to 2006, so it is impossible to verify the potential changes in population growth during that period. Although cercarial densities may be abating, *C. formosanus* still poses a real threat to fountain darters in the Comal River. As such, continued monitoring is essential along with targeted conservation efforts focused on reducing levels of infection pressure from the parasite where possible.

Comal Springs Salamander Visual Observations

Total salamanders counted in areas sampled was 72 during May 2010, the highest count since this study began in 2001 (Table 7). Most were observed in Spring Run 1 because of large areal coverage of bryophytes (88% of salamanders observed were found in these mosses). The Spring Island Spring Run and East Outfall continued to yield low numbers of salamanders due to reduced optimal habitat conditions in these areas. The high-flow event in June resulted in increased sedimentation at all sites, and subsequently the number of salamander observations decreased at all sites except the Spring Island East Outfall. Movement of sediment could be seen at each site following the flood event (Figure 26). At Spring Runs 1 and 3, the increased sedimentation from smaller diameter substrate (i.e. sand/silt) filled interstitial spaces leaving less space for salamanders to find refuge. This led to a 23% decrease of salamanders at Spring Run 1 (where few bryophytes persisted), and a 56% decrease at Spring Run 3. Unlike these two sites, the East Outfall population increased by 6 salamanders. Although sedimentation occurred here too, it may be the flushing of green algae covering the rocks that led to an increase in the number of observations.

As 2010 continued, constant flows in the springs and the river contributed to pushing much of the fine sediment out of these reaches leaving more optimal habitat for salamanders. Numbers increased at Spring Run 1 with 93% of observations occurring where bryophytes were present. Fewer than half as many salamanders were observed in fall compared to summer at the East Outfall, exemplifying the variability present at this site throughout the study. Results from the June flood event and subsequent recovery period reconfirm the importance of sediment free interstitial spaces and bryophytes as key habitat components for the Comal Springs salamander.

Table 7. Total number of Comal Springs salamanders observed at each survey site during 2001 – 2010.

SAMPLE PERIOD	SPRING RUN 1	SPRING RUN 3	SPRING ISLAND SPRING RUN	SPRING ISLAND EAST OUTFALL	TOTAL BY SAMPLE
Spring 2001	20	7	17	6	55
Summer 2001	23	15	4	4	46
High-flow 1 2001	31	12	1	6	50
Fall 2001	11	8	13	7	39
High-flow 2 2001	18	2	6	5	31
Winter 2002	18	9	7	3	53
Spring 2002	10	15	6	5	62
High Flow 2002	18	7	3	16	67
Fall 2002	20	10	8	9	47
Spring 2003	20	21	6	13	60
Summer 2003	25	10	3	13	51
Fall 2003	31	10	3	19	63
Spring 2004	36	14	7	12	69
Summer 2004	27	14	4	14	59
Fall 2004	20	2	2	35	59
Spring 2005	18	10	2	11	41
Fall 2005	22	7	0	16	45
Spring 2006	12	13	2	8	35
Fall 2006	14	11	2	29	56
Spring 2007	15	10	2	23	50
Fall 2007	18	13	0	11	42
Spring 2008	27	28	0	6	61
Fall 2008	26	19	0	6	51
Spring 2009	32	26	1	12	71
Low-flow 2009	35	26	0	10	71
Fall 2009	37	9	0	4	50
Spring 2010	52	18	1	1	72
High-flow 2010	40	8	0	7	55
Fall 2010	44	7	1	3	55
Average	**20.7**	**12.2**	**4.3**	**10.4**	**47.6**

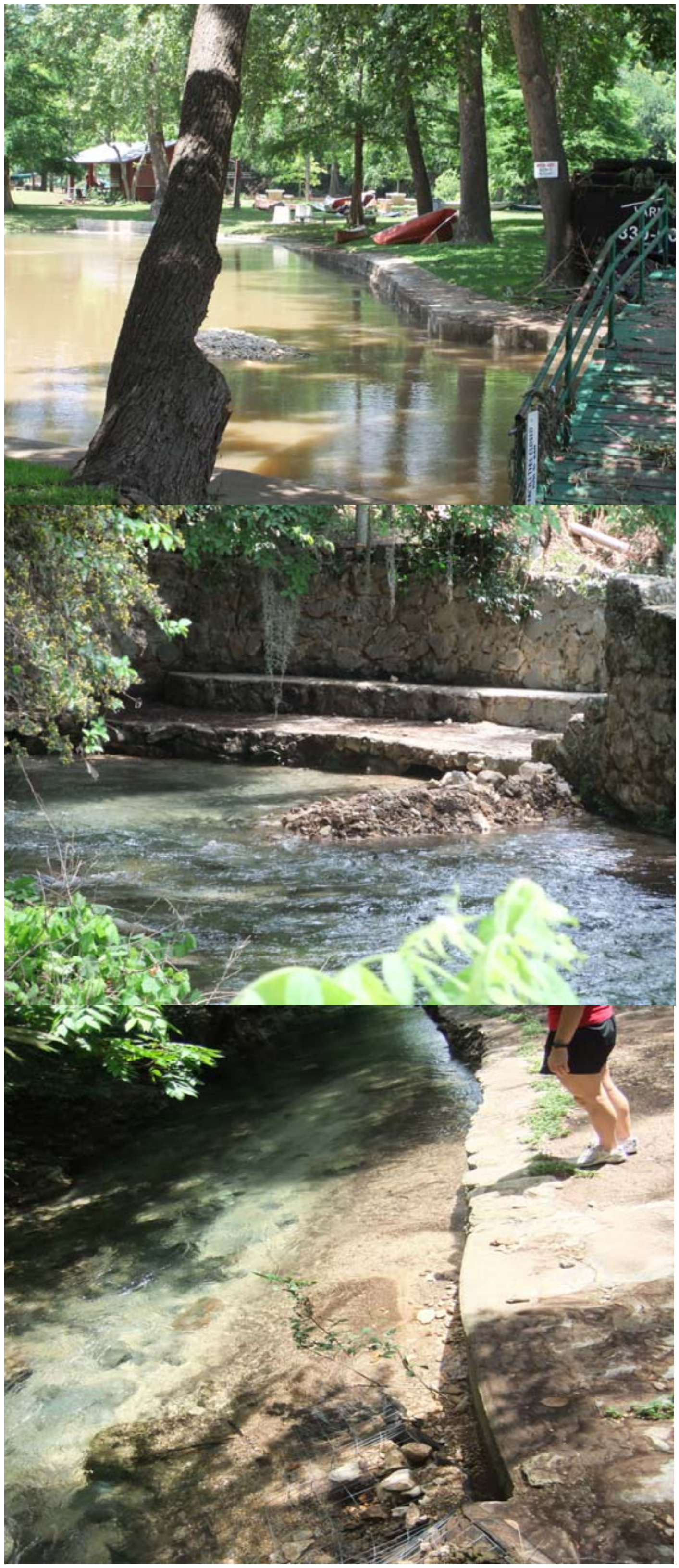


Figure 26. Increased sedimentation following the June 2010 flood event at Spring Island (top), Spring Run 1 (middle), and Spring Run 3 (bottom).

Macroinvertebrate Sampling

In 2010, drift net sampling around spring openings and regular monitoring of Comal Springs riffle beetles were conducted in several locations to assess habitat requirements and population dynamics of the federally listed invertebrate species. Due to the shifting of substrate after the June 2010 flood, a new sampling site was added just downstream of the confluence of Spring Runs 1 and 2 in Landa Park. The fall sampling effort reflects these additional data. It should also be noted that several of the lures at Spring Run 3, the western shoreline of Landa Lake, and most at Spring Island were washed away during the June flood affecting the total numbers of organisms found in the May/June sampling effort.

Drift Net Sampling

At least 14 taxa were captured from 144 hours of sample time at the three drift net sites in Comal Springs during 2010 (Table 8). Table 9 displays the physico-chemical data collected at these sites during sampling. Total numbers of Peck's cave amphipods continued to increase totaling 119 in 2010. The bulk of the population is located at the spring upwellings along the western shore of Landa Lake. The 16 individuals observed in Spring Run 3 are the most since 2008 (BIO-WEST 2009a). Another undescribed amphipod was captured in 2010 (*Ingolfiella* sp.), bringing the total to 3 undescribed amphipod species that have been caught from Comal Springs during this study. *Ingolfiella* sp. was also recently recorded in springs along the Devil's River. Most amphipods caught in this study were only a few millimeters long, which suggests that smaller individuals may be more susceptible to expulsion from the aquifer. Those individuals that were too small to identify to species were recorded as *Stygobromus* sp. and most likely consisted of both *S. russelli* and *S. pecki*.

As in the past two years, a troglobitic (cave-dwelling) flatworm was collected alive and transferred to Texas State University for description. There is only one described blind flatworm recorded in Texas, *Sphalloplana mohri* from caves and wells in Hays, Kendall, Mason, San Saba, and Travis Counties, and one undescribed, *Phagocata* sp. from the hyporheos of Hondo Creek in Medina County.

Table 8. Total numbers of troglobitic and endangered species collected in drift nets during May and November, 2010. Federally endangered species are designated with (E). A = adult beetles. L = larvae, P = probable pupae.

	Run 1	Run 3	Upwelling	Total
Total Drift Net Time (hrs)	48	48	48	144
Crustaceans				
Amphipoda				
Crangonyctidae				
Stygobromus pecki (E)	19	16	84	119
Stygobromus russelli	1	1	1	3
Stygobromus spp.	104	170	501	775
All *Stygobromus*	124	187	586	897
Hadziidae				
Mexiweckelia hardeni	17	14	2	33
Sebidae				
Seborgia relicta	7	9	2	18
Bogidiellidae				
Artesia subterranea				
Parabogidiella n. sp				
Ingolfiellidae				
Ingolfiella n. sp		1		1
Isopoda				
Asellidae				
Lirceolus (2spp.)	49	37	19	105
Cirolanidae				
Cirolanides texensis		1	1	2
Arachnids				
Hydrachnoidea				
Hydryphantidae				
Almuerzothyas n. sp	30	1		31
Insects				
Coleoptera				
Dytiscidae				
Comaldessus stygius		15 A	1 A	16
Haideoporus texanus	1 A	1 A		2
Dryopidae				
Stygoparnus comalensis	5 (1L, 1P)	1 L		6
Elmidae				
Heterelmis comalensis	1 P	1 L		2

Table 9. Results of water quality measurements conducted in 2010 during drift net sampling efforts at Comal Springs.

	Spring Run 1		Spring Run 3		West Shore Upwelling	
Date	June	Nov	June	Nov	June	Nov
Temperature (°C)	23.1	22.8	23.3	23.0	23.7	23.4
Conductivity (mS)	0.572	0.565	0.6	0.566	0.565	0.564
pH	6.8	7.4	6.8	7.4	6.9	7.5
Dissolved Oxygen (mg/L)	5.0	5.9	4.9	5.8	5.0	5.6
Current Velocity (m/s)	1.5	0.4	1.1	0.3	1.0	0.2

Near the headwaters of Spring Run 3, shifting and scouring of sediment along the spring wall (river-right) opened up several new springs. They were 0.3 ºC warmer than the spring at the headwaters of the spring run. As in previous years, water quality variables remained relatively constant at all sites in 2010, indicating a stable environment for the organisms at the observed discharges.

Comal Springs Riffle Beetle

Comal Springs riffle beetle sampling conducted as part of this study provides basic information on the population dynamics and distribution of the species among sample sites. The higher flows and flood event in 2010 did not appear to negatively affect total numbers of beetles (849, Table 10), which was a 10% increase from 2009 (762). The low number of riffle beetles (20) at Spring Island in spring was because of the flood washing away 7 of the 10 rags at this site. A large area upstream of the island was buried under approximately 6 inches to 2 feet of gravel presumably washed in from Blieder's Creek. Only one of the 5 lures (rags) that were used to sample this area collected *Heterelmis* and this lure was on the edge of the gravel cover and not greatly changed. By November, this population was close to what it has been in previous years. In November, a total of 298 beetles were found in Spring Run 3 of which 87% were adults. This is the largest total for any one sampling effort since the study began.

As in previous years, beetles tended to be patchily distributed with wide ranges of abundance between sites and seasons. Therefore, temporal patterns in overall abundance of Comal Springs riffle beetles are extremely variable (Figure 27). Since sampling with cotton lures began, the number of Comal Springs riffle beetles has varied between 293 and 666 per sample period. Densities ranged from 7 to 28 beetles per rag. The low densities in May/June 2010 are likely a result of a lower sample size because of the rags washed away in the flood. Although this limited amount of data does not allow for detailed analysis of population trends at this time, it will provide critical baseline data for comparison to that collected during potential critical periods in the future.

Table 10. Total number of Comal Springs riffle beetles (*Heterelmis comalensis*) collected with cotton lures (adults and larvae) for each sampling date from 2004 – 2010.

Sample Period	Spring Run 3	Western Shore	Spring Island	Total
May-June 2004	88	83	122	**293**
August 2004	169	143	90	**402**
Nov-Dec 2004	170	175	146	**491**
April 2005	119	121	121	**361**
Nov-Dec 2005	262	201	185	**648**
May-June 2006	256	195	160	**611**
Nov-Dec 2006	185	92	125	**402**
May-June 2007	59	161	119	**339**
Nov-Dec 2007	204	83	132	**419**
May-June 2008	155	139	156	**450**
Nov-Dec 2008	144	133	227	**504**
May-June 2009	136	226	74	**436**
Nov-Dec 2009	72	56	198	**326**
May-June 2010	53	110	20	**183**
Nov-Dec 2010	298	264	104	**666**
Total	**2,370**	**2,182**	**1,979**	**6,531**
Average	158.0	145.5	131.9	458.3

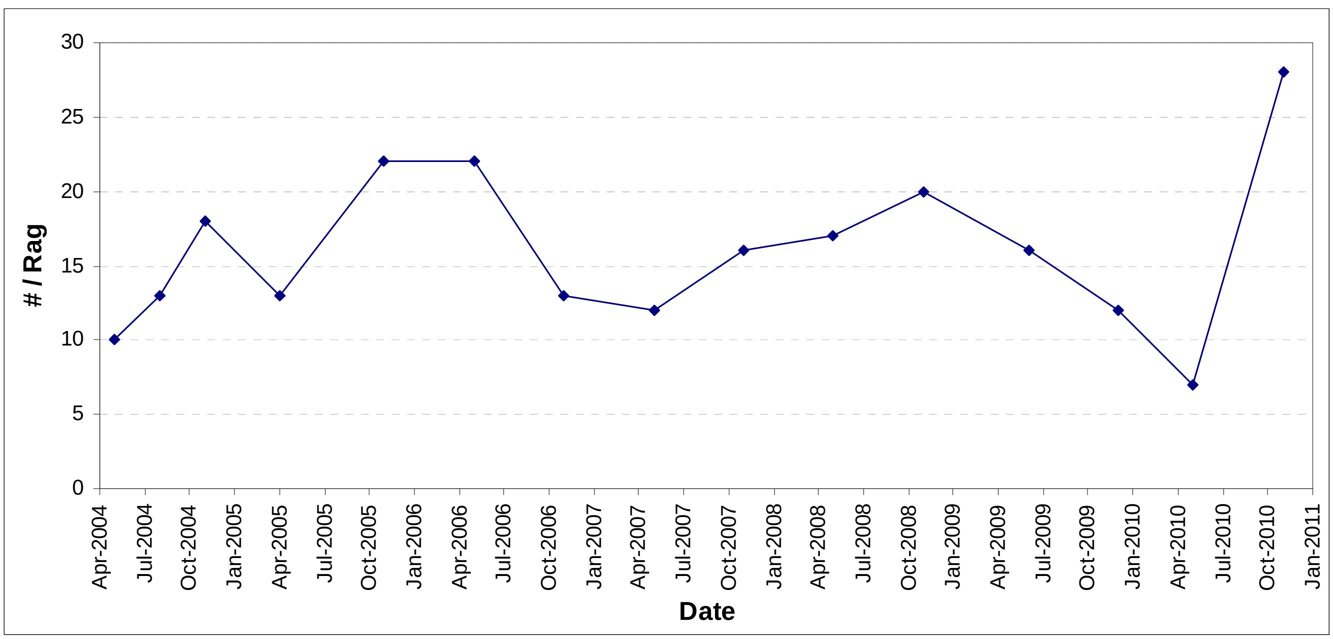


Figure 27. Combined density (#/cotton lure) of Comal Springs riffle beetles (*Heterelmis comalensis*) for each sampling date from 2004 – 2010.

