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

Final 2012 Annual Report

Prepared for:

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

Prepared by:

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

Submitted: March 2013

TABLE OF CONTENTS

APPENDICES

APPENDIX A: AQUATIC VEGETATION MAPS

APPENDIX B: DATA AND GRAPHS

APPENDIX C: DROP NET RAW DATA

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This annual summary report presents a synopsis of methodology used and an account of sampling activities conducted during two Comprehensive Monitoring efforts on the Comal Springs/River ecosystem in 2012. For ease of comparison, the data are reported here in an annual report format similar to previous reports (BIO-WEST 2001-2012).

The drought in Central Texas continued through 2012 and flows in the Comal River were below the historic average for the entire year. A minimum flow of 155 cubic feet per second (cfs) was reached in September, and it was the lowest minimum flow since the first year of this study (2000). With rain events few and far between, flows stayed near 200 cfs for the remainder of 2012. Although water temperatures remained constant in spring runs and Landa Lake, hot and dry conditions led to water temperatures in the mouth of Blieder's Creek that exceeded the state water quality standard for the Comal River (26.7 °C). Monitoring by Texas Master Naturalists continued to confirm that dissolved carbon dioxide (CO_2) decreases and pH increases with distance from spring inputs. However, values for these parameters were similar to those observed in previous years. Recreation pressure was highest at the New Channel during the summer months, and was relatively low year-round at all other monitored sites.

Monitoring of aquatic vegetation during these prolonged droughts is important to understanding potential impacts to fountain darter (*Etheostoma fonticola*) habitat. Bryophytes (mosses) hold high densities of fountain darters and can be abundant within the Upper Spring Run Reach. This was the case in spring, but by fall many of the bryophytes had died likely due to shading by green algae that often bloom in summer with abundant sunlight. *Sagittaria* continued to be stable in the lower half of the reach. Bryophytes are also an important component of the upper section of the Landa Lake Reach. Unlike the Upper Spring Run Reach, bryophytes at Landa Lake remained relatively constant over the entire year. *Cabomba*, another native plant with relatively high densities of darters has been increasing in coverage in Landa Lake, and by fall 2012 had the highest coverage observed in this study. Lower than average flows did not appear to negatively affect aquatic vegetation in the Landa Lake Reach in 2012. The Old Channel Reach exemplifies the interaction between native (*Ludwigia*) and non-native (*Hygrophila*) vegetation. Over the past several years *Ludwigia* has become sparse (filamentous algae is rarely present) while *Hygrophila* has come to dominate most of the reach. *Cabomba* flourished in the New Channel Reach in 2012, while coverage of *Hygrophila* was only slightly less in this scour-prone reach.

A high-flow event (7,280 cfs) in 2010 scoured out much of the vegetation in upper reaches of the Comal River resulting in low population estimates of fountain darters; however, by 2012 aquatic vegetation had recovered and fountain darter population estimates were similar to years prior to the flood. Estimates in the Upper Spring Run Reach decreased considerably from spring to fall due to the loss of bryophytes (which appears to be a regular cycle). These bryophytes hold the highest densities of fountain darters in the Comal River. Of non-native aquatic vegetation, *Hygrophila* holds the highest densities of darters. Length-frequency distribution indicates that higher quality habitats exhibit year-round reproduction, whereas lower quality habitats (i.e., *Hygrophila*) typically only exhibit a spring reproductive peak. This may be tied to fountain darter spawning preferences, as other studies suggest that egg deposition in native vegetation is higher than in non-native vegetation (Phillips et al. 2011). Catches of exotic giant ramshorn snail (*Marisa cornuarietis*) have increased in 2011 and 2012. It is unclear if this is related to the ongoing drought, but monitoring will help determine if they are impacting aquatic vegetation. Additionally, continued monitoring of giant ramshorn snail will aid in evaluating the success of

Edward's Aquifer Habitat Conservation Plan (EAHCP) measures aimed at controlling this exotic species.

Comal Springs salamander (*Eurycea* sp.) counts appeared to be increasing during 2012 following the post-flood decline in 2011 (the lowest during the study period). Few salamanders continue to be found at the Spring Island Spring Run, but this is likely a result of lower quality habitat compared to other reaches. A total of 749 Comal Springs Riffle Beetles (*Heterelmis comalensis*) were observed on cotton lures in 2012, the lowest total since 2003. Fewer have been found at Spring Island since the flood of 2010 because spring outlets have shifted locations, and riffle beetles may have moved.

The flood of 2010 impacted the biota and associated habitat in the Comal River, but monitoring efforts in 2012 indicate that much of the system has recovered. Aquatic vegetation is flourishing in all reaches, and fountain darter populations are similar to pre-flood estimates. The interaction between native and non-native vegetation will continue to be an important driver of fountain darter populations. As EAHCP efforts get under way in 2013, including aquatic vegetation restoration and non-native species control, continued monitoring is more important than ever to assess effectiveness of EAHCP activities.

METHODS

Study Location

Comal Springs, which consists of numerous 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 approximately 5 kilometers to its confluence with the Guadalupe River. 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 (*Stygobromus pecki*). One additional species that is monitored during this study is the undescribed Comal Springs salamander.

Two full comprehensive (spring and fall) sampling efforts were conducted in 2012. 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:

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

<u>Aquatic Vegetation</u>
- GPS Mapping

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

<u>Salamander Observations</u>
- Scuba/snorkel surveys

<u>Macroinvertebrate Sampling</u>
- Drift Nets
- Comal Springs Riffle Beetle Surveys

<u>Recreation Observations</u>
- 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 2012). The discharge data for the Comal Springs ecosystem were taken from USGS gage 08169000 on the Comal River in New Braunfels. This site represents the cumulative discharge of the springs that form this river system.

In addition to the cumulative discharge measurement, the USGS now maintains gages (08168913) and (08168932) on the Old and New Channels, respectively. Specific to each comprehensive sampling effort, discharge was also measured in Spring Runs 1, 2, and 3, and in the Old Channel. These data were used to estimate the contribution of each major Spring Run to total discharge in the river, and to evaluate the relative proportion of water flowing in the Old and New Channels. In 2012, a new site downstream of the Upper Spring Run Reach was added to assess the contribution of the springs in this section of the river. All discharge measurements were taken using a SonTek® FlowTracker.

Low-Flow Sampling

There were no low-flow sampling events on the Comal Springs/River ecosystem in 2012. Full system sampling is triggered at 200 cfs (daily average flow at nearest USGS gage) and reliant upon evaluation and approval from Edward's Aquifer Authority personnel.

High-Flow Sampling

There were no high-flow sampling events on the Comal Springs/River ecosystem in 2012. Full system sampling is triggered at 500 cfs (daily average flow at nearest USGS gage) and reliant upon evaluation and approval from Edward's Aquifer Authority personnel.

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. One important component for maintenance of long-term baseline data is temperature loggers (thermistors), which are placed throughout the river. In addition, fixed station photography continues to provide visual proof of changes in the system. Conventional physico-chemical parameters (water temperature, conductivity, pH, dissolved oxygen, water depth at sampling point, and observations of local conditions) were taken at all drop-net sampling sites using a calibrated handheld multiprobe.

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. To provide a more manageable dataset, 10 minute readings are converted into four-hour averages for analysis. Thermistors were also placed in two deeper locations within Landa Lake using SCUBA. The thermistor locations will not be described in detail here to minimize the potential for 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.

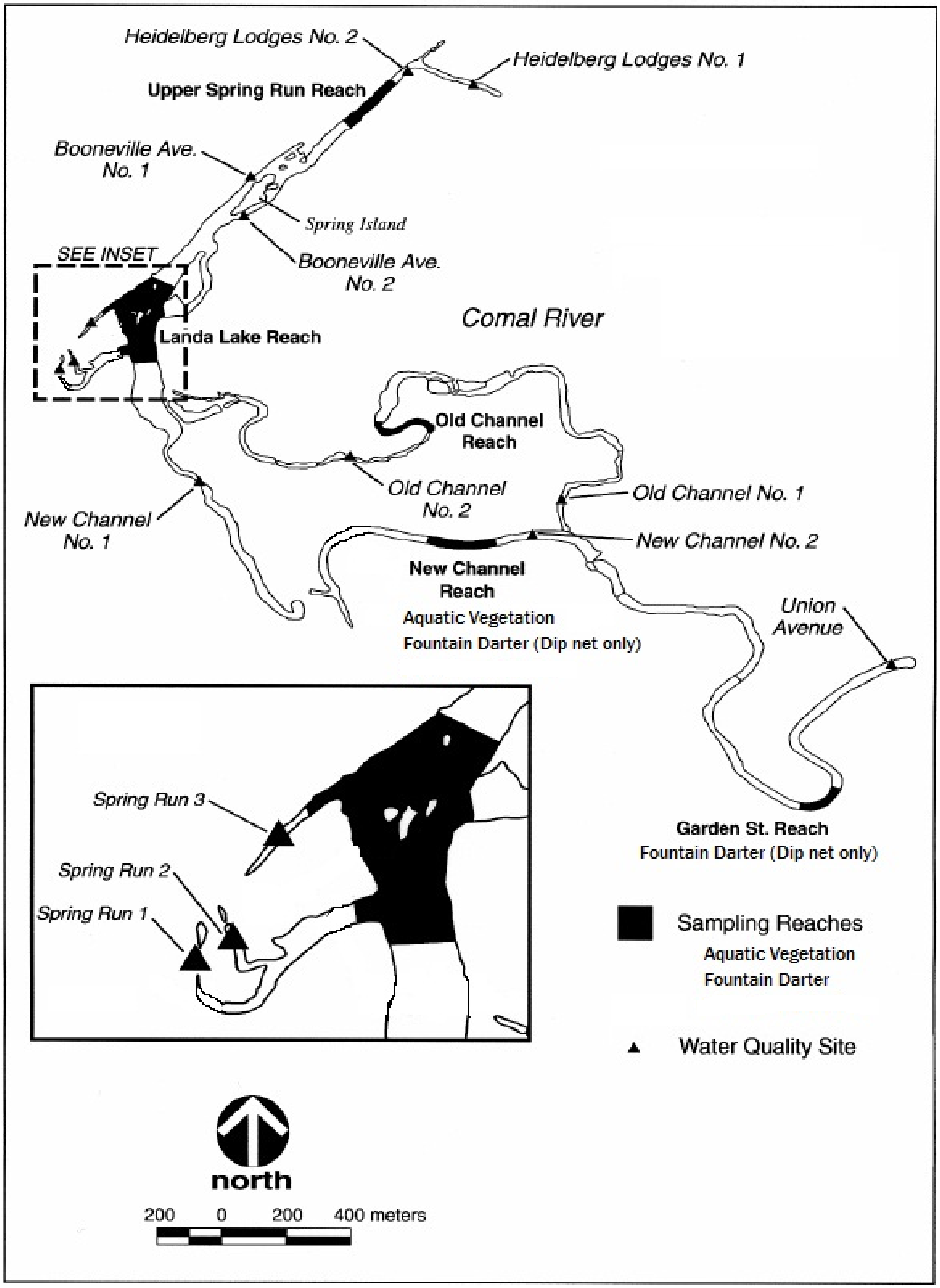


Figure 1. Comal River water quality and biological sampling areas.

Master Naturalist Monitoring

Volunteers with the Texas Master Naturalist program continued their monitoring efforts in 2012 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 was 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.

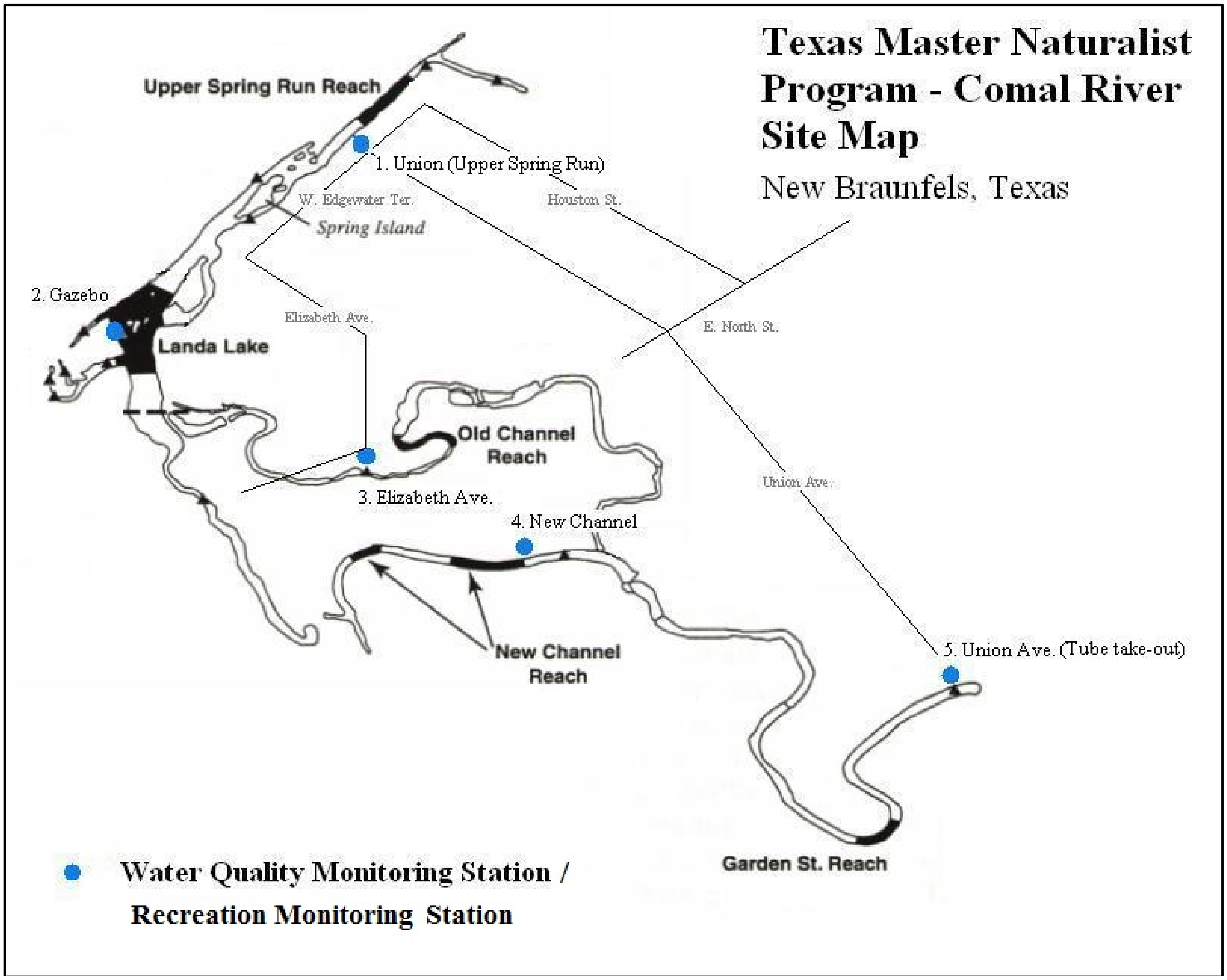
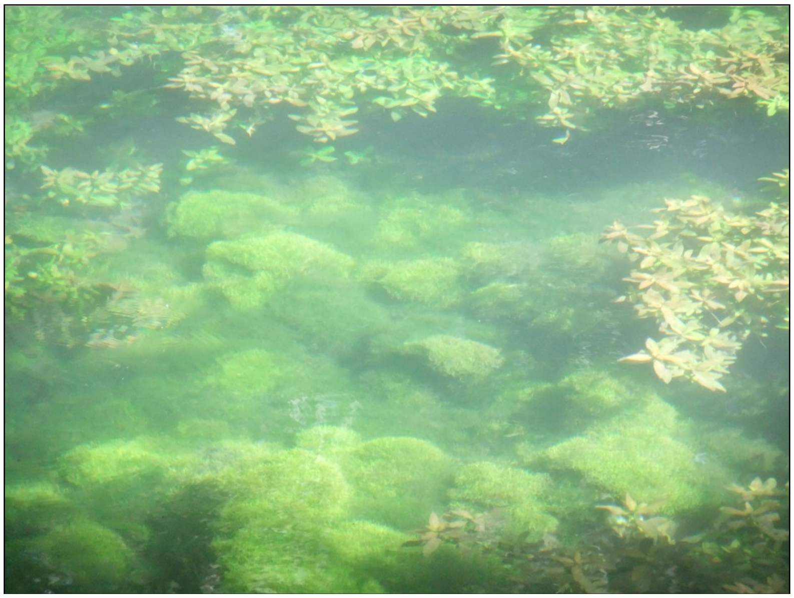


Figure 2. Weekly water quality / recreation monitoring sites on the Comal River used by Texas Master Naturalist volunteers.

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 sub-meter accuracy. The Pro-XH receiver was linked to a Trimble Recon Windows CE device (or similar device) with TerraSync software that displays field data in real time and improves efficiency and accuracy. The GPS unit was placed in a 10.6-foot (ft) Necky Rip 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.



Hygrophila (top) and bryophytes (bottom) in the Old Channel Reach.

Fountain Darter Sampling Methods

Drop Nets

A drop net is a sampling device used by the United States Fish and Wildlife Service (USFWS) to sample fountain darters and other fish species. The net 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 vegetation 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 tuberculatus* and *Tarebia 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 2000-2012 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 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 includes variation. Population estimates based on those densities are greatly influenced by this variation. Part of the variation is due to changes in environmental conditions 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, is based 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 (all values 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 also 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, and the same general areas are sampled during each survey. 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 in 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). 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.

An 8 mm fountain darter collected in the Upper Spring Run 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 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 Springs 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.

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 2012 sampling events. These two-person surveys were conducted in Spring Run 1, Spring Run 3, 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. 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 Run and in the upwelling area on the east side of Spring Island (closest to Edgewater Drive).

Macroinvertebrate Sampling

In 2012, 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 2012 (May/June and November). 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 2012 sampling on the dates shown in Table 1.

Table 1. Study components and sampling dates of the 2012 sampling events.

EVENT	DATES
Spring	
Vegetation Mapping	May 5 - 6, 9, 21
Fountain Darter Sampling	May 14 - 16, 21 - 22
Comal Salamander Observations	May 15
Macroinvertebrate Sampling	May 21 - June 15
Fall	
Vegetation Mapping	Oct. 29 - 31
Fountain Darter Sampling	Oct. 31 – Nov. 1, 5 - 6
Comal Salamander Observations	Nov. 12
Macroinvertebrate Sampling	Nov. 7 – Dec. 9

Comal Springflow

The drought that plagued much of Central Texas during 2011 continued into 2012. Unlike 2011, flows in the Comal River were below the historic average for the entire year (Figure 3). The minimum flow recorded (155 cfs) is the lowest since 2000 (the first year of the current Comprehensive Monitoring study, Table 2). Although flows were consistently lower than average in 2012, no low-flow Critical Period events were triggered. A maximum discharge of 513 cfs was reached during a rain event in late March, which was higher than the maximum discharge (385 cfs) in 2011.

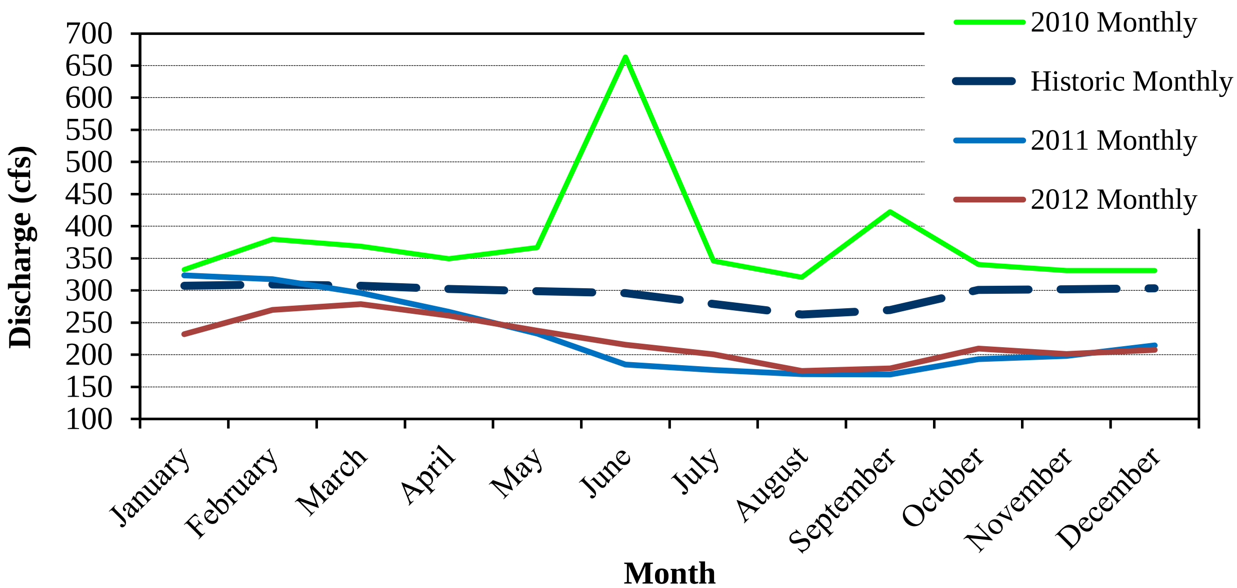


Figure 3. Mean monthly discharge in the Comal River during the 1934 – 2012 period of record.