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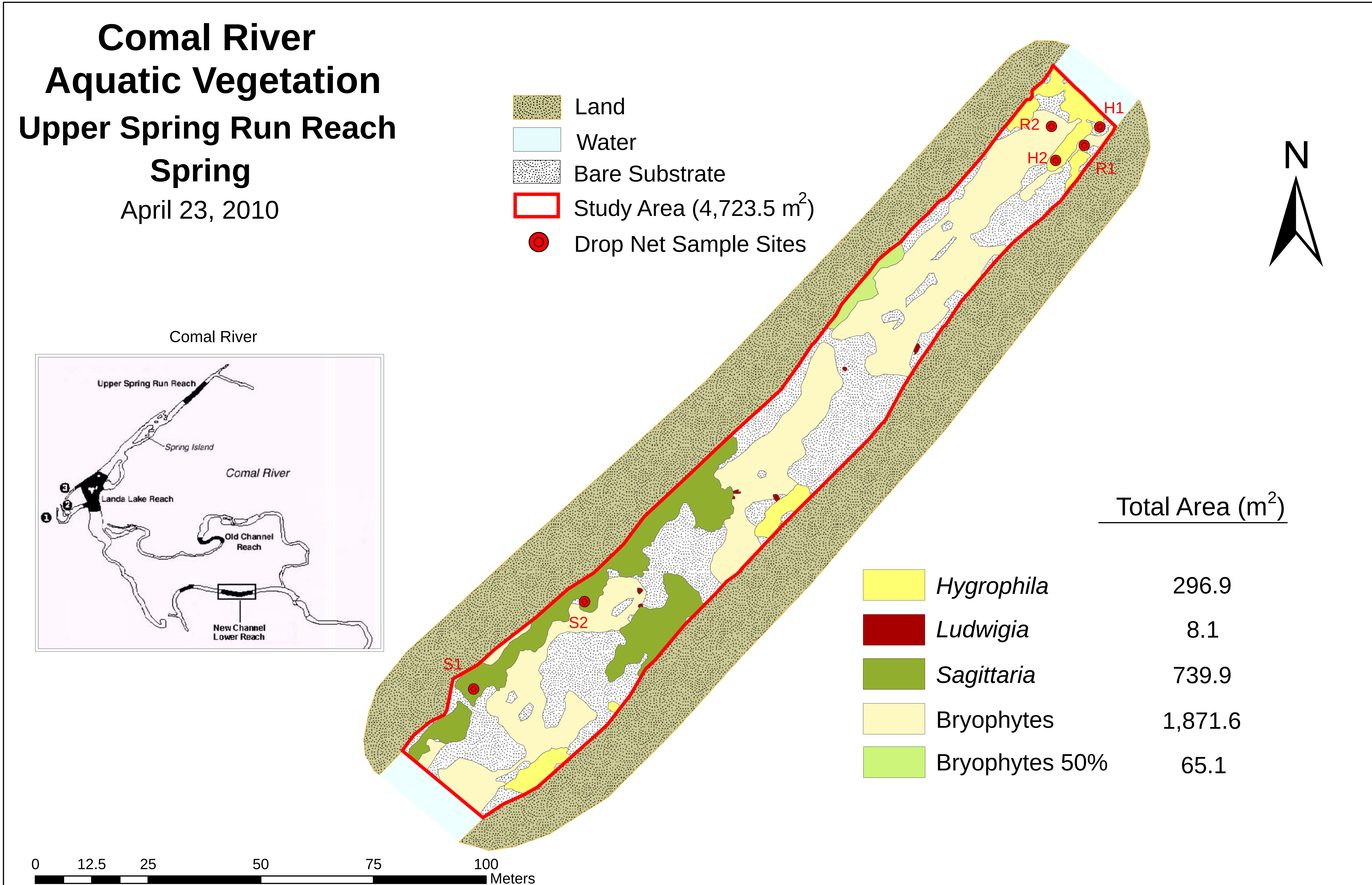
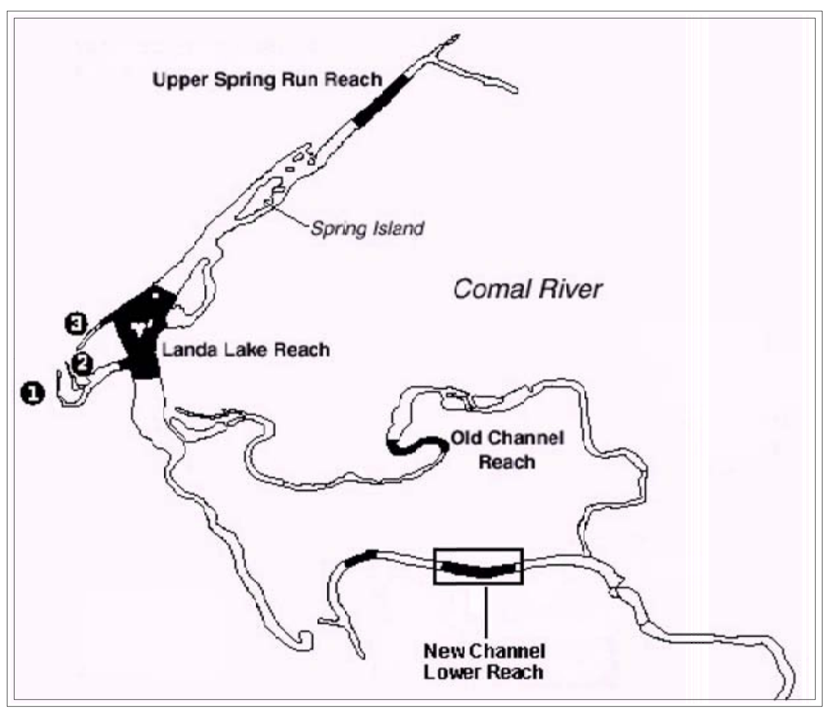
APPENDIX A:
AQUATIC VEGETATION MAPS

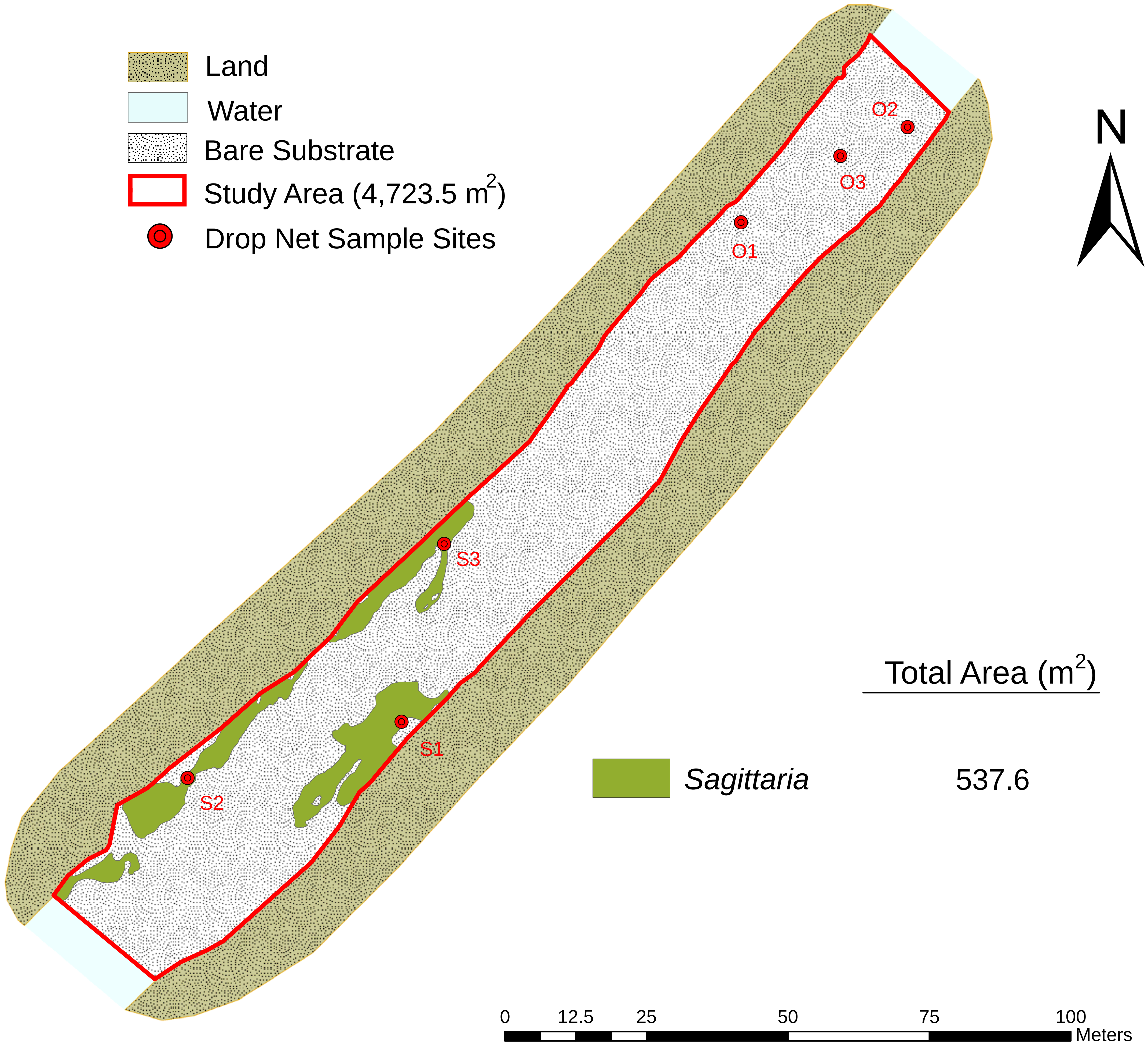
Upper Spring Run Reach


Comal River
Aquatic Vegetation
Upper Spring Run Reach
Spring
April 23, 2010
Land
Water
Bare Substrate
Study Area (4,723.5 m2)
Drop Net Sample Sites
H1
R2
H2
R1
S2
S1
N
Comal River
Upper Spring Run Reach
Spring Island
Comal River
Landa Lake Reach
Old Channel Reach
New Channel Lower Reach
Total Area (m2)
Hygrophila 296.9
Ludwigia 8.1
Sagittaria 739.9
Bryophytes 1,871.6
Bryophytes 50% 65.1
0 12.5 25 50 75 100
Meters

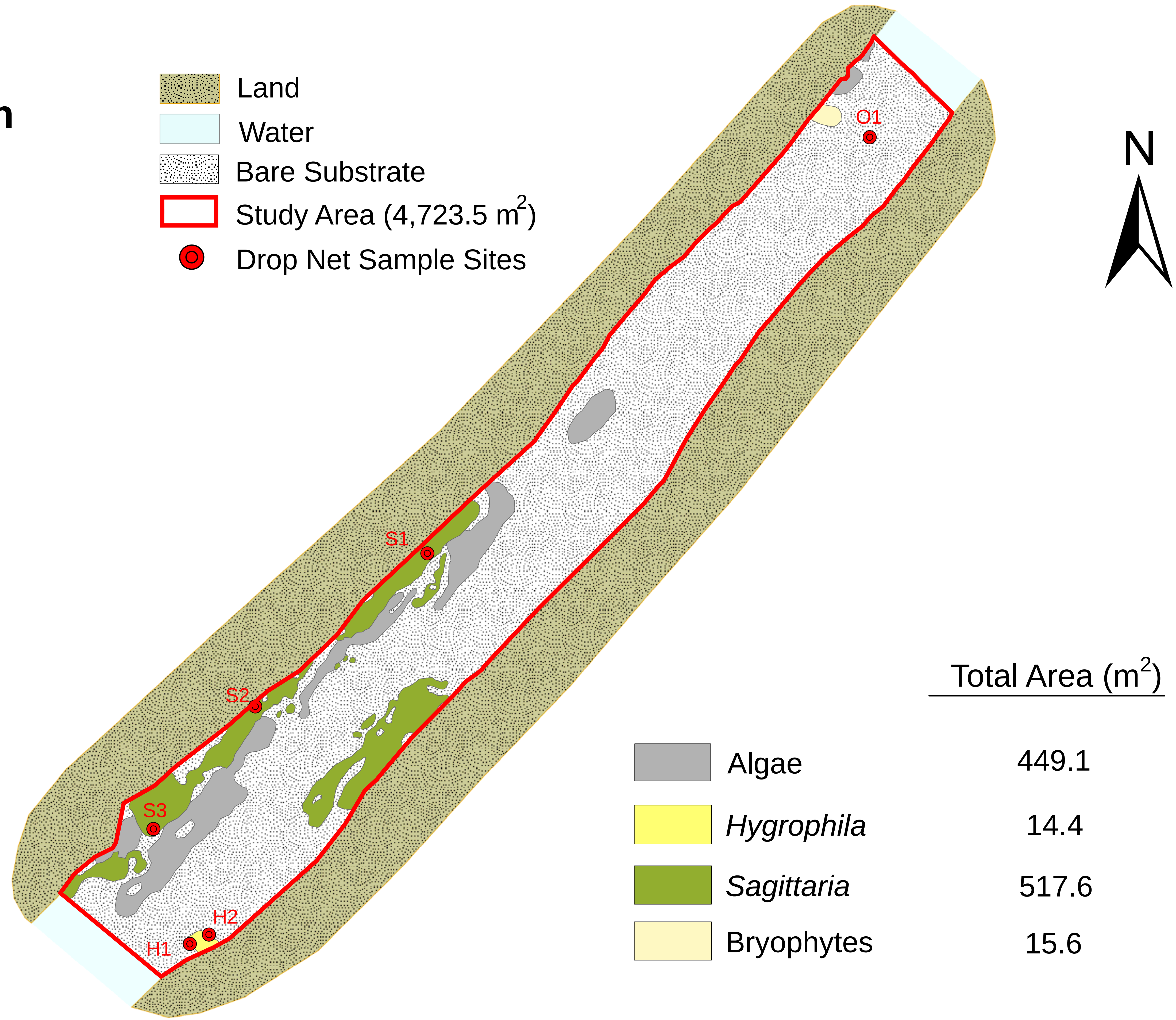
Comal River
Aquatic Vegetation
Upper Spring Run Reach
Critical Period Sampling
June 23, 2010