Table 2. Lowest discharge during each year of the study (2000-2012), 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
2011	159	Sept. 14
2012	155	Sept. 13

In addition to monitoring the cumulative discharge of the Comal River, this study also monitors flow at several specific sites contributing discharge to the river (Table 3). These sites include several spring runs, as well as the Old Channel. In fall 2011, a new site was added to monitor the cumulative discharge of the Upper Spring Run Reach. As discharge increased from fall 2011 to spring 2012 in the Comal River, flows also increased at all sites except the Upper Spring Run Reach. As in most years, Spring Run 3 contributes the most flow of all spring runs. At 20.2 cfs Spring Run 1 flows in spring 2012 were the highest they had been since fall 2010. By fall 2012, total discharge decreased to 199 cfs, which was similar to the discharge observed in fall 2011. Consequently, site-specific discharge was similar at most sites. Fluctuations in discharge at the Old Channel (the downstream-most location which includes flows from other upstream sites) corresponded well with total discharge, but remained below 50 cfs throughout 2012.

Table 4 shows the percent contribution to total discharge for each site-specific discharge measurement. At total flows observed in 2011 and 2012, Spring Run 3 (downstream) contributes the most (of sites measured) flow to the system (≈13%), followed by the Upper Spring Run (6-9%), Spring Run 1 (6-8%), and finally, Spring Run 2 (≈2%). Contributions from springs in other areas in and around Landa Lake are not directly measured, but provide the greatest overall contribution. Approximately, 21-24% of total discharge flows down the Old Channel, whereas the rest is diverted down the New Channel. These percentages change as total flow changes. Continued collection of site-specific discharge data under variable flow conditions will allow for a more complete understanding of flow dynamics in this complex karst spring system.

Table 3. Total discharge in the Comal River (USGS data) and discharge estimates for Spring Runs 1, 2, 3, and Old Channel reach during 2011 and 2012.

Location	Discharge (cfs)			
	Spring 2011	Fall 2011	Spring 2012	Fall 2012
Total Discharge Comal River (USGS)	239	205	242	199
Spring Run 1	15.8	12.5	20.2	12.3
Spring Run 2	5.2	3.2	4.4	4.9
Spring Run 3 (upstream)	9.5	10.4	18.2	14.8
Spring Run 3 (downstream)	30.7	26.4	30.4	25.0
Old Channel	57.7	43.5	49.5	44.2
Upper Spring Run	n/a	16.5	15.5	18.5

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 2011 and 2012.

Location	Percentage of Total Discharge			
	Spring 2011	Fall 2011	Spring 2012	Fall 2012
Spring Run 1	6.6 %	6.1 %	8.3 %	6.1 %
Spring Run 2	2.2 %	1.6 %	1.8 %	1.6 %
Spring Run 3 (upstream)	2.4 %	5.1 %	7.5 %	5.1 %
Spring Run 3 (downstream)	12.8 %	12.9 %	12.6 %	12.9 %
Old Channel	24.2 %	21.2 %	20.5 %	21.2 %
Upper Spring Run	n/a	8.0 %	6.4 %	9.3 %

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/River ecosystem from 2000-2012. 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 dips. 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).

Four-hour average water temperature data for the Comal Headwaters (Blieder's Creek and Heidelberg) are presented in Figure 4. This figure exhibits the disparity between a thermistor near a spring input (Heidelberg) and a non-spring area (Blieder's Creek). Blieder's Creek is fed by runoff from the surrounding area, and backup from the springs near the upstream end of the Upper Spring Run Reach. As a result, ambient air temperatures typically cause large water temperature fluctuations in Blieder's Creek, whereas water temperatures at Heidelberg are relatively constant due to the constant temperature of the spring inputs. Blieder's Creek was also the only site where four-hour average water temperatures exceeded the 26.7 ºC Texas Commission on Environmental Quality [TCEQ] water quality standard for the Comal River. Downstream sites like the Other Place, New Channel, and Old Channel had wider temperature fluctuations than sites closer to spring inputs, but did not exceed the water quality standard. Temperatures in the Spring Runs and Landa Lake vary little (<1 ºC) as most of the water comes from the near constant temperatures of the Edward's Aquifer.

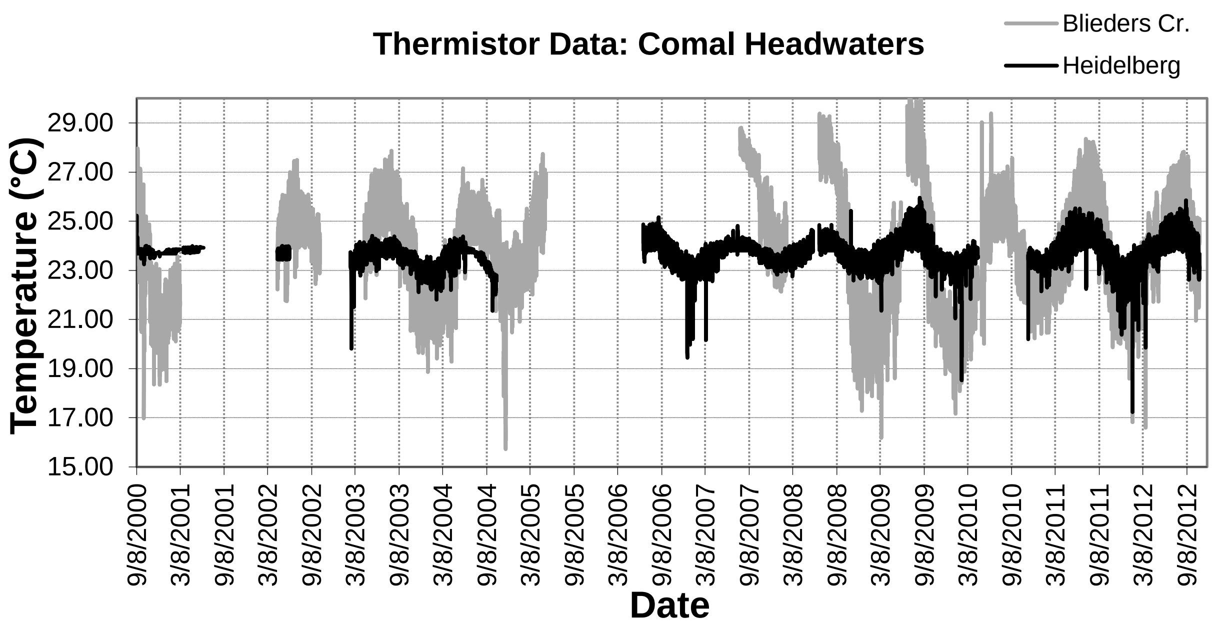


Figure 4. Water temperature (°C) data at Comal Headwaters from 2000 – 2012.

Texas Master Naturalist Monitoring

Water quality data collected by Master Naturalist volunteers in 2012 showed that carbon dioxide (CO_2) concentrations continue to be highest near springs (Houston Street [Upper Spring Run Reach], Gazebo [Landa Lake/ Spring Run 3], Figure 5), whereas pH increased going downstream (Figure 6). The inverse relationship between these two variables is due to the presence of carbonic acid in spring waters. As CO_2 concentrations (and thus, carbonic acid concentrations) decline going downstream, pH rises. Within sites, year to year variation was relatively small in both CO_2 concentrations and pH. However, discharge-related trends are apparent, with 2007 (a high flow year) exhibiting slightly lower pH and slightly higher CO_2 than in other years. Discharge-related trends in these two parameters will become more predictable as additional data is collected.

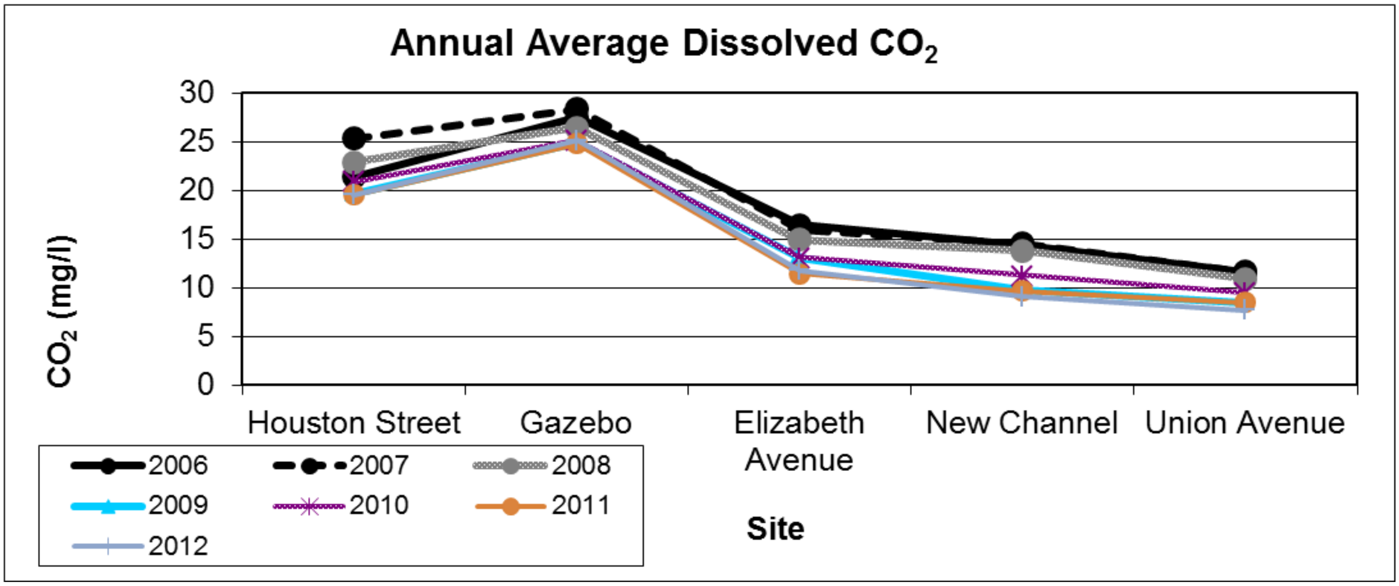


Figure 5. Annual average dissolved carbon dioxide (CO_2) concentrations at five sites on the Comal River system (2006-2012).

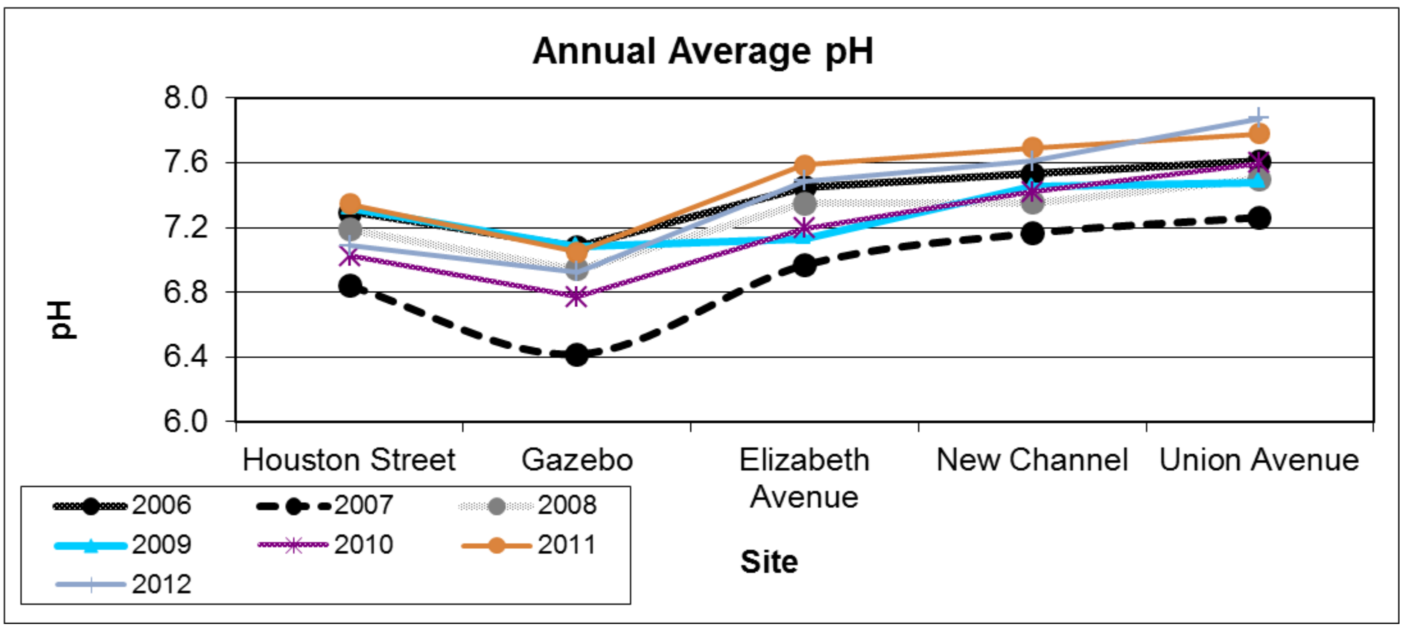


Figure 6. Annual average pH values at five sites on the Comal River system (2006-2012).

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 7 - 11). As in previous years, recreation use at Elizabeth Street was very low (Figure 7) because this area is not located within a city park. The annual summer increase in recreation at the Upper Spring Run is likely a result of more people staying at the Heidelberg Lodges (Figure 8). The Landa Lake park gazebo area is used for recreation regularly during all months of the year (Figure 9), and expectedly decreased after this area was closed to vehicles (2010 – 2012) following the 2010 flood. The New Channel site is the most heavily recreated site, with recreation concentrated from March until September (Figure 10). Tubing is the dominant recreational activity at this site, especially between May and September. This site is heavily used by tubers as an access point to the river. 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 11).

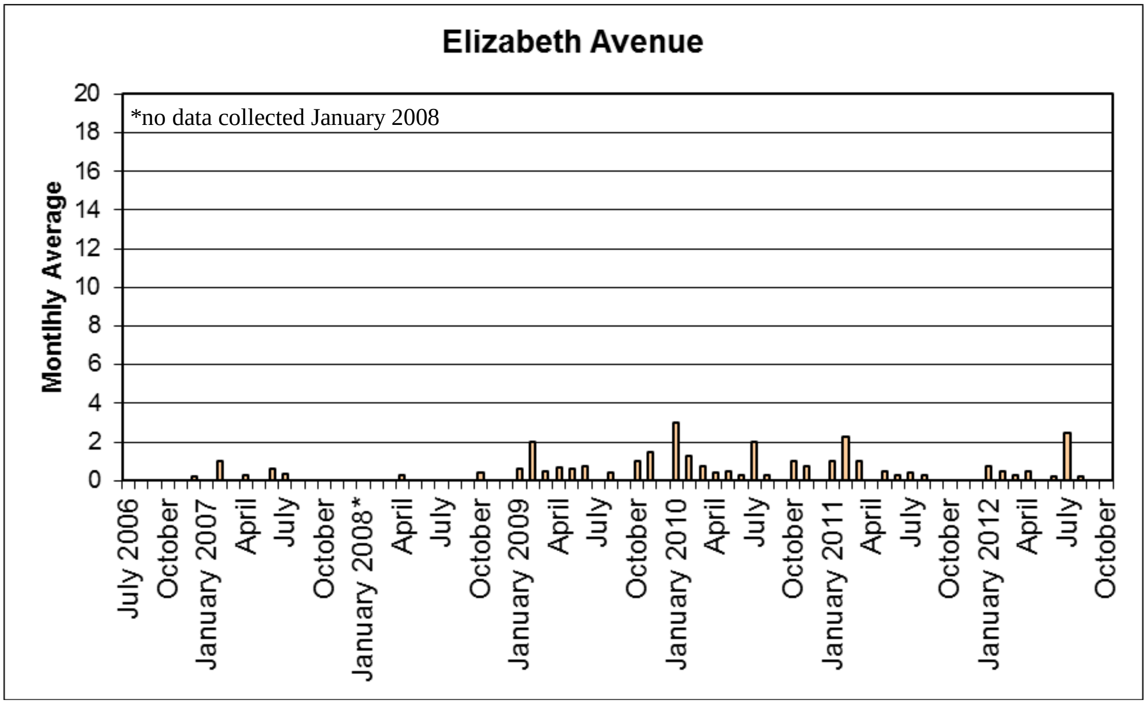


Figure 7. Average recreational use counts at the Elizabeth Avenue site (2006-2012).

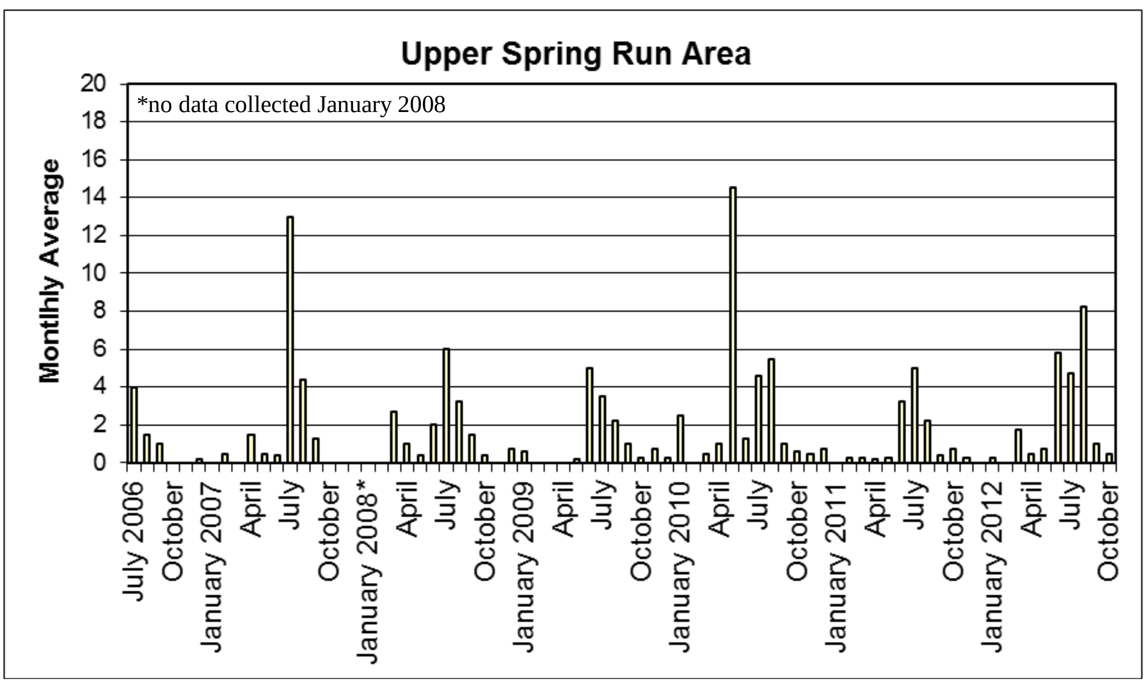


Figure 8. Average recreational use counts at the Upper Spring Run area (2006-2012).

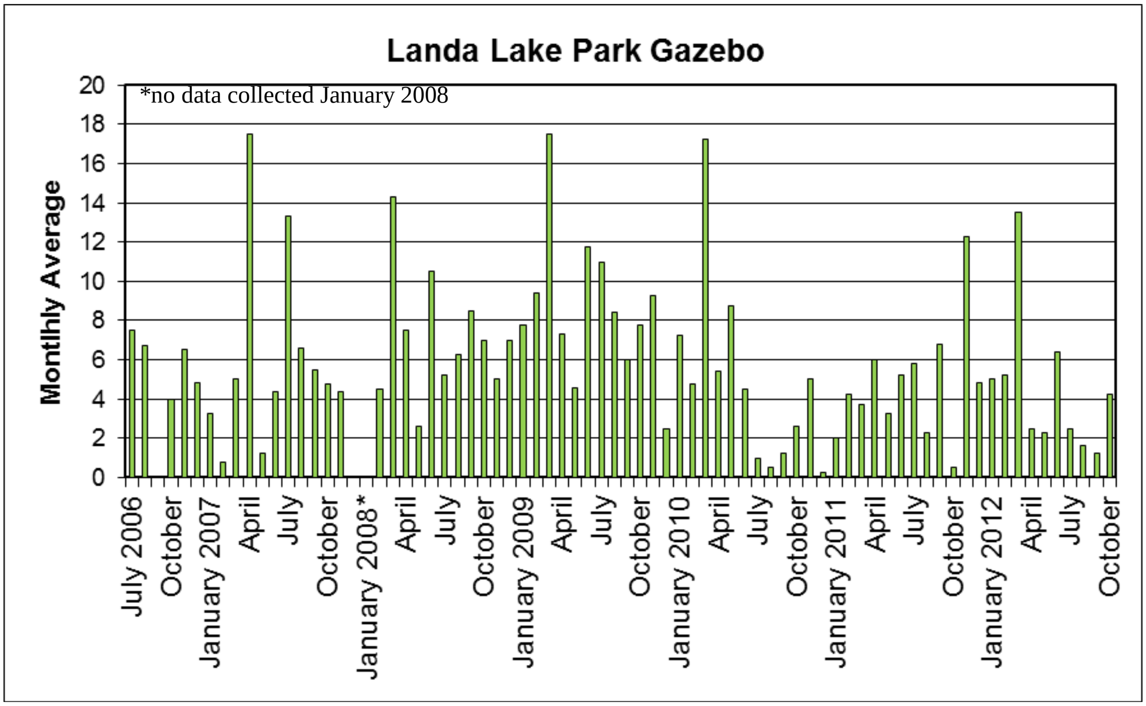


Figure 9. Average recreational use counts at the Landa Lake Park Gazebo site (2006-2012).