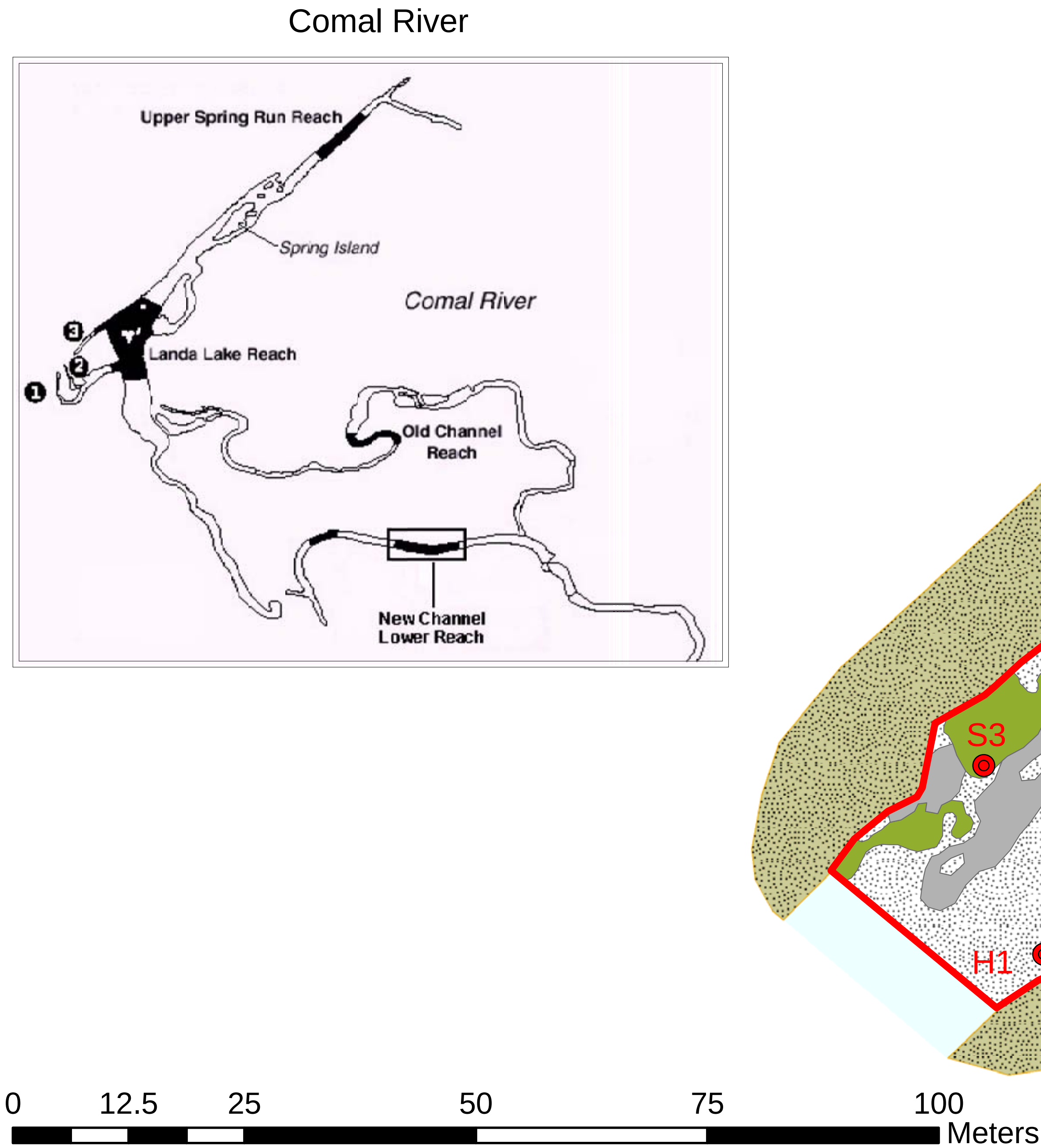
Comal River





Comal River
Aquatic Vegetation
Upper Spring Run Reach
Fall
October 22, 2010





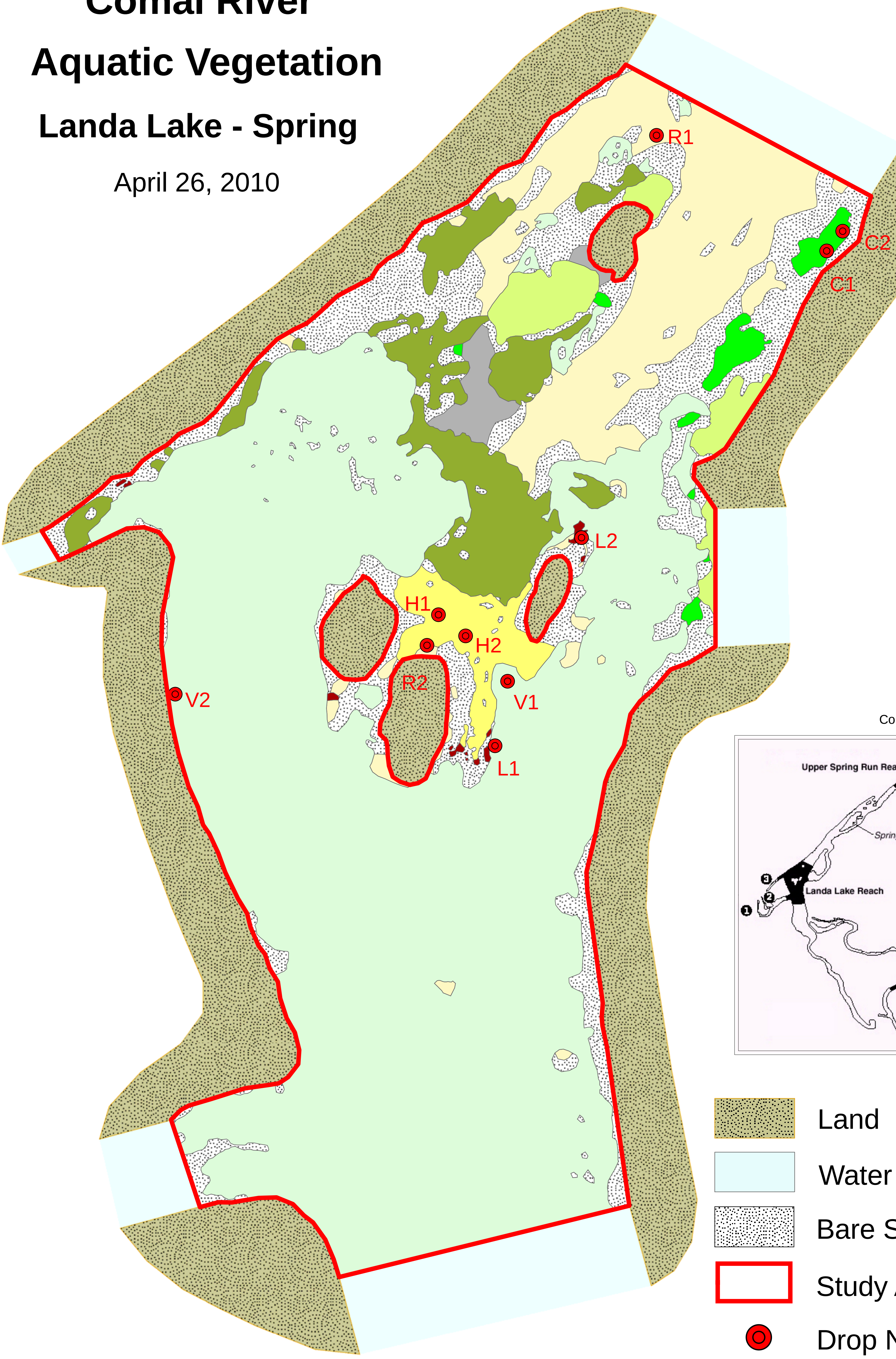
Landa Lake Reach

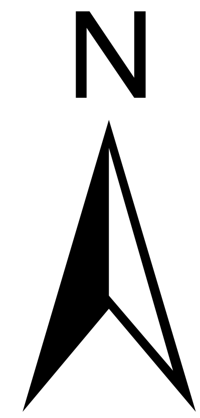
Comal River

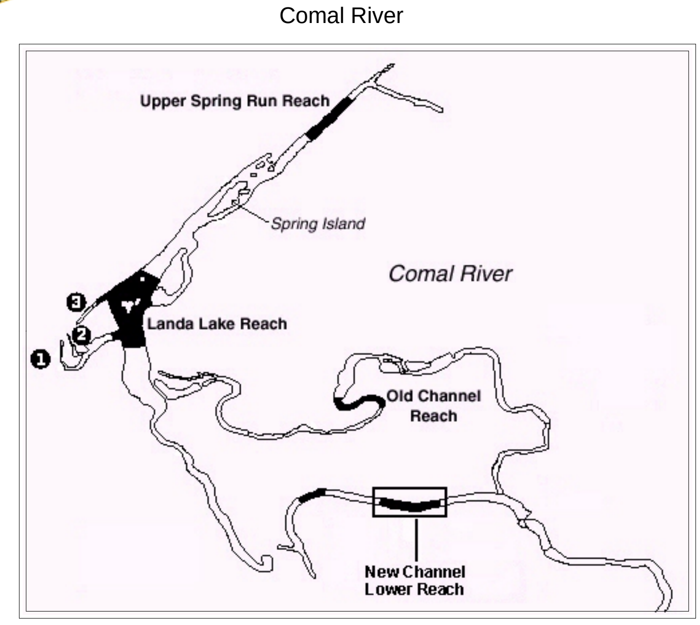
Aquatic Vegetation

Landa Lake - Spring

April 26, 2010







Land

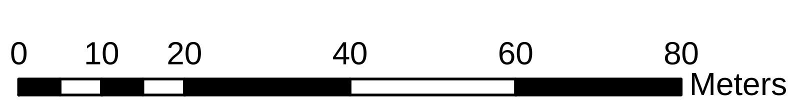
Water

Bare Substrate

Study Area (22,551.2 m^2)

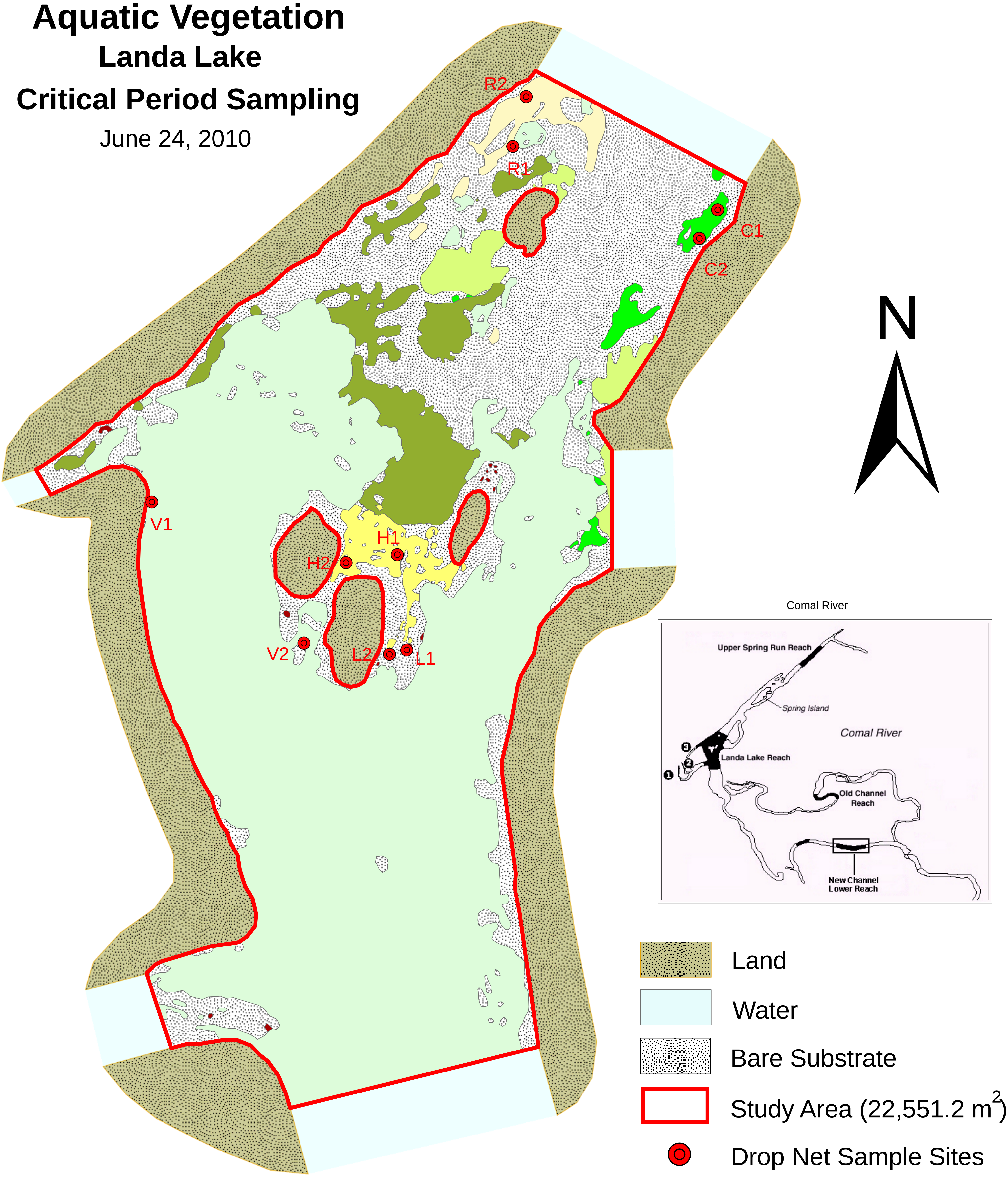
Drop Net Sample Sites

	Total Area (m^2)		Total Area (m^2)
Algae	222.5	*Ludwigia*	29.0
Bryophytes	2,586.9	*Nuphar*	524.0
Cabomba	229.3	*Sagittaria*	1,458.1
Hygrophila	511.6	*Vallisneria*	13,671.2



Comal River
Aquatic Vegetation
Landa Lake
Critical Period Sampling

June 24, 2010

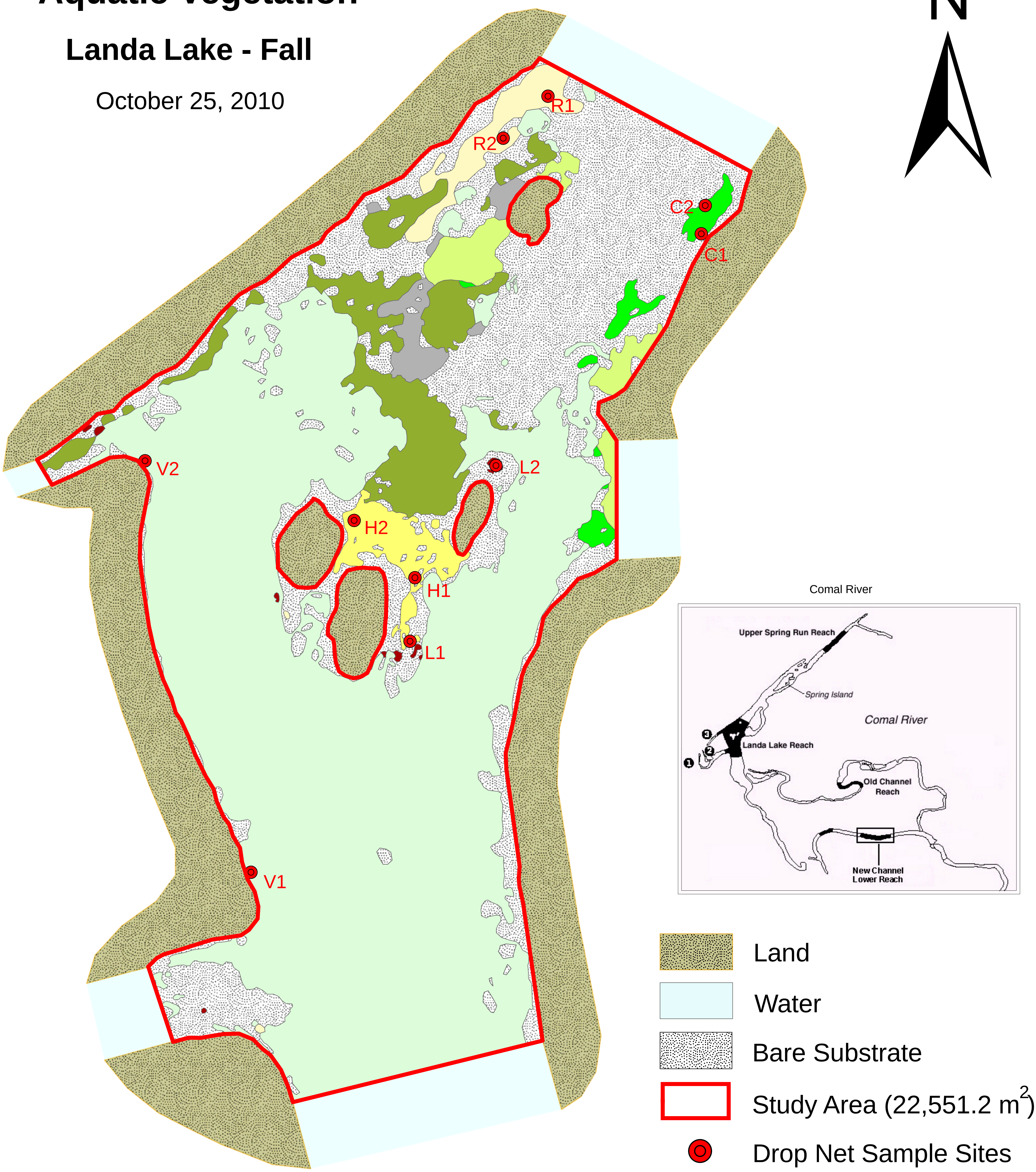


	Total Area (m^2)		Total Area (m^2)
Bryophytes	348.0	*Nuphar*	454.2
Cabomba	217.1	*Sagittaria*	1,340.3
Hygrophila	367.1	*Vallisneria*	13,259.1
Ludwigia	18.5		

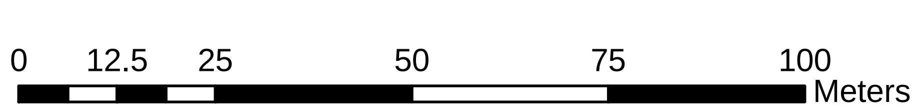
0 4.5 9 18 27 36 Meters

Comal River
Aquatic Vegetation
Landa Lake - Fall

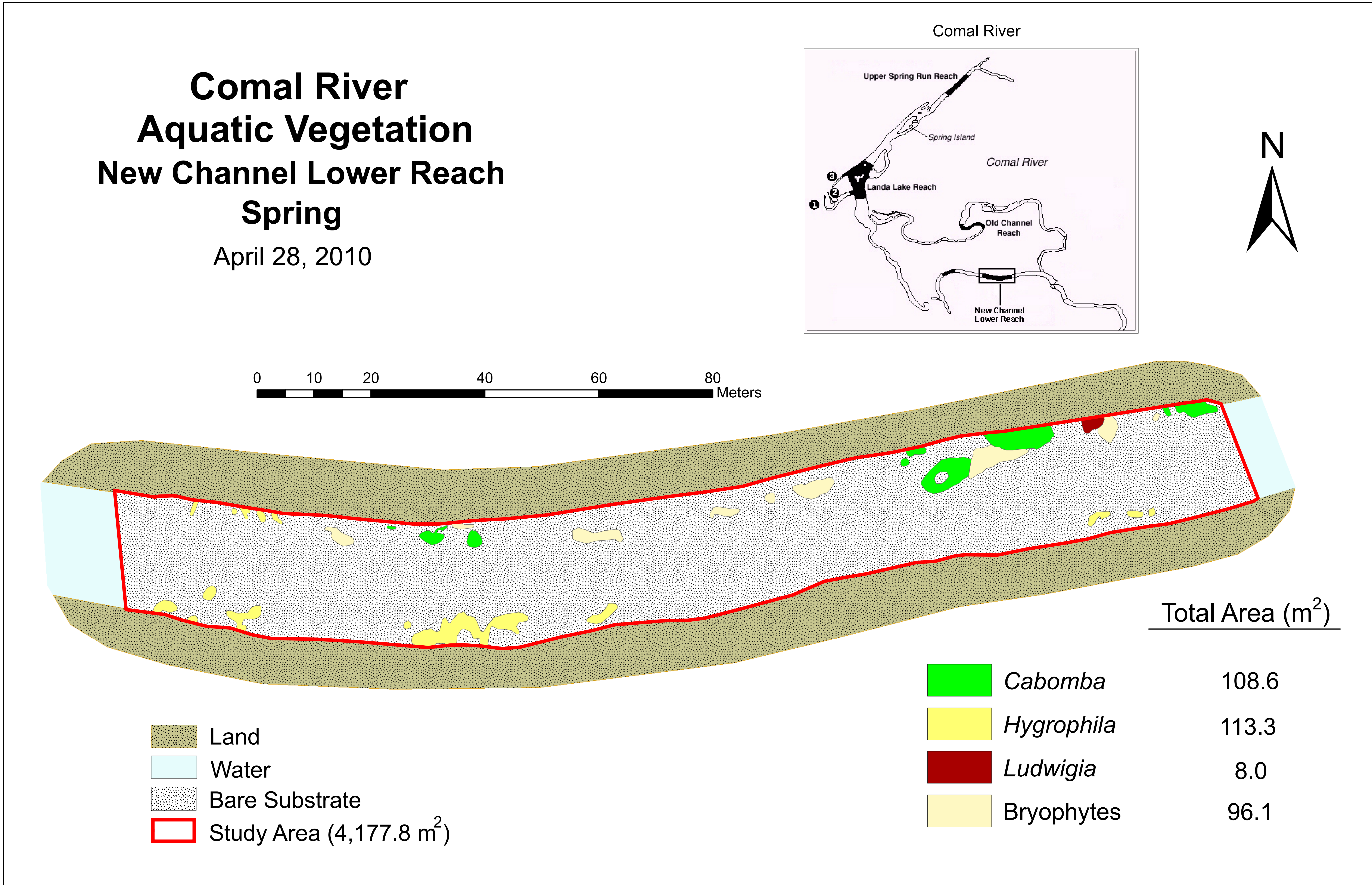
October 25, 2010



	Total Area (m^2)		Total Area (m^2)
Algae	288.6	*Ludwigia*	27.9
Bryophytes	411.7	*Nuphar*	470.2
Cabomba	238.9	*Sagittaria*	1,483.9
Hygrophila	411.6	*Vallisneria*	12,923.2



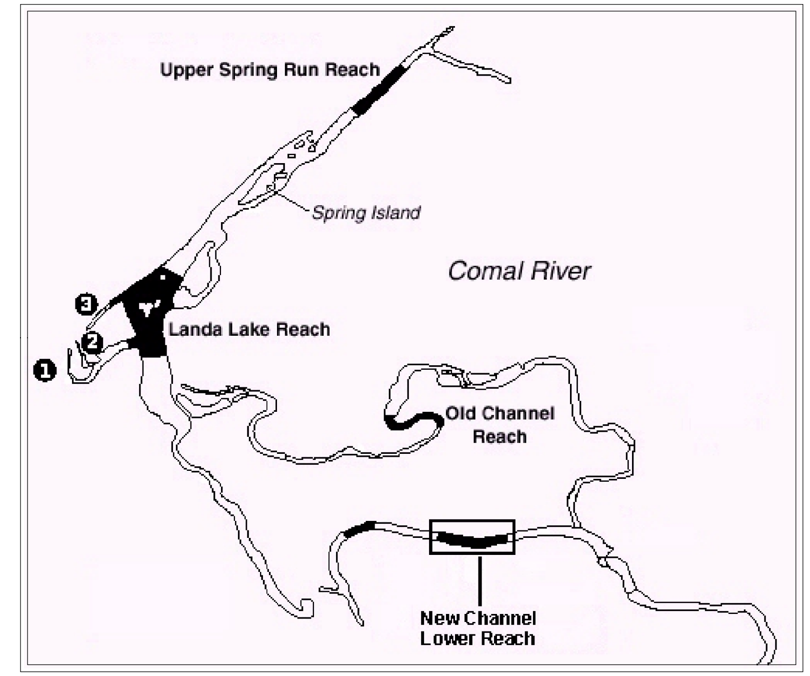
New Channel Reach

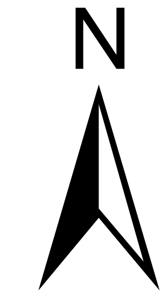

Comal River
Aquatic Vegetation
New Channel Lower Reach
Spring
April 28, 2010
Comal River
Upper Spring Run Reach
Spring Island
Comal River
Landa Lake Reach
Old Channel Reach
New Channel Lower Reach
N
0 10 20 40 60 80 Meters
Total Area (m²)
Cabomba 108.6
Hygrophila 113.3
Ludwigia 8.0
Bryophytes 96.1
Land
Water
Bare Substrate
Study Area (4,177.8 m²)

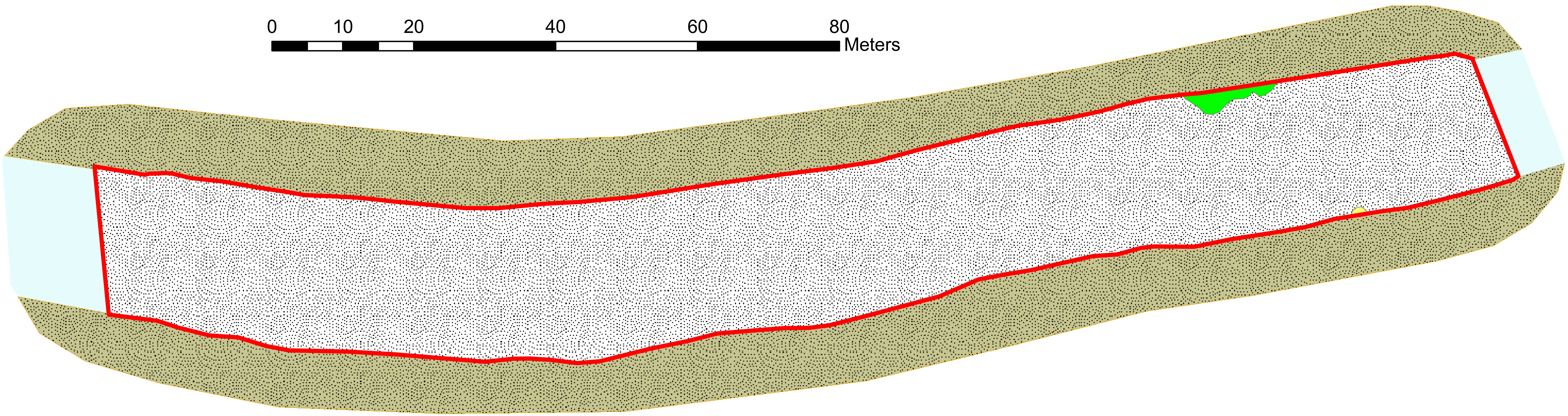
Comal River
Aquatic Vegetation
New Channel Lower Reach
Critical Period Sampling

June 28, 2010

Comal River







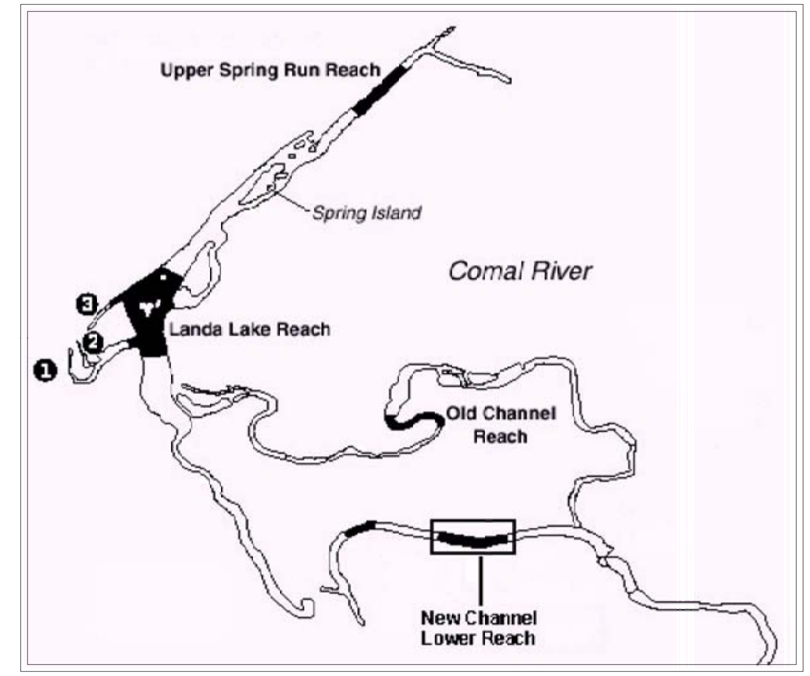
- Land
- Water
- Bare Substrate
- Study Area (4,177.8 m^2)

	Total Area (m^2)
Cabomba	24.4
Hygrophila	1.9

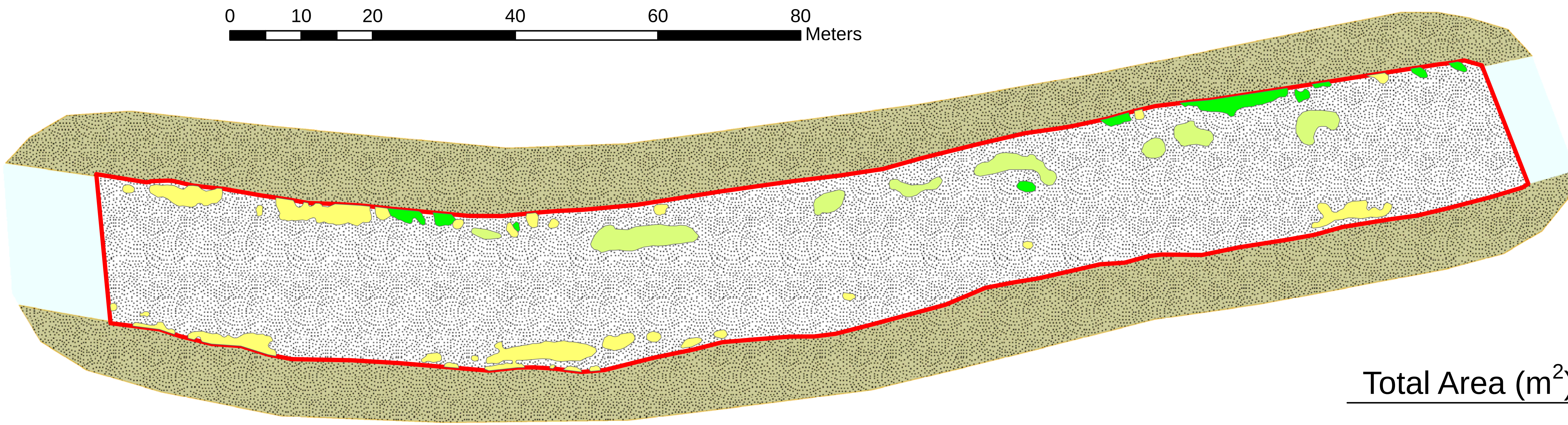
Comal River
Aquatic Vegetation
New Channel Lower Reach
Fall