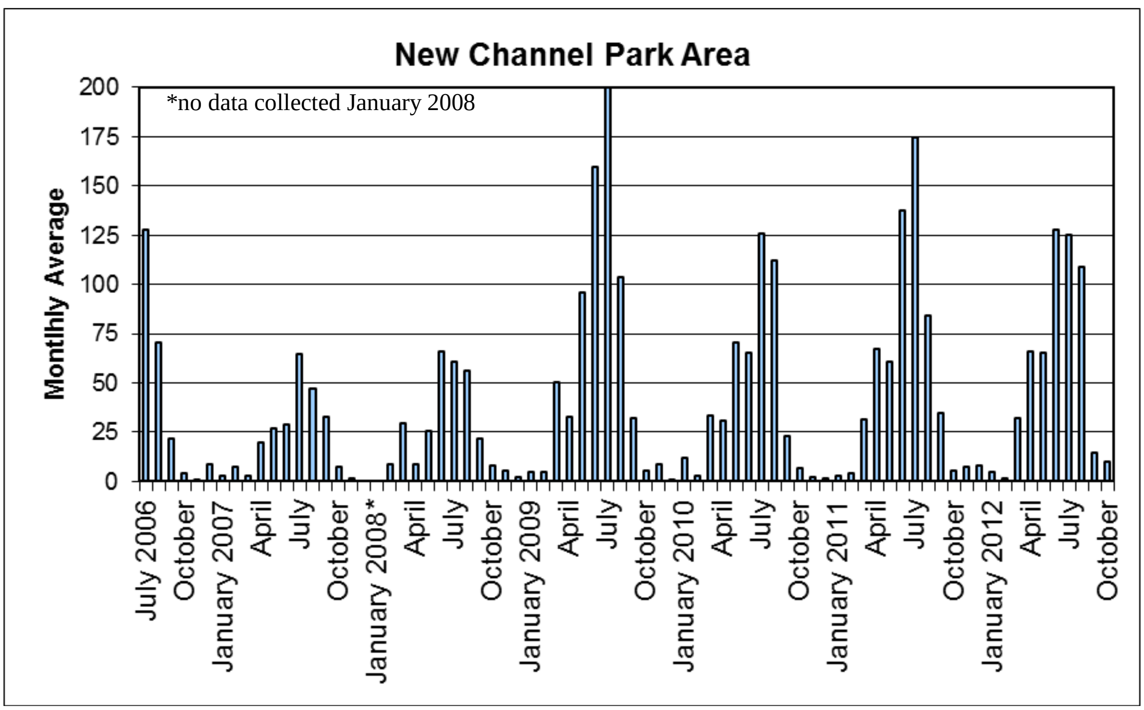


Figure 10. Average recreational use counts at the New Channel site (2006-2012) (note y-axis scale difference from previous recreation figures).

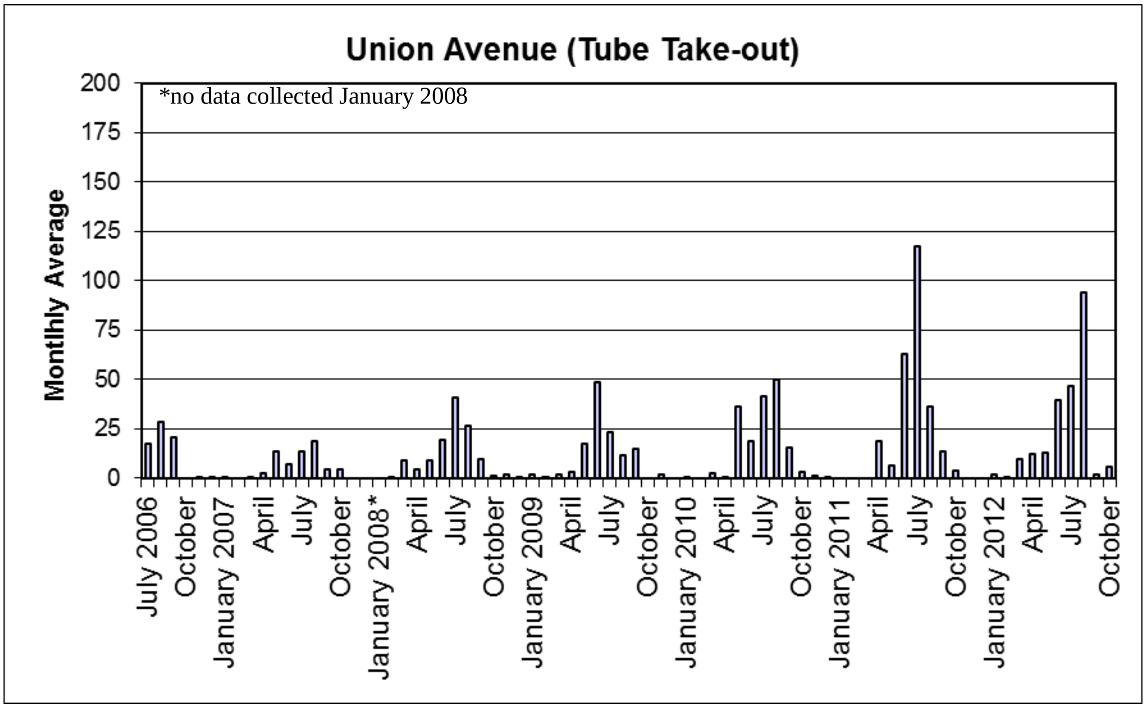


Figure 11. Recreational use counts at the Union Avenue site (2006-2012).

Aquatic Vegetation Mapping

Maps of 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

The Upper Spring Run Reach is the most upstream reach of the Comal River in this study. In addition, the springs creating much of the flow here are higher in elevation than their downstream counterparts (Spring Island, Landa Lake complex). This creates a unique reach where vegetation often responds differently than in other reaches.

Despite lower than average flows in the Comal River entering spring 2012, aquatic vegetation continued to recolonize this reach. Bryophytes dominated much of the upper section of the reach after it was only found in small patches in fall 2011. This boom/bust cycle typifies these mosses because they don't adhere to the substrate well and are prone to scouring during rainfall events. Understanding changes in bryophytes is very important because high densities ($\approx 28/m^2$) of fountain darters are found here. The other dominant vegetation in this reach is *Sagittaria*. Although this plant exhibits lower densities of fountain darters ($\approx 4/m^2$), this native plant is none the less important because it can withstand scouring events (2010) and may be a refuge for darters because it is not easily uprooted. The most abundant non-native plant in this reach is *Hygrophila*, which nearly tripled in coverage from fall 2011 to spring 2012 (60.2 m^2 to 175.0 m^2). *Ludwigia*, a native plant, continued to have a tenuous foothold in the Upper Spring Run Reach.

Lower flows combined with abundant sunlight often results in large algal blooms in this reach that inhibit the growth of bryophytes. This is likely why total coverage of bryophytes decreased by almost 1,400 m^2 (1,727.0 m^2 to 356.5 m^2) from spring to fall 2012. At the same time, green algae coverage increased nearly 25X from spring to fall. As with bryophytes, this appears to be part of a natural boom/bust cycle related to seasons. With few precipitation events in 2012, *Hygrophila* changed little, while *Ludwigia* increased over the course of 2012. *Sagittaria* also changed little in total coverage (772.1 m^2 to 803.0 m^2).

Landa Lake Reach

While discharge remained below the historic average in the Comal River in 2012, all vegetation types (except *Cabomba*) increased in coverage in the Landa Lake reach from fall 2011 to spring 2012. Bryophytes occupied their usual location in the upstream part of the reach increasing in surface area by 20X over winter. As in the Upper Spring Run Reach, bryophytes exemplify the boom/bust cycle of some plants. However, their importance to fountain darters cannot be overstated due to the high numbers of the endangered fish found in them. By fall, bryophytes increased slightly (2,404 m^2 to 2,515.3 m^2) and continued to dominate the upper portions of the Landa Lake Reach. *Vallisneria* continues to dominate the rest of Landa Lake, especially in the deeper portions of the lake. It increased from 12,855.8 m^2 (fall 2011) to 13,027.7 m^2 (spring 2012), and continued to expand by fall 2012 (13,591.7 m^2). Although it is less important to fountain darters compared to other vegetation, its dominance in the reach makes it an important feature of the ecology of Landa Lake.

Ludwigia is a native plant that has been decreasing in coverage over the last several years, but is important habitat to fountain darters. However, unlike previous years it showed a continual increase in 2012. It more than doubled in coverage from 2011 to 2012 (11.8 m^2 to 24.7 m^2), and increased further by fall 2012 (31.4 m^2). These plants will be closely monitored to try and understand what is affecting their tenuous hold in this reach. *Cabomba* is another native plant that maintains relatively high densities of darters. Unlike *Ludwigia*, *Cabomba* coverage has been increasing over the past couple years in the Landa Lake Reach. It reached its highest coverage in fall 2011 (481.4 m^2), but decreased slightly by spring 2012 (445.8 m^2, though some of this decrease may be due to it mixing with *Vallisneria* in some parts of the lake). By fall, *Cabomba* had the greatest coverage (495.5 m^2) in Landa Lake since the inception of the study. The central part of the reach has long been dominated by non-native *Hygrophila*. In 2011 it reached its lowest coverage (346.8 m^2) in the reach since the study began, but quickly rebounded in 2012. By spring it reached 575.5 m^2, but fell off slightly by fall 2012 (459.6 m^2). Although not preferred as much as other native plants, this plant maintains the highest densities of fountain darters of any non-native vegetation in the Comal River.

Old Channel Reach

Hygrophila continues to be the most dominant vegetation type in the Old Channel Reach increasing slightly from fall 2011 (1,816.8 m^2) to spring 2012 (1,820.2 m^2). It decreased by fall (1,696.6 m^2), but still makes up the greatest portion of vegetation in this reach. *Hygrophila* flourishes in the Old Channel, and has been crowding out native *Ludwigia* (which has higher fountain darter densities) over the last several years. *Ludwigia* declined over the course of 2012, from 29.2 m^2 to 20.4 m^2 (fall); this is near the lowest coverage observed in this study. Bryophytes increased coverage from fall 2011 (28.4 m^2) to fall 2012 (280.8 m^2), a ten-fold increase to the highest coverage ever observed at the Old Channel Reach in this study. It currently occupies large portions of the deeper slower habitat near a bend in the Comal River. Since high densities of fountain darters occupy bryophytes in the Comal River, this could mean increased populations of the endangered fish if bryophytes remain in the Old Channel Reach.

Filamentous algae, which covered a significant portion of this reach in the past, were still absent from the reach in 2012.

New Channel Reach

Lack of any major precipitation events in the Comal River in 2012 resulted in the continued growth of vegetation in the New Channel Reach. Because this reach is channelized with cement walls on both sides running the length of the reach, storm events often lead to intense scouring. Native *Cabomba* increased from 743.1 m^2 (fall 2011) to 930.7 m^2 (spring 2012), and it continued to grow into the fall (1,409.6 m^2) along river left near the mid and bottom parts of the reach. This coverage of *Cabomba* in 2012 was the highest recorded thus far in the study. *Hygrophila* followed a similar path increasing from fall 2011 (733.1 m^2) to spring (1,054.9 m^2) and fall 2012 (1,159.7 m^2). *Hygrophila* currently covers much of the upper and river right sections of the reach. No *Ludwigia* plants were found in fall 2012, after two plants disappeared that were present in spring. Close monitoring of this reach will continue as it is most susceptible to plant loss due to scouring following storm events.

Fountain Darter Sampling Results

Drop Nets

A total of 44 drop net samples were conducted during 2012 in the Comal Springs/River Ecosystem. Table 5 shows the number of drop net samples taken from each vegetation type in each reach during 2012 sampling events.

Table 5. Number of drop net samples collected in each vegetation type per reach during 2012 sampling events.

Vegetation Type	Spring (May 14-16)			Fall (Oct. 31-Nov. 1)		
	Upper Spring Run	Landa Lake	Old Channel	Upper Spring Run	Landa Lake	Old Channel
Bryophytes	2	2		2	2	1
Ludwigia		2	2		2	2
Hygrophila	2	2	4	2	2	3
Sagittaria	2			2		
Vallisneria		2			2	
Cabomba		2			2	
TOTAL	6	10	6	6	10	6

From the above samples, a total of 1,013 fountain darters were collected. Six hundred and eleven darters were collected during spring sampling, and 402 were collected during fall. Excluding collections from the New Channel Reach since it is no longer sampled; the number captured during each full event over the course of the study has varied from 224 to 901. Figure 12 demonstrates 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 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 12 shows that fountain darter abundance varies considerably. Data suggests a rather dynamic but stable population throughout the study period.

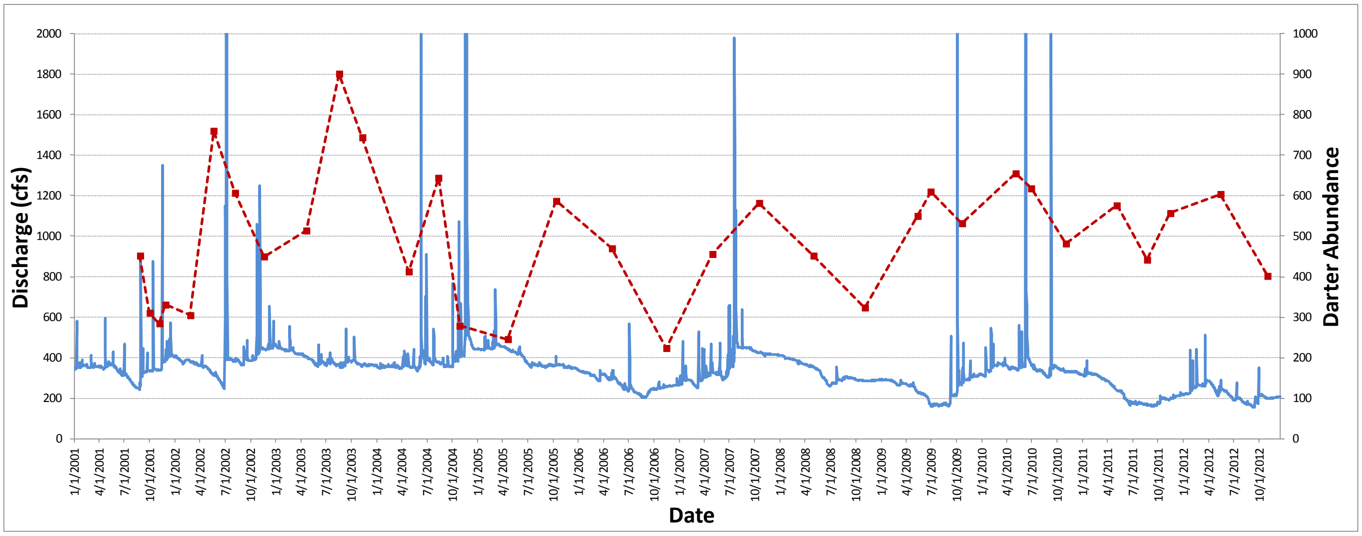


Figure 12. Abundance of fountain darters from each drop net sampling event (red dashed line) plotted over a hydrograph of mean daily discharge from the USGS gauge on the Comal River at New Braunfels (blue line).

Drop net data collected from 2000-2012 show that average densities of fountain darters in the various vegetation types ranged from $3.6/m^2$ in *Ceratopteris* to $27.8/m^2$ in bryophytes (Figure 13). 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 [$22.4/m^2$]) 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* [$4.6/m^2$] and *Sagittaria* [$4.2/m^2$]) 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 (10.0 and $13.5/m^2$, 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. These plants are not firmly rooted to the substrate, and can be easily uprooted in higher velocities. Filamentous algae were once the dominant vegetation type in the Old Channel Reach; however, it has been replaced in recent years mostly by *Hygrophila*. 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 considered an important habitat component because it is abundant in all sample reaches.

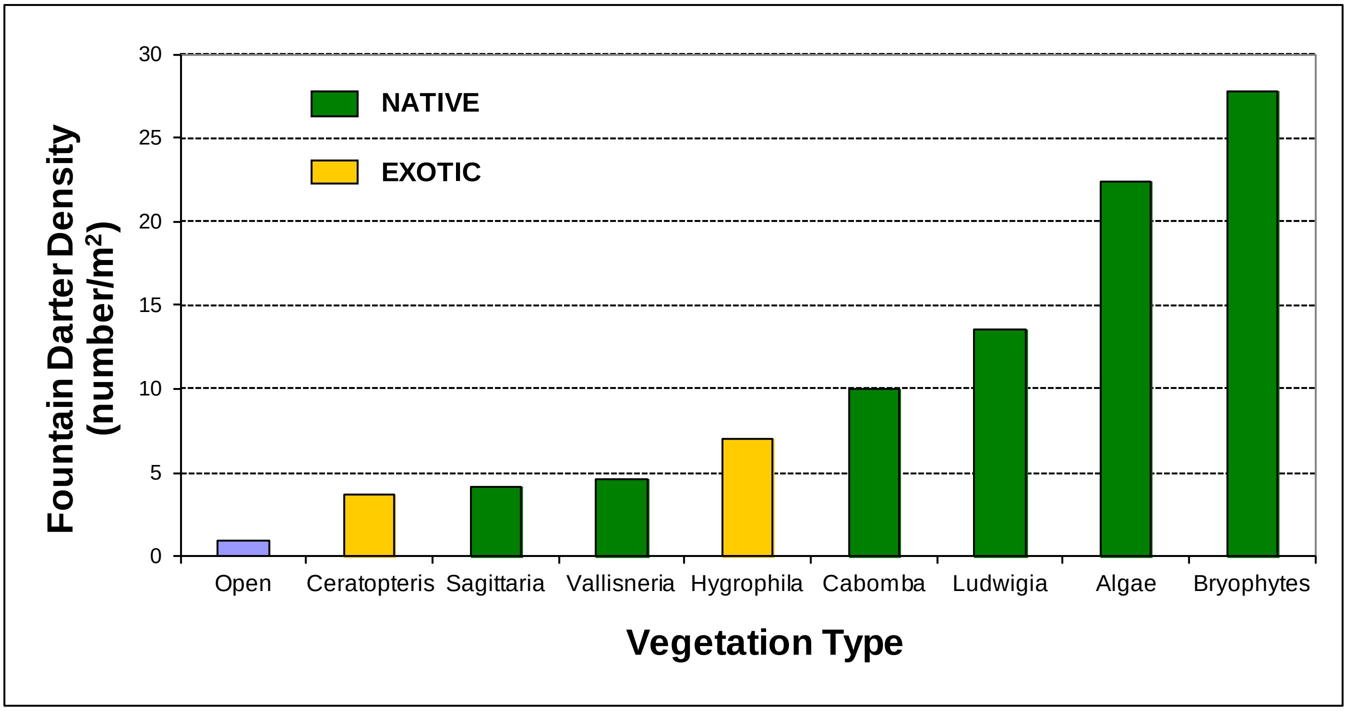


Figure 13. Density of fountain darters collected by vegetation type in the Comal Springs/River Ecosystem from 2000-2012.

Estimates of fountain darter population abundance in all reaches (Figure 14) 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 large 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. In fact, prior to summer 2001, bryophytes in the Landa Lake Reach were not sampled – leading to considerably lower population estimates. Estimates of population abundance were highest in spring 2003 when coverage of bryophytes peaked in Landa Lake (Figure 14).

Population estimates were low throughout most of 2010 and 2011. A large localized flood event (the largest during the study) in June 2010 resulted in intensive scouring of the aquatic vegetation in the Upper Spring Run Reach and Old Channel Reach. Previous high-flow events have led to less-intense scouring, and the system typically recovers quickly as large rainfall events often lead to increased springflow. However, sustained low flows following the June 2010 event resulted in limited recovery of vegetation within the Upper Spring Run Reach. Although conditions had begun to improve by spring 2011, low springflows in summer 2011 led to a continued decline in the bryophytes of this reach, resulting in low fountain darter habitat quality. As a result, population estimates remained low through summer and fall 2011. Fortunately, habitat conditions in the Upper Spring Run and upper portion of the Landa Lake Reach improved considerably between fall 2011 and spring 2012. Large contiguous patches of bryophytes returned to these areas, resulting in an increase in available fountain darter habitat. Relatively stable flows through summer 2012 resulted in only a slight decrease in population estimates by fall 2012. This slight decrease is expected, as vegetation conditions are typically best in spring and decline slightly by fall.