October 22, 2010

Comal River



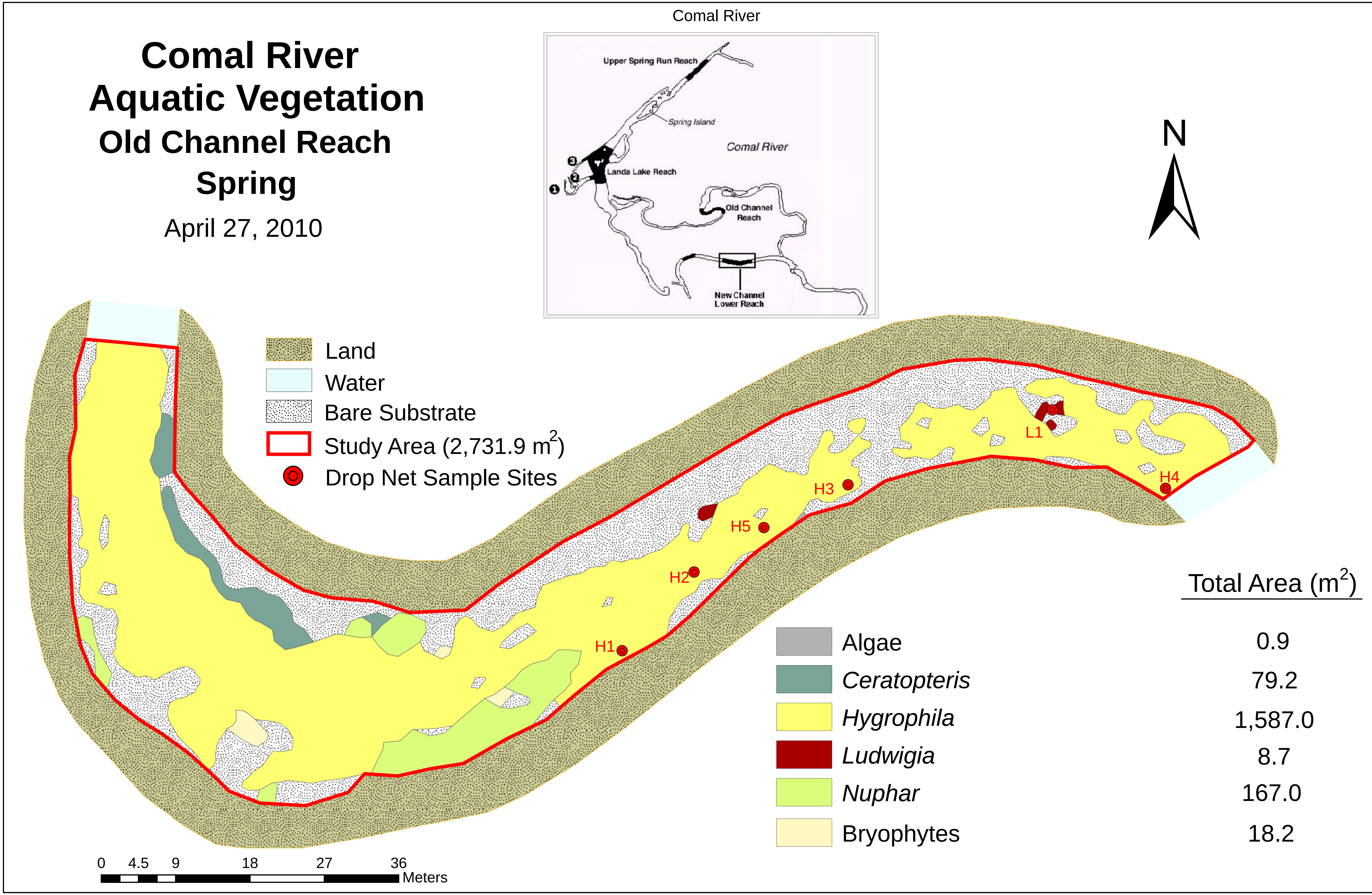
N

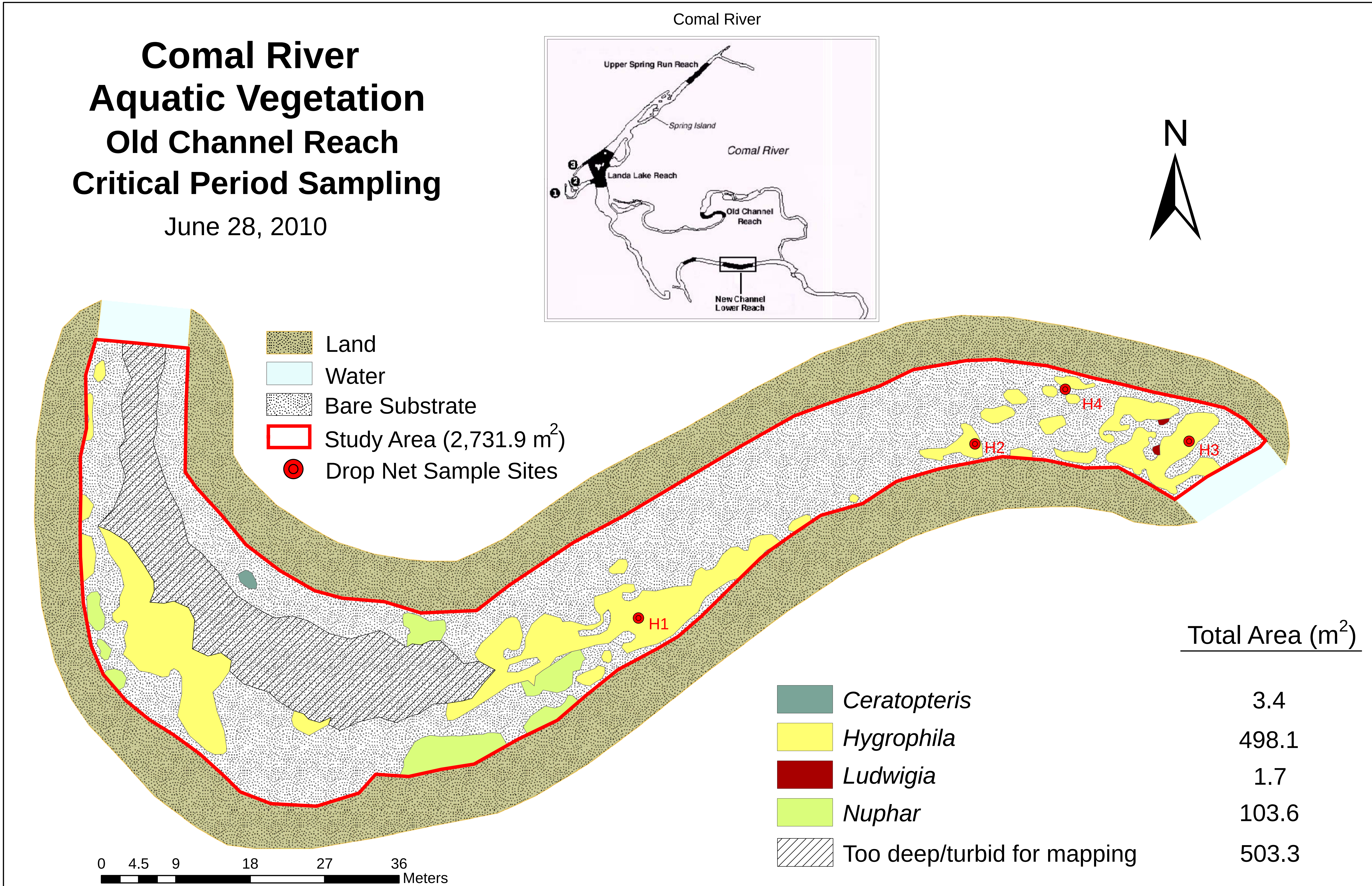


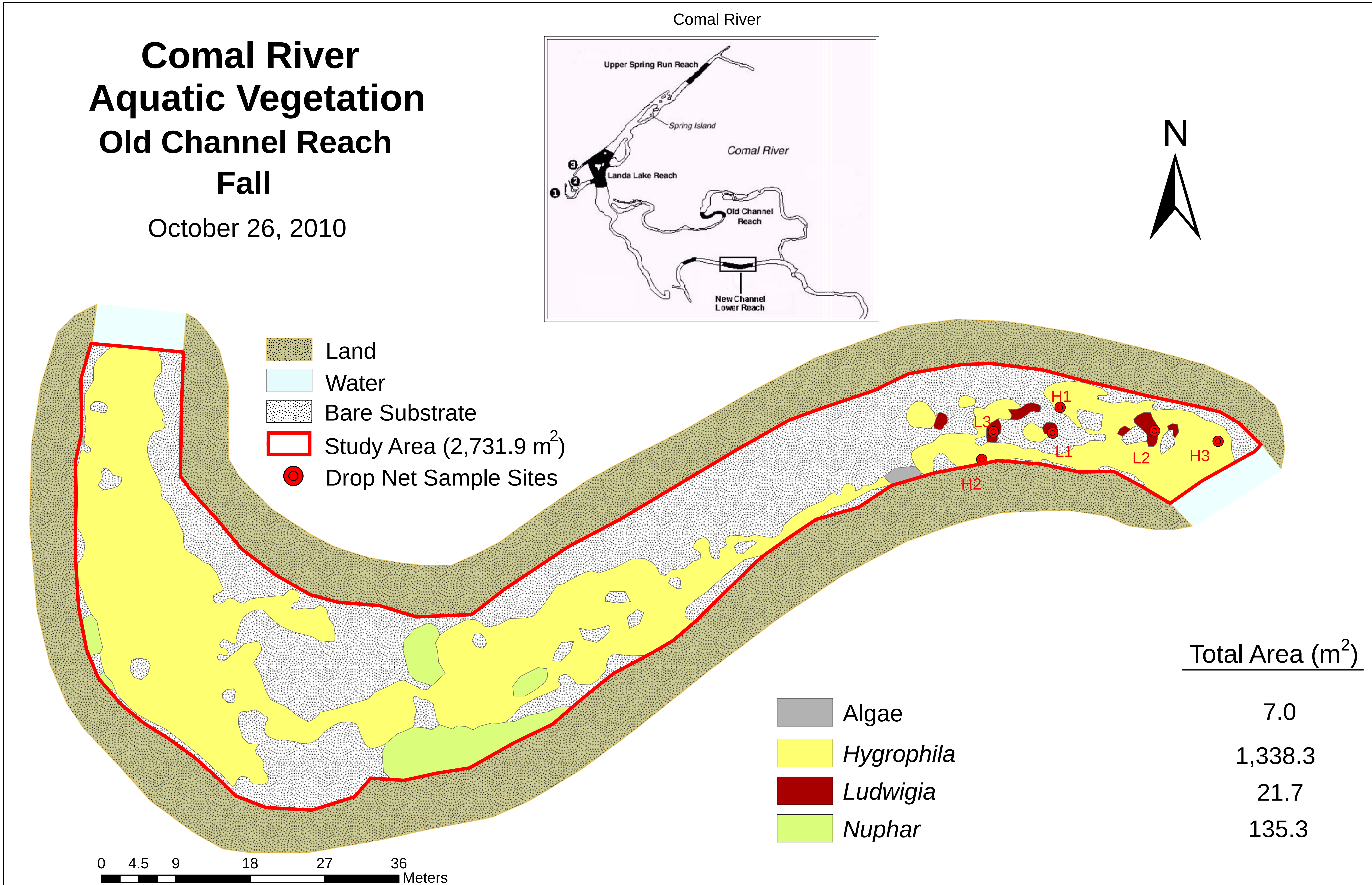
- Land
- Water
- Bare Substrate
- Study Area (4,177.8 m^2)

	Total Area (m^2)
Cabomba	51.5
Hygrophila	180.6
Nuphar	131.0

Old Channel Reach


Comal River
Aquatic Vegetation
Old Channel Reach
Spring
April 27, 2010
Comal River
Upper Spring Run Reach
Spring Island
Comal River
Landa Lake Reach
Old Channel Reach
New Channel Lower Reach
N
Land
Water
Bare Substrate
Study Area (2,731.9 m2)
Drop Net Sample Sites
H1
H2
H3
H4
H5
L1
Total Area (m2)
Algae 0.9
Ceratopteris 79.2
Hygrophila 1,587.0
Ludwigia 8.7
Nuphar 167.0
Bryophytes 18.2
0 4.5 9 18 27 36
Meters

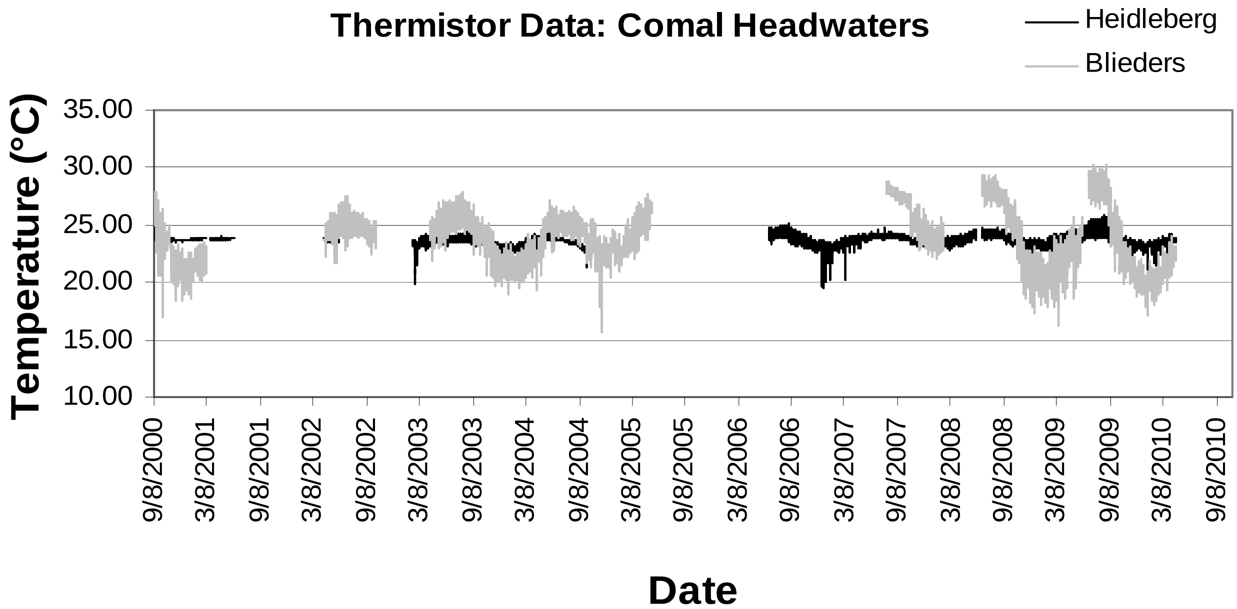

Comal River
Aquatic Vegetation
Old Channel Reach
Critical Period Sampling
June 28, 2010
Comal River
Upper Spring Run Reach
Spring Island
Comal River
Landa Lake Reach
Old Channel Reach
New Channel Lower Reach
N
Land
Water
Bare Substrate
Study Area (2,731.9 m2)
Drop Net Sample Sites
H1
H2
H3
H4
Total Area (m2)
Ceratopteris 3.4
Hygrophila 498.1
Ludwigia 1.7
Nuphar 103.6
Too deep/turbid for mapping 503.3
0 4.5 9 18 27 36
Meters