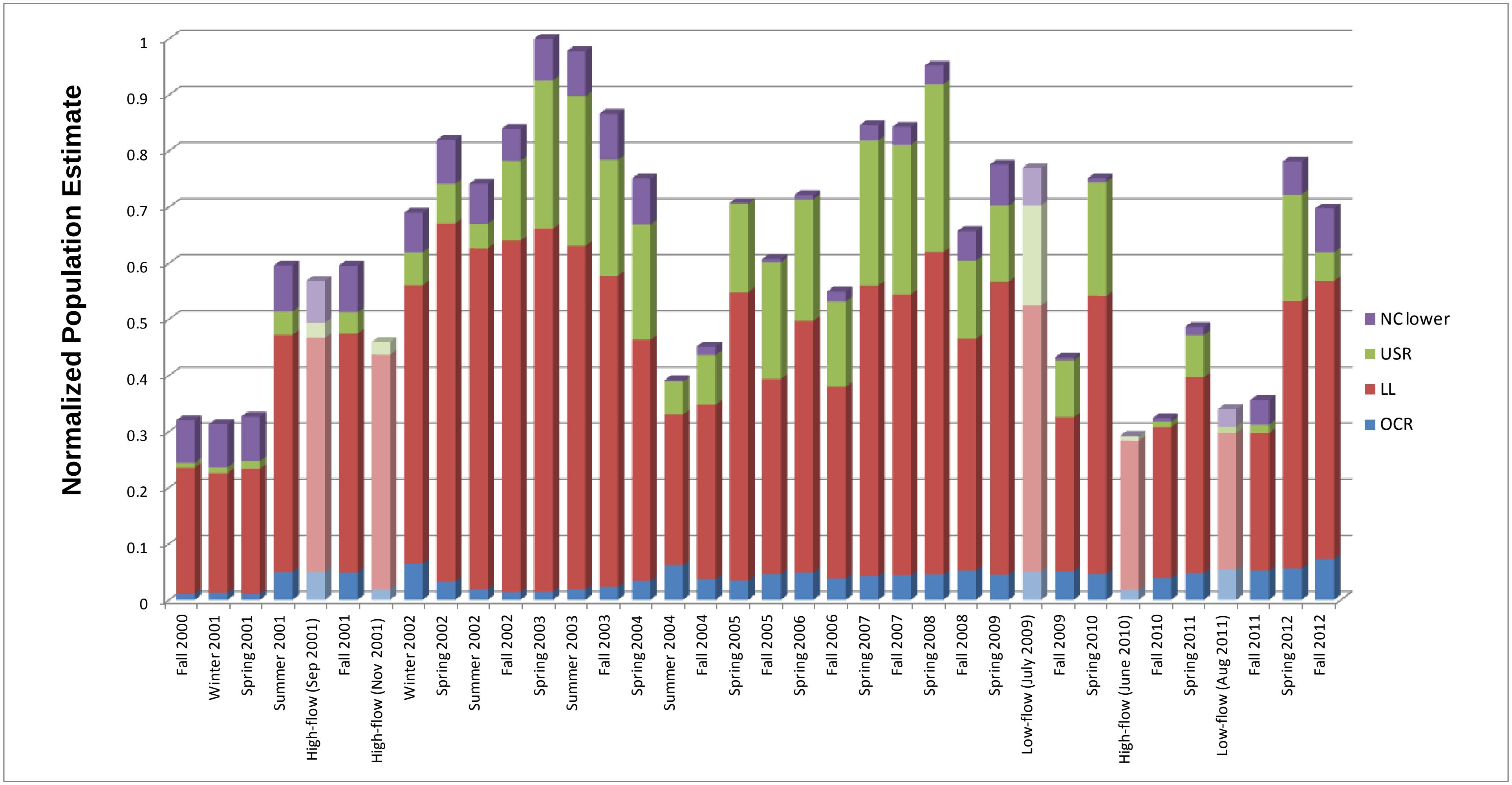


Figure 14. Population estimates of fountain darters in all four sample reaches combined (2000-2012). Values are normalized to the maximum sample. Lighter colors represent critical period sampling events.

The length-frequency distribution for fountain darters collected by drop nets from each reach of the Comal ecosystem during each 2012 sampling event is presented in Figure15 (data collected in previous years is presented in Appendix B). Analysis of length-frequency data from previous years suggests year-round reproduction with a spring time reproductive peak. However, length frequency data varies by habitat. For example, in Landa Lake bryophytes, small darters (<16 mm, and thus less than approximately 60 days old) are present year-round. However, in Landa Lake *Hygrophila*, small darters are typically only present in substantial numbers during spring samples. Although this could be a function of small darters simply selecting bryophyte habitats, this is doubtful given the distance between these habitat types in Landa Lake and considering that studies show little movement by fountain darters in such habitats (Dammeyer 2010). More likely, this represents continuous reproduction/recruitment of fountain darters in bryophytes, and more limited seasonal reproduction/recruitment in other areas. Whether this results from increased spawning activity/egg deposition in bryophytes or increased survival/recruitment of juvenile fountain darters in these habitats is currently unknown. Recent studies on fountain darter egg deposition in the San Marcos River support the egg deposition theory, finding significantly more eggs were deposited on filamentous algae (similar in growth form to bryophytes) than on common vegetation with other growth forms including *Hygrophila* (Phillips et al. 2011). An egg deposition study with a seasonal component, in which bryophytes were included, could potentially confirm this. Additionally, studies examining recruitment of juvenile fountain darters in various habitat types could help explain the biological mechanisms behind these habitat-specific patterns in length frequency.

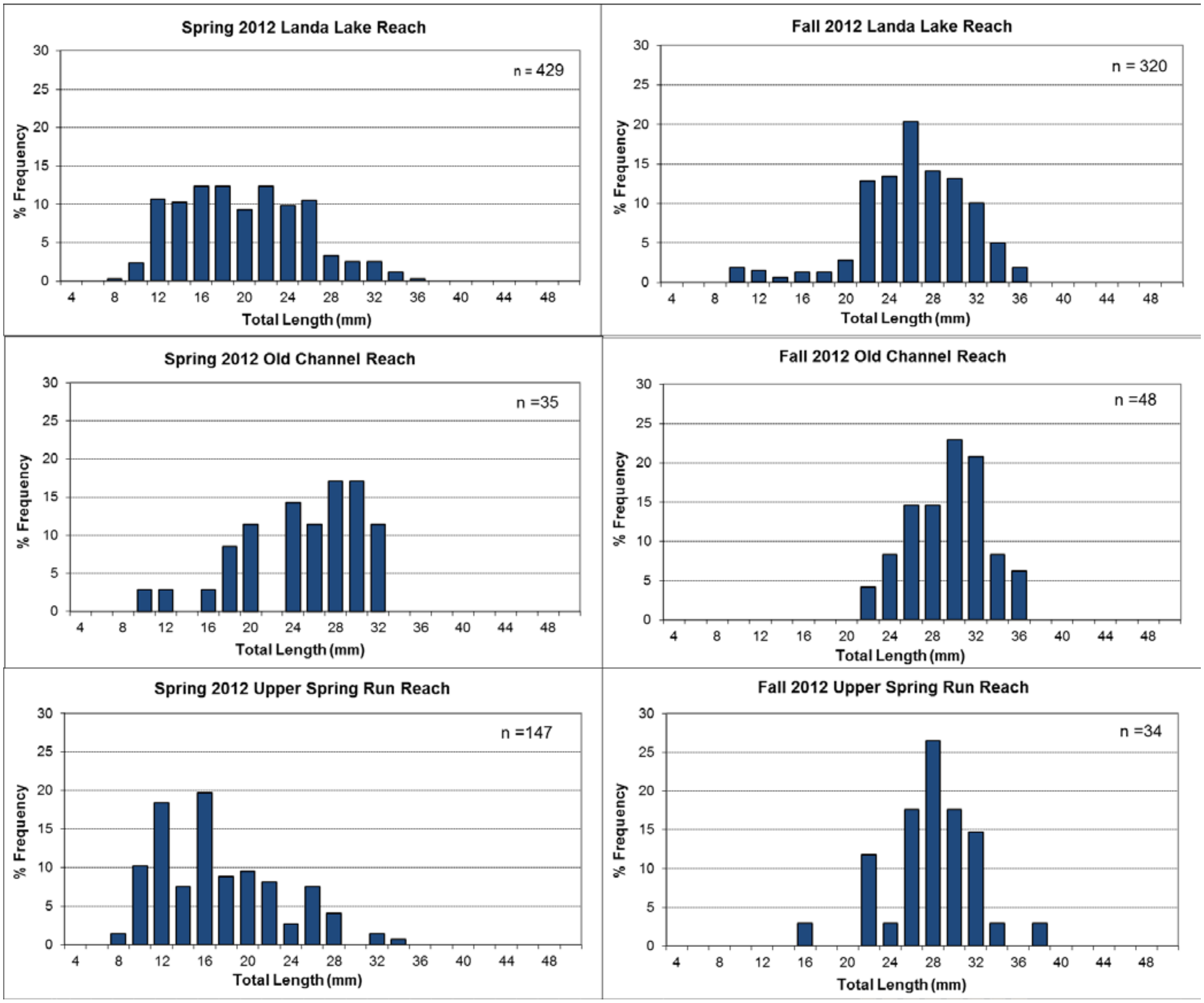


Figure 15. Length frequency distribution of fountain darters collected from the Comal River by drop netting in 2012.

In addition to fountain darters, 140,298 specimens representing at least 25 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 suggests 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. Therefore, close monitoring and management of the *H. plecostomus* population is crucial.

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

Family	Scientific Name	Common Name	Status	2012	2000-2012
Cyprinidae	*Campostoma anomalum*	Central stoneroller	Native	0	1
	Dionda nigrotaeniata	Guadalupe roundnose minnow	Native	102	1,148
	Notropis amabilis	Texas shiner	Native	183	410
	Notropis volucellus	Mimic shiner	Native	0	32
	Pimephales vigilax	Bullhead minnow	Native	0	4
Characidae	*Astyanax mexicanus*	Mexican tetra	Introduced	47	479
Ictaluridae	*Ameiurus melas*	Black bullhead	Native	0	1
	Ameiurus natalis	Yellow bullhead	Native	0	108
Loricariidae	*Hypostomus plecostomus*	Armadillo del rio	Introduced	1	72
Poeciliidae	*Gambusia* sp.	Mosquitofish	Native	5,754	128,177
	Poecilia latipinna	Sailfin molly	Introduced	170	4,843
Centrarchidae	*Ambloplites rupestris*	Rock bass	Introduced	0	24
	Lepomis auritus	Redbreast sunfish	Introduced	0	143
	Lepomis cyanellus	Green sunfish	Native	0	10
	Lepomis gulosus	Warmouth	Native	0	32
	Lepomis macrochirus	Bluegill	Native	2	215
	Lepomis megalotis	Longear sunfish	Native	5	263
	Lepomis microlophus	Redear sunfish	Native	0	2
	Lepomis miniatus	Redspotted sunfish	Native	138	2,052
	Lepomis sp.	Sunfish	Native/Introduced	58	840
	Micropterus punctulatus	Spotted bass	Native	0	3
	Micropterus salmoides	Largemouth bass	Native	449	639
Percidae	*Etheostoma fonticola*	Fountain darter	Native	1,013	17,980
	Etheostoma lepidum	Greenthroat darter	Native	3	54
Cichlidae	*Cichlasoma cyanoguttatum*	Rio Grande cichlid	Introduced	15	680
	Oreochromis aureus	Blue tilapia	Introduced	0	66
Total				7,940	158,278

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 (*Marisa cornuarietis*). During the late 1980s and early 1990s, giant ramshorn snails were reported to be extremely abundant in the Comal System, and apparently denuded macrophyte beds in portions of Landa Lake (Horne et al. 1992). During this period, between 2 and 12 million ramshorn snails were believed to be present in the Comal Springs/Landa Lake area (Arsuffi et al. 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 System. In 2009 and 2010, three snails were collected each year. In 2011, this number increased to 35, and in 2012, 34 giant ramshorn snails were collected. The reason for the increase in 2011 and 2012 is currently unknown. Although the bulk of these snails were collected from the Landa Lake Reach, they have also been documented in the Upper Spring Run and Old Channel reaches. Figure 16 shows the number of giant ramshorn snails collected per drop net sample during each year. Given the recent increase in numbers of giant ramshorn snails, close monitoring of the population will be necessary in the coming years. Continued monitoring will also allow for assessing the effectiveness of EAHCP measures aimed at controlling this exotic species.