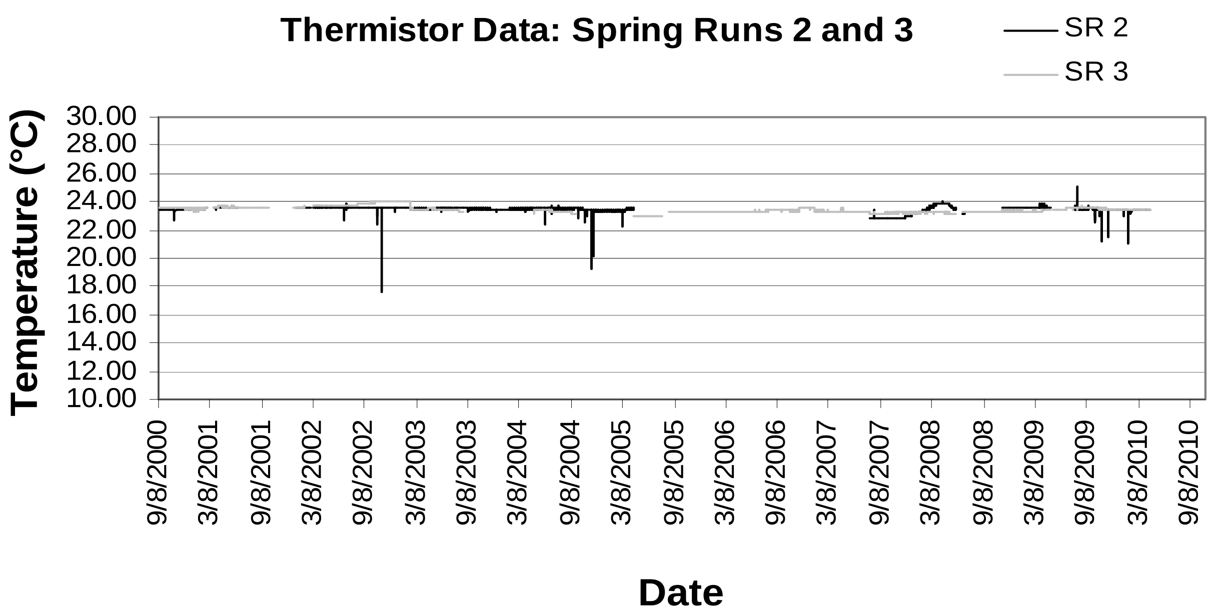


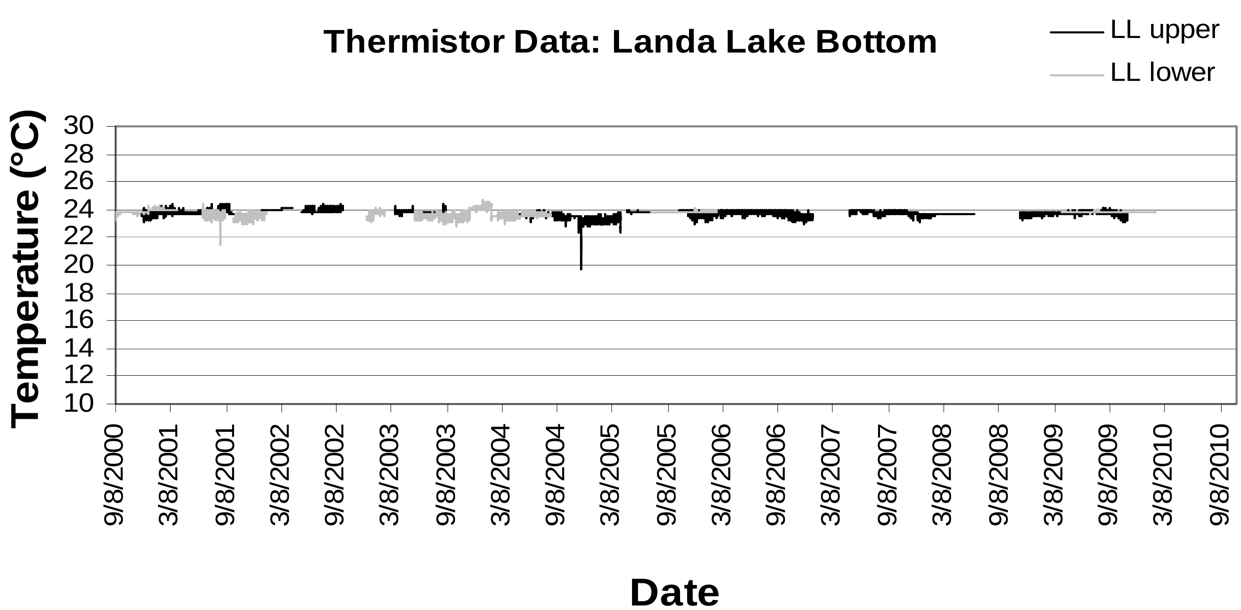
Comal River
Aquatic Vegetation
Old Channel Reach
Fall
October 26, 2010
Comal River
Upper Spring Run Reach
Spring Island
Comal River
Landa Lake Reach
Old Channel Reach
New Channel Lower Reach
N
Land
Water
Bare Substrate
Study Area (2,731.9 m²)
Drop Net Sample Sites
H1
L3
L1
L2
H3
H2
Total Area (m²)
Algae 7.0
Hygrophila 1,338.3
Ludwigia 21.7
Nuphar 135.3
0 4.5 9 18 27 36
Meters

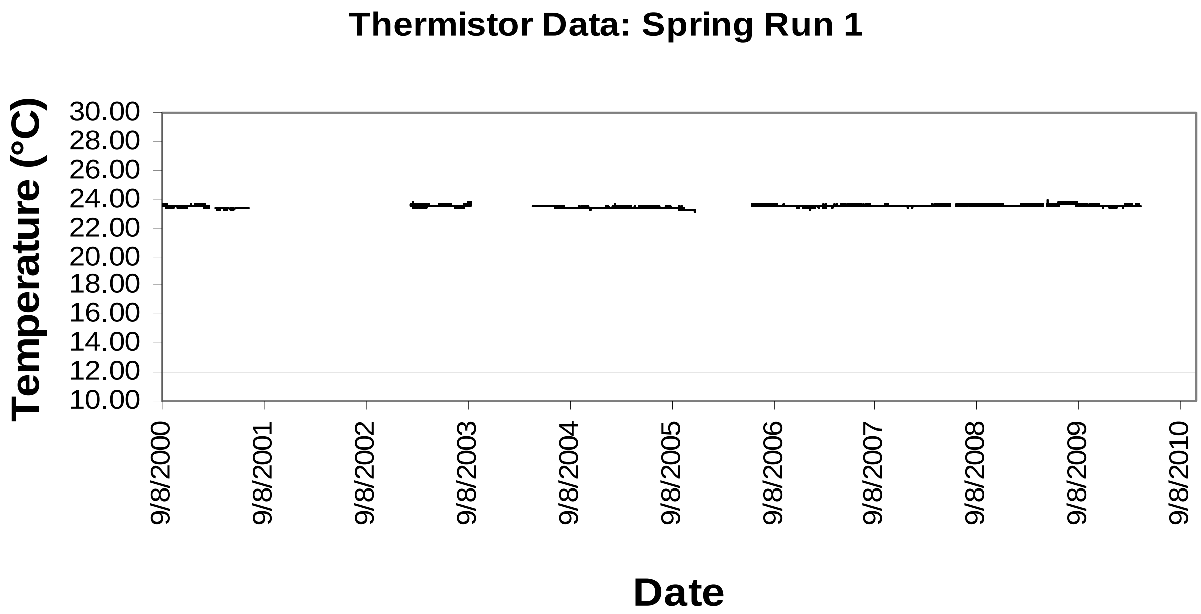
APPENDIX B:
DATA AND GRAPHS

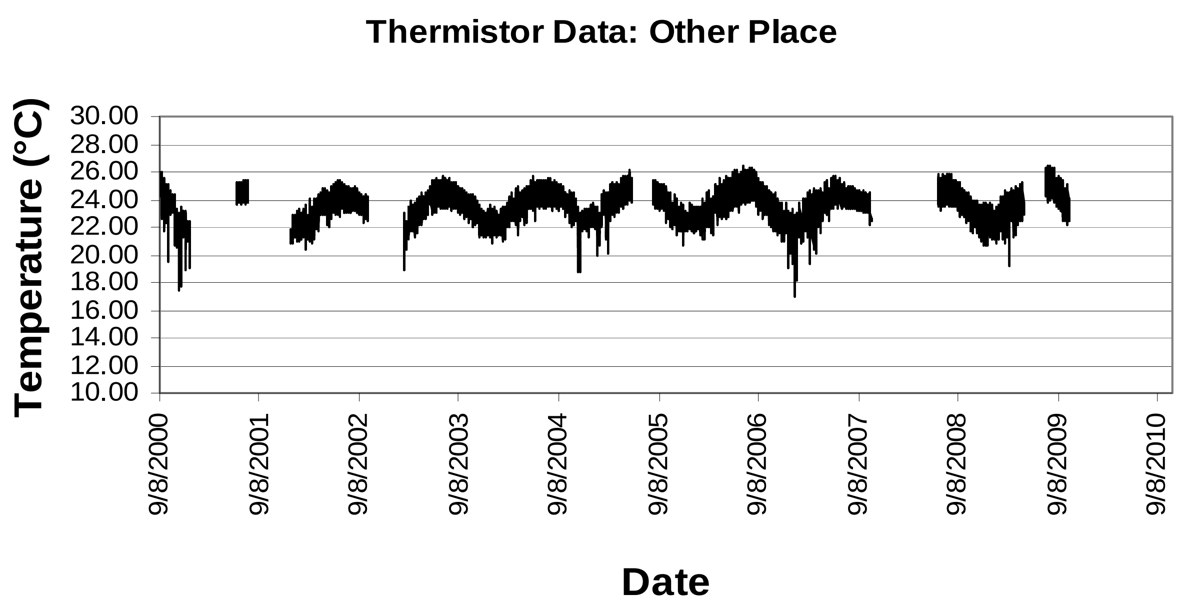
Water Quality Data
and
Thermistor Graphs

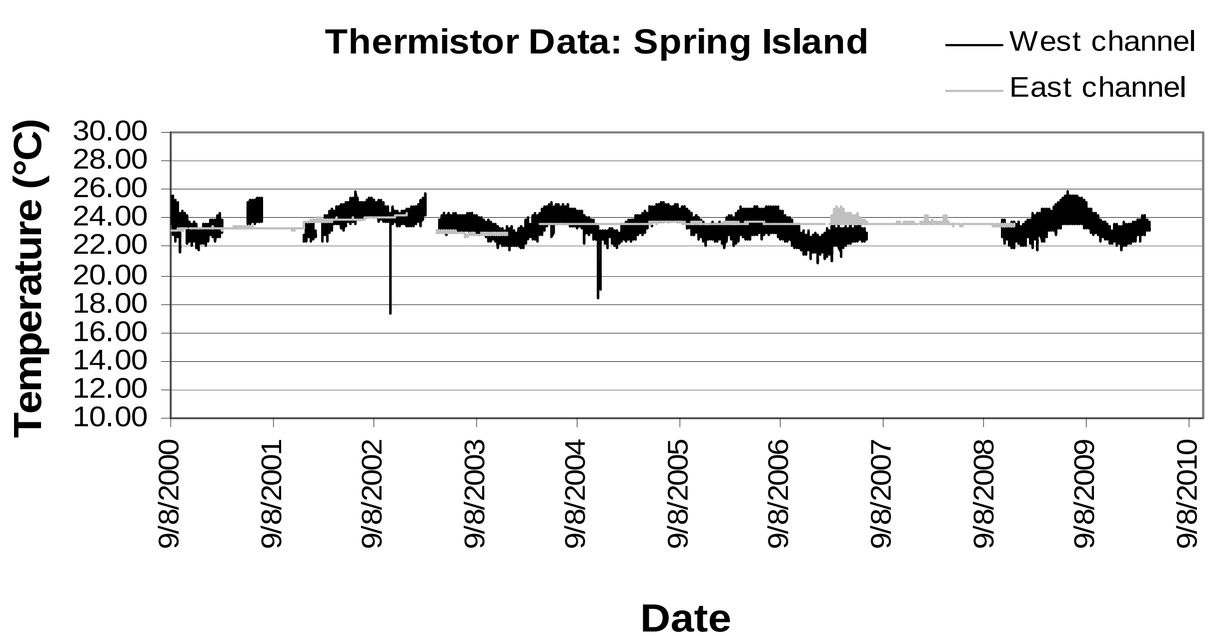

Thermistor Data: Comal Headwaters
Heidleberg
Blieders
Temperature (°C)
35.00
30.00
25.00
20.00
15.00
10.00
9/8/2000
3/8/2001
9/8/2001
3/8/2002
9/8/2002
3/8/2003
9/8/2003
3/8/2004
9/8/2004
3/8/2005
9/8/2005
3/8/2006
9/8/2006
3/8/2007
9/8/2007
3/8/2008
9/8/2008
3/8/2009
9/8/2009
3/8/2010
9/8/2010
Date

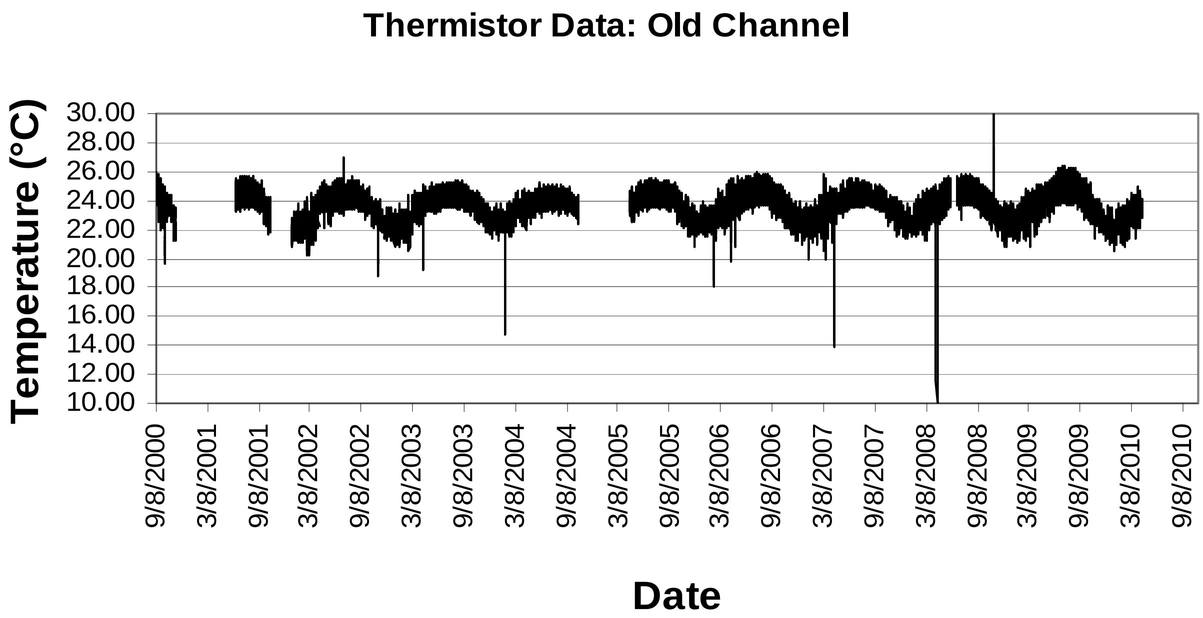

Thermistor Data: Spring Runs 2 and 3
SR 2
SR 3
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
9/8/2000
3/8/2001
9/8/2001
3/8/2002
9/8/2002
3/8/2003
9/8/2003
3/8/2004
9/8/2004
3/8/2005
9/8/2005
3/8/2006
9/8/2006
3/8/2007
9/8/2007
3/8/2008
9/8/2008
3/8/2009
9/8/2009
3/8/2010
9/8/2010
Date


Thermistor Data: Landa Lake Bottom
LL upper
LL lower
Temperature (°C)
30
28
26
24
22
20
18
16
14
12
10
9/8/2000
3/8/2001
9/8/2001
3/8/2002
9/8/2002
3/8/2003
9/8/2003
3/8/2004
9/8/2004
3/8/2005
9/8/2005
3/8/2006
9/8/2006
3/8/2007
9/8/2007
3/8/2008
9/8/2008
3/8/2009
9/8/2009
3/8/2010
9/8/2010
Date


Thermistor Data: Spring Run 1
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
9/8/2000
9/8/2001
9/8/2002
9/8/2003
9/8/2004
9/8/2005
9/8/2006
9/8/2007
9/8/2008
9/8/2009
9/8/2010
Date

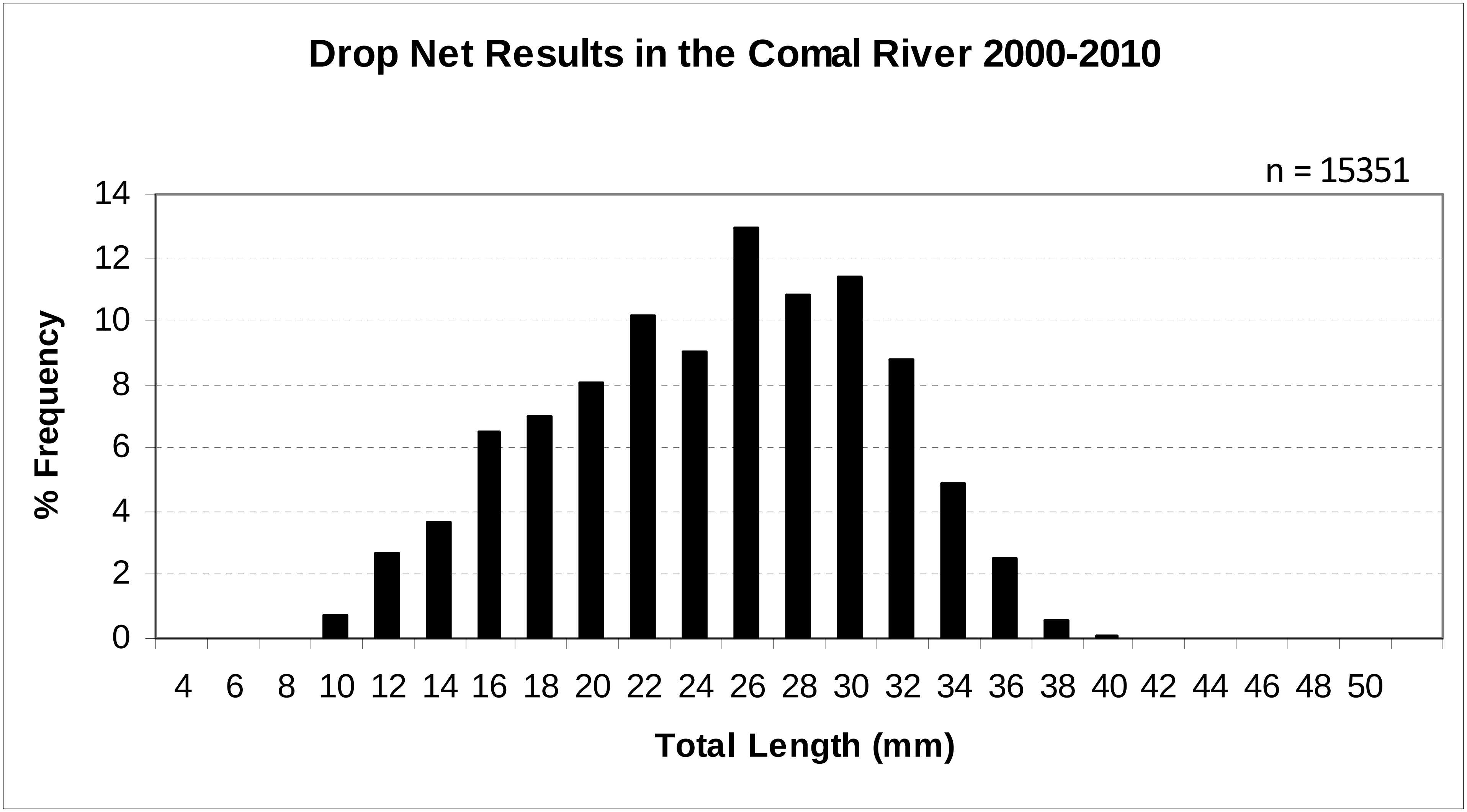

Thermistor Data: Other Place
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
9/8/2000
9/8/2001
9/8/2002
9/8/2003
9/8/2004
9/8/2005
9/8/2006
9/8/2007
9/8/2008
9/8/2009
9/8/2010
Date


Thermistor Data: Spring Island
West channel
East channel
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
9/8/2000
9/8/2001
9/8/2002
9/8/2003
9/8/2004
9/8/2005
9/8/2006
9/8/2007
9/8/2008
9/8/2009
9/8/2010
Date



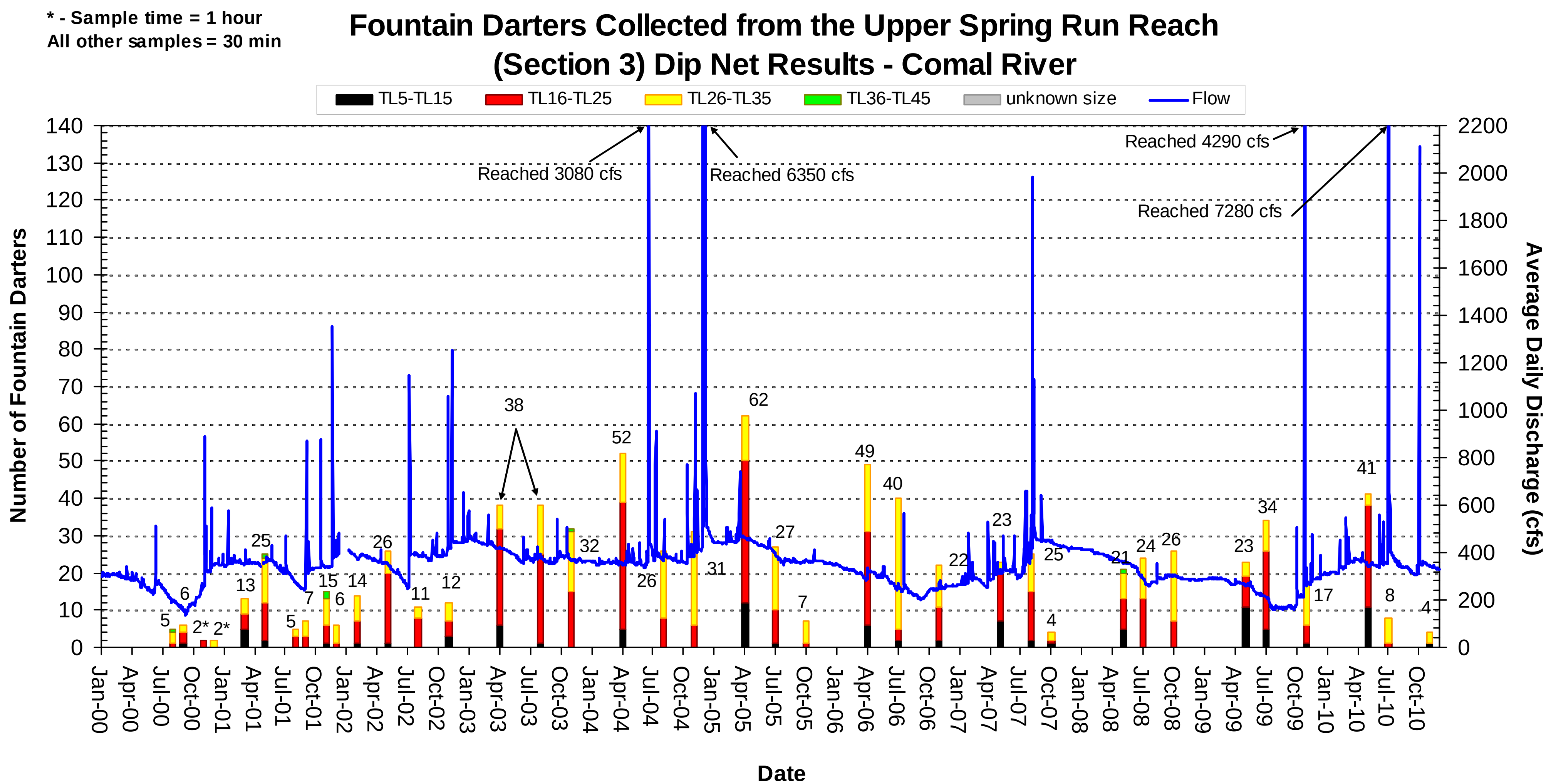
Thermistor Data: Old Channel
Temperature (°C)
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
9/8/2000
3/8/2001
9/8/2001
3/8/2002
9/8/2002
3/8/2003
9/8/2003
3/8/2004
9/8/2004
3/8/2005
9/8/2005
3/8/2006
9/8/2006
3/8/2007
9/8/2007
3/8/2008
9/8/2008
3/8/2009
9/8/2009
3/8/2010
9/8/2010
Date

Drop Net Graph



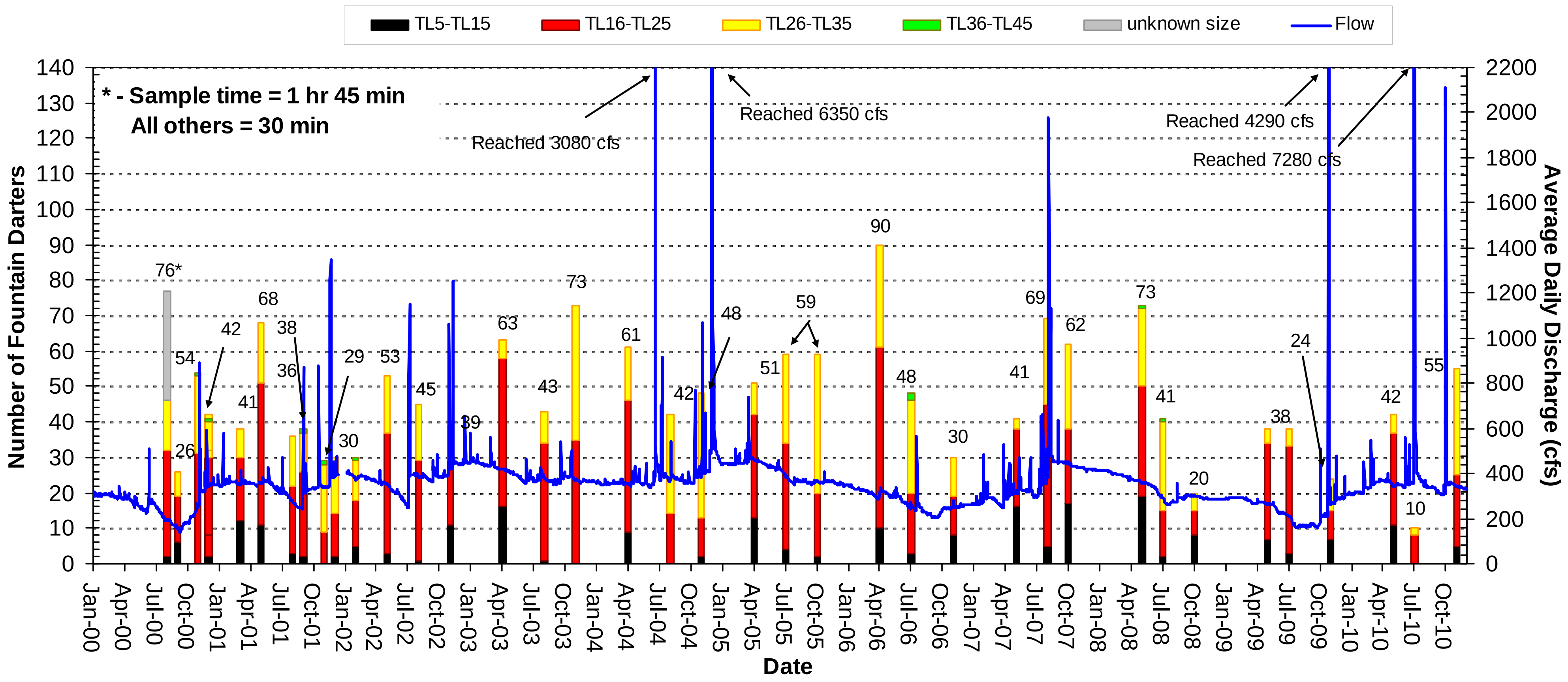
Drop Net Results in the Comal River 2000-2010
n = 15351
% Frequency
0
2
4
6
8
10
12
14
4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
Total Length (mm)

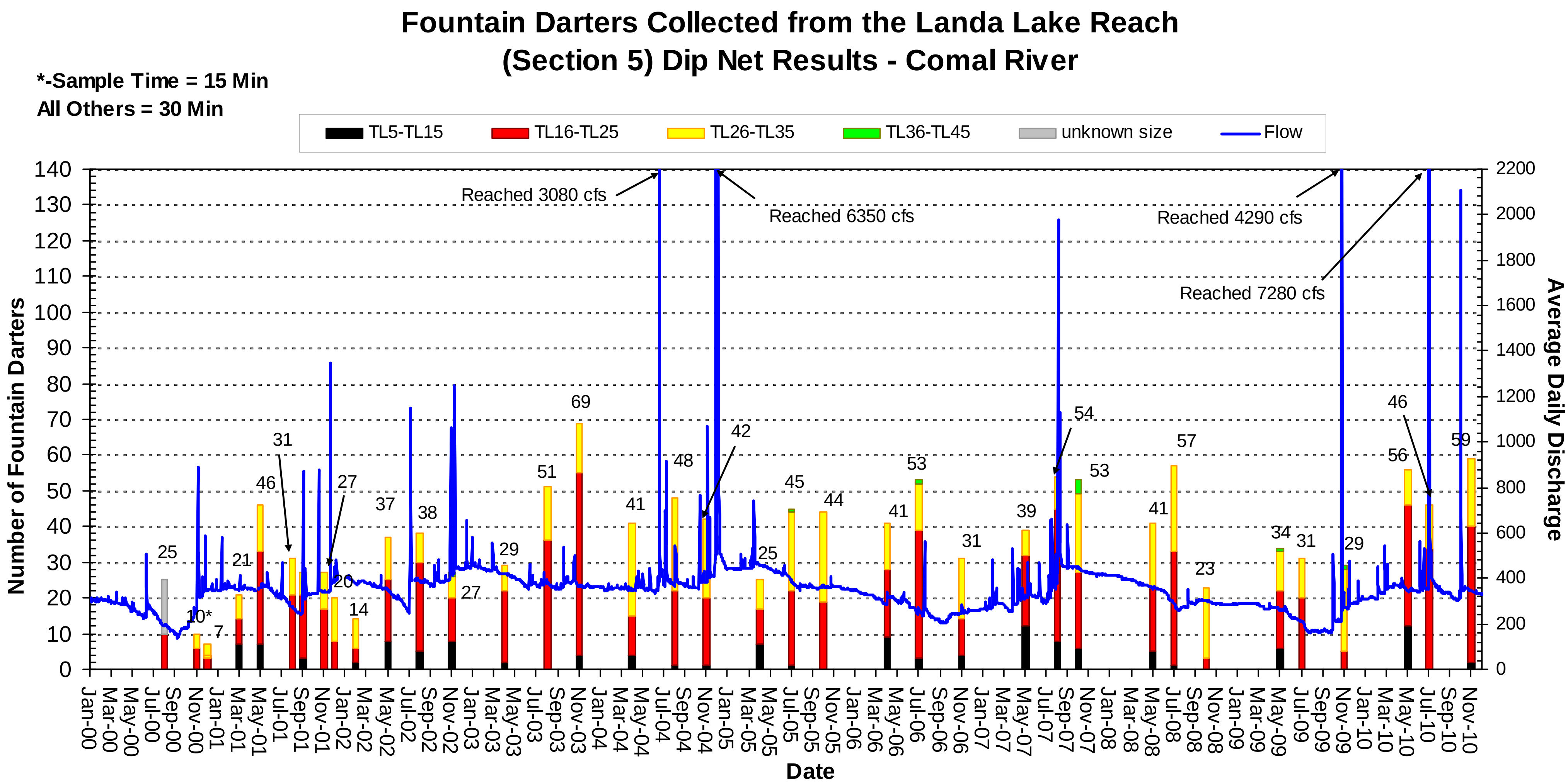
Dip Net Graphs



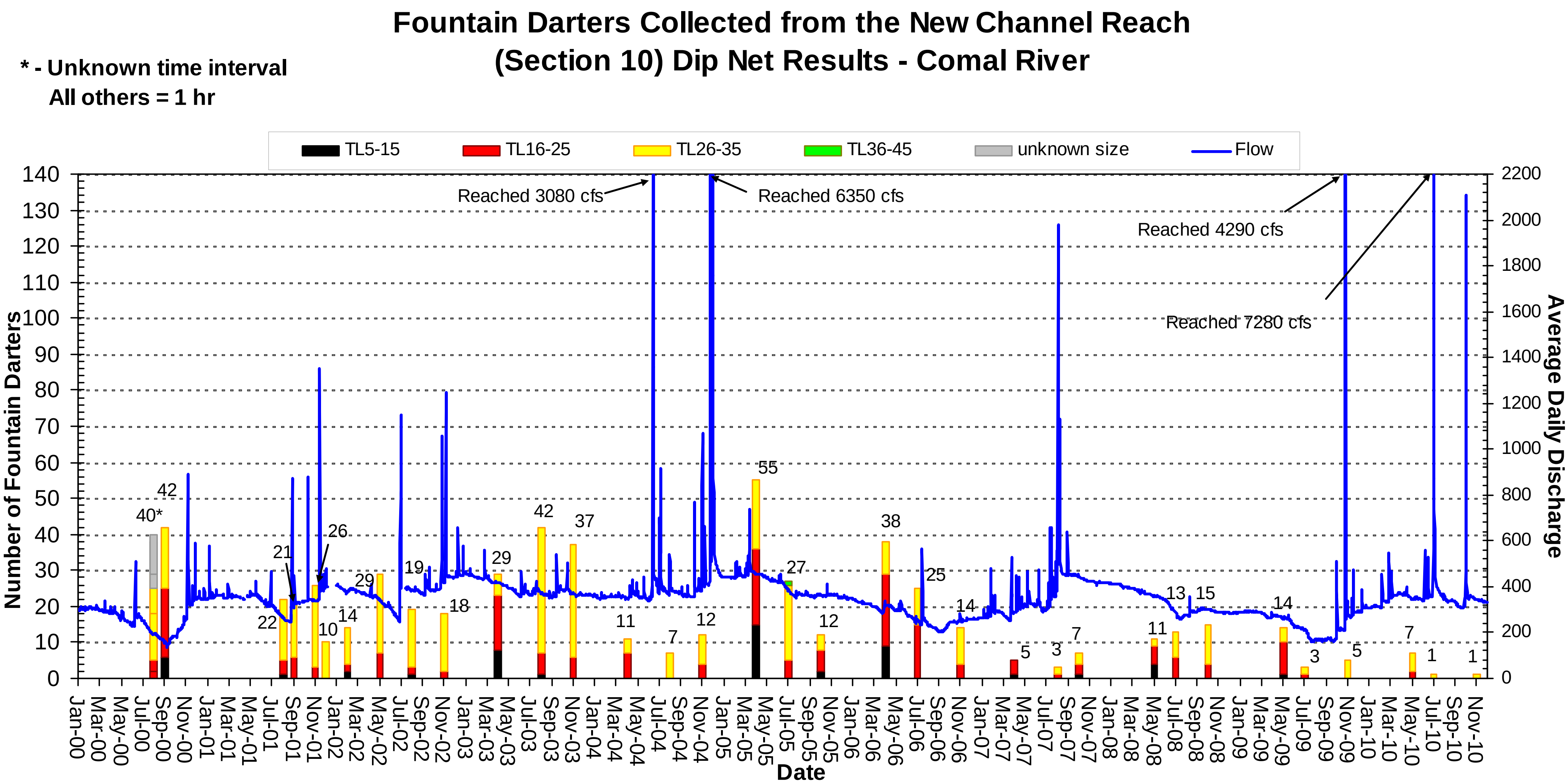
* - Sample time = 1 hour
All other samples = 30 min
Fountain Darters Collected from the Upper Spring Run Reach
(Section 3) Dip Net Results - Comal River
TL5-TL15
TL16-TL25
TL26-TL35
TL36-TL45
unknown size
Flow
Number of Fountain Darters
Average Daily Discharge (cfs)
Date
Reached 3080 cfs
Reached 6350 cfs
Reached 4290 cfs
Reached 7280 cfs
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Jul-08
Oct-08
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
Apr-10
Jul-10
Oct-10

Fountain Darters Collected from the Spring Island Area (Section 4U-M) Dip Net Results - Comal River



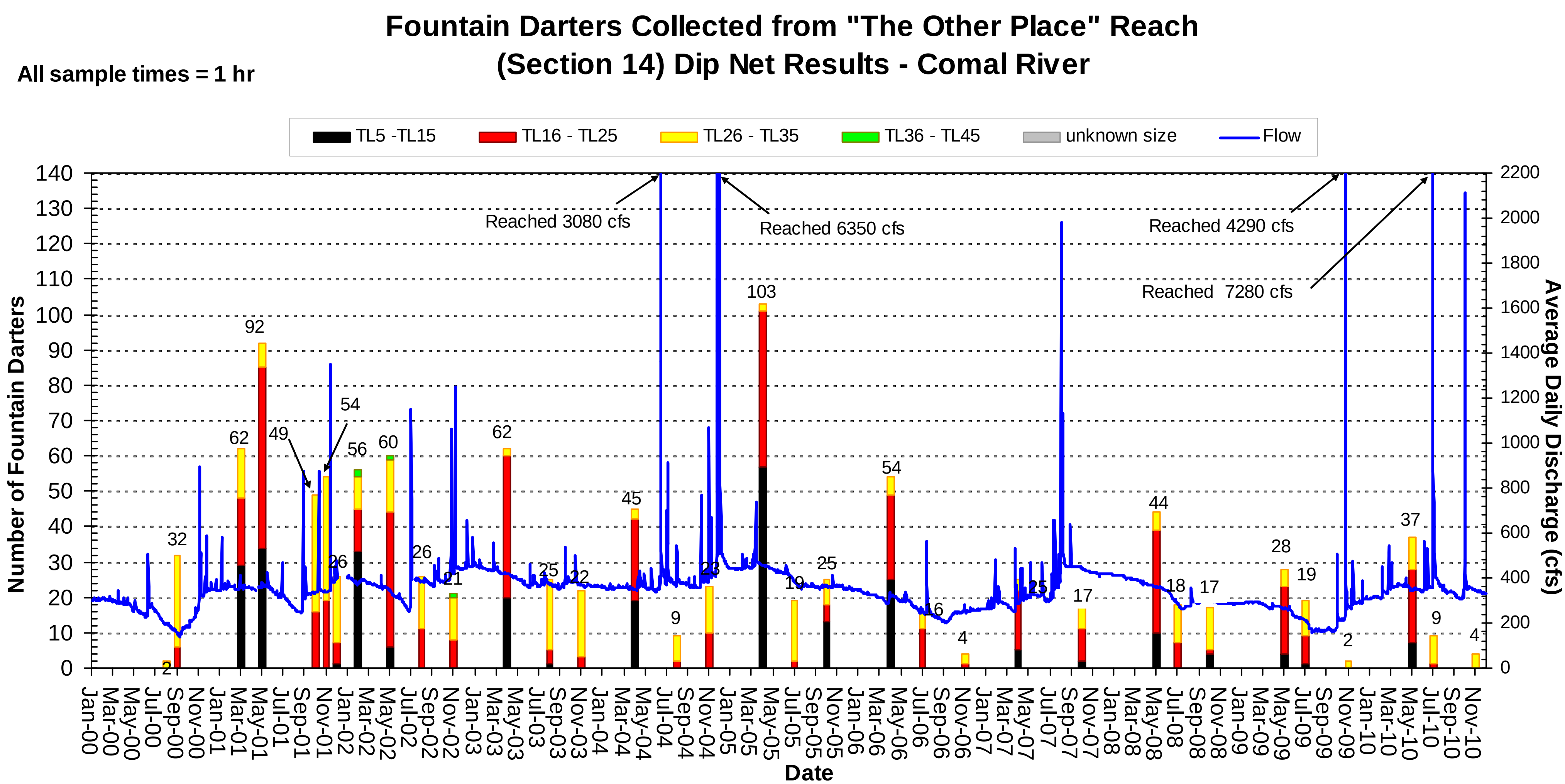


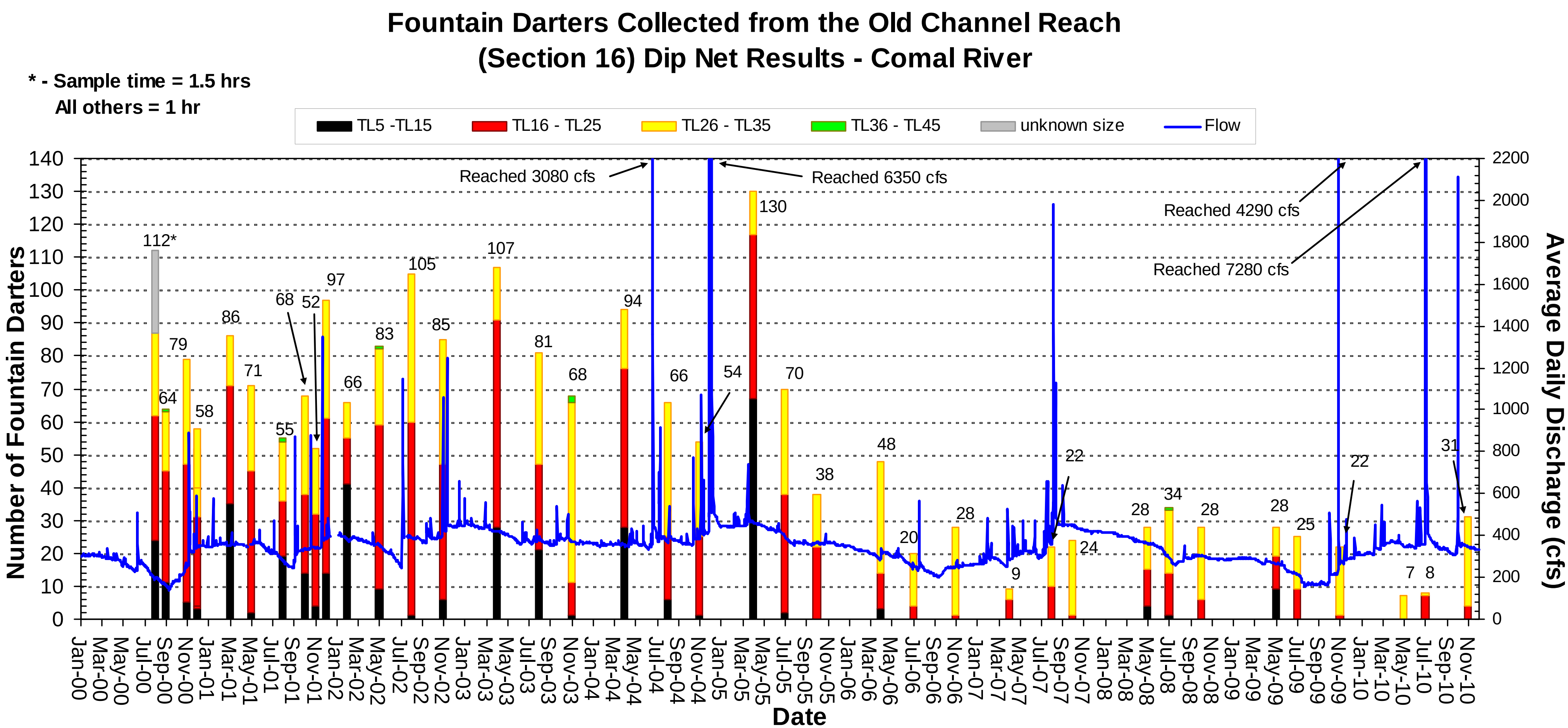
Fountain Darters Collected from the Landa Lake Reach
(Section 5) Dip Net Results - Comal River
*-Sample Time = 15 Min
All Others = 30 Min
TL5-TL15
TL16-TL25
TL26-TL35
TL36-TL45
unknown size
Flow
Reached 3080 cfs
Reached 6350 cfs
Reached 4290 cfs
Reached 7280 cfs
Number of Fountain Darters
Average Daily Discharge
Date



Fountain Darters Collected from the New Channel Reach
(Section 10) Dip Net Results - Comal River
* - Unknown time interval
All others = 1 hr
TL5-15
TL16-25
TL26-35
TL36-45
unknown size
Flow
Reached 3080 cfs
Reached 6350 cfs
Reached 4290 cfs
Reached 7280 cfs
Number of Fountain Darters
Average Daily Discharge
Date
40*
42
22
21
10
26
14
29
19
18
29
42
37
11
7
12
55
27
12
38
25
14
5
3
7
11
13
15
14
3
5
7
1
1

All sample times = 1 hr




Fountain Darters Collected from the Old Channel Reach
(Section 16) Dip Net Results - Comal River
* - Sample time = 1.5 hrs
All others = 1 hr
TL5 -TL15
TL16 - TL25
TL26 - TL35
TL36 - TL45
unknown size
Flow
Number of Fountain Darters
Average Daily Discharge (cfs)
Date
Reached 3080 cfs
Reached 6350 cfs
Reached 4290 cfs
Reached 7280 cfs
112*
64
79
58
86
71
55
68
52
97
66
83
105
85
107
81
68
94
66
54
130
70
38
48
20
28
9
22
24
28
34
28
28
25
22
7
8
31

APPENDIX C:
DROP NET RAW DATA

(not available online)