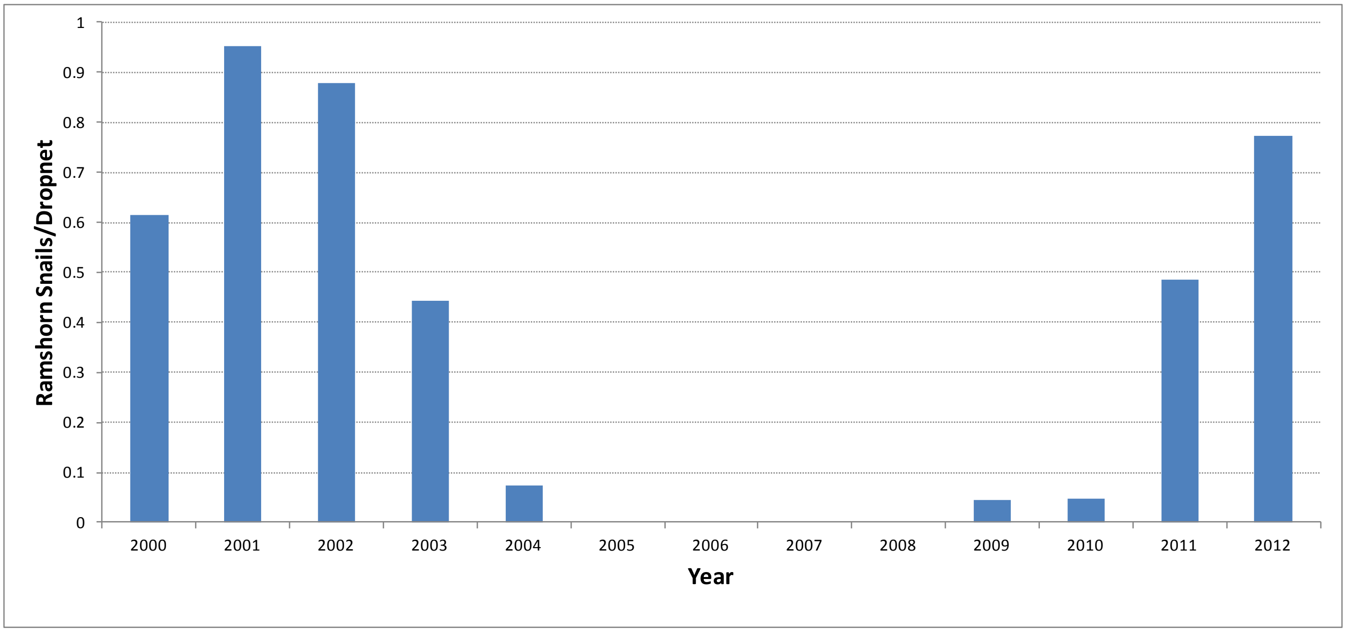


Figure 16. Abundance of giant ramshorn snails in drop net collections from the Comal Springs/River Ecosystem during 2000-2012.

Giant ramshorn snails collected in the Comal River.

Dip Nets

The boundaries for each section of the dip net collection efforts are depicted in Figure 17. Data gathered using dip nets are graphically represented in Figure 18 for the Old Channel Reach, Figure 19 for the Upper Spring Run Reach, and in Appendix B for all other reaches.

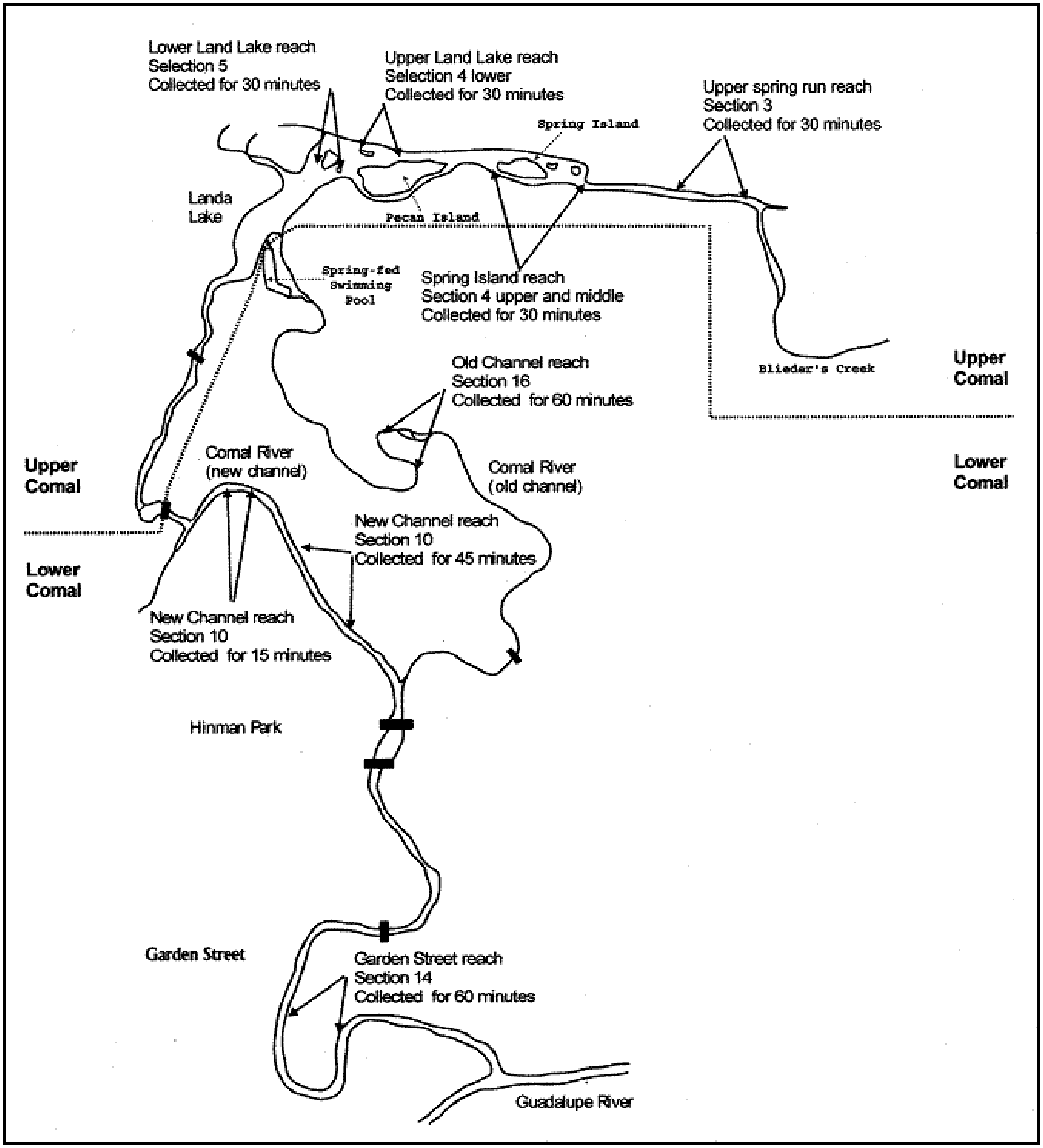


Figure 17. Areas where fountain darters were collected with dip nets, measured, and released in the Comal River.

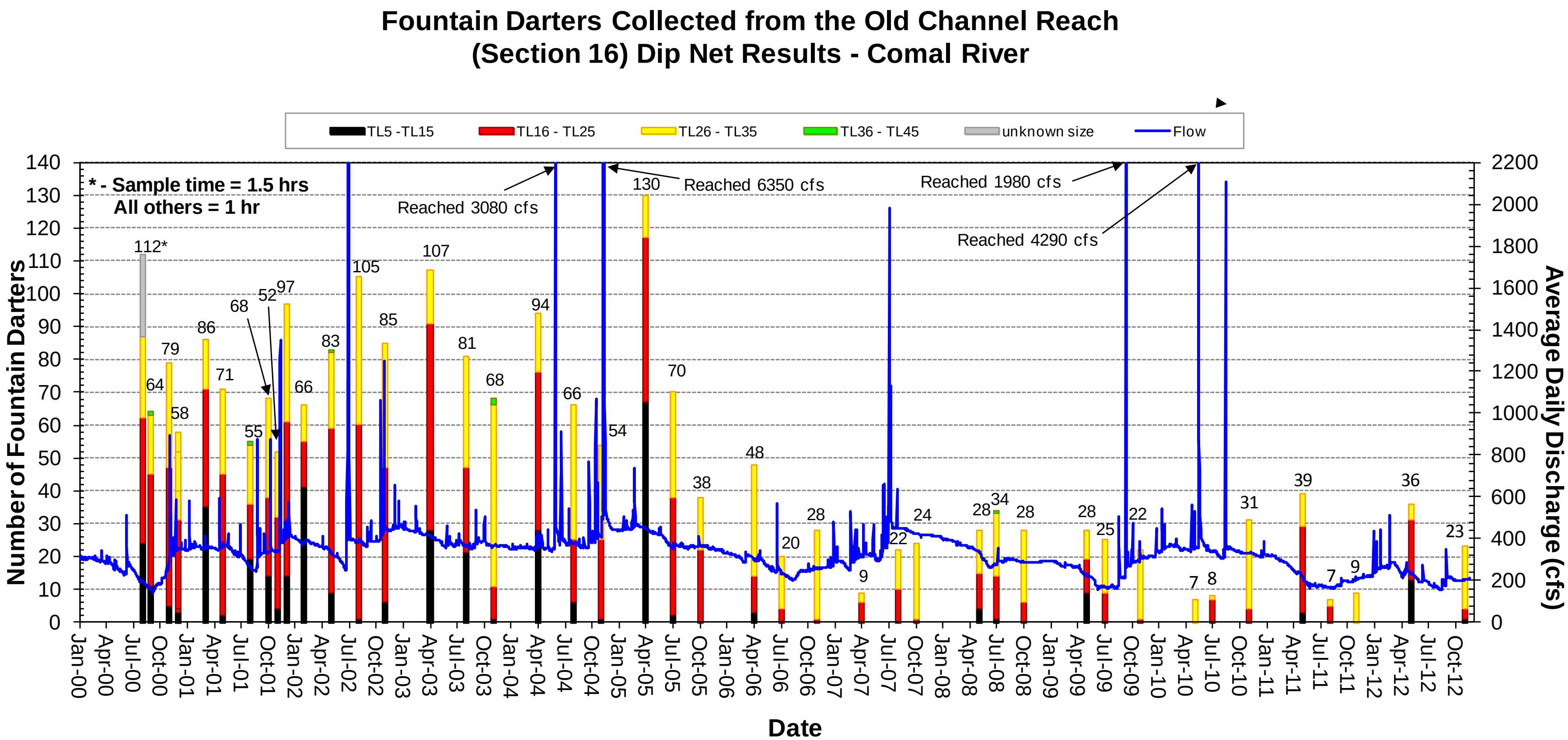


Figure 18. Number of fountain darters, by sample date and size class, collected from the Old Channel Reach (section 16) using dip nets.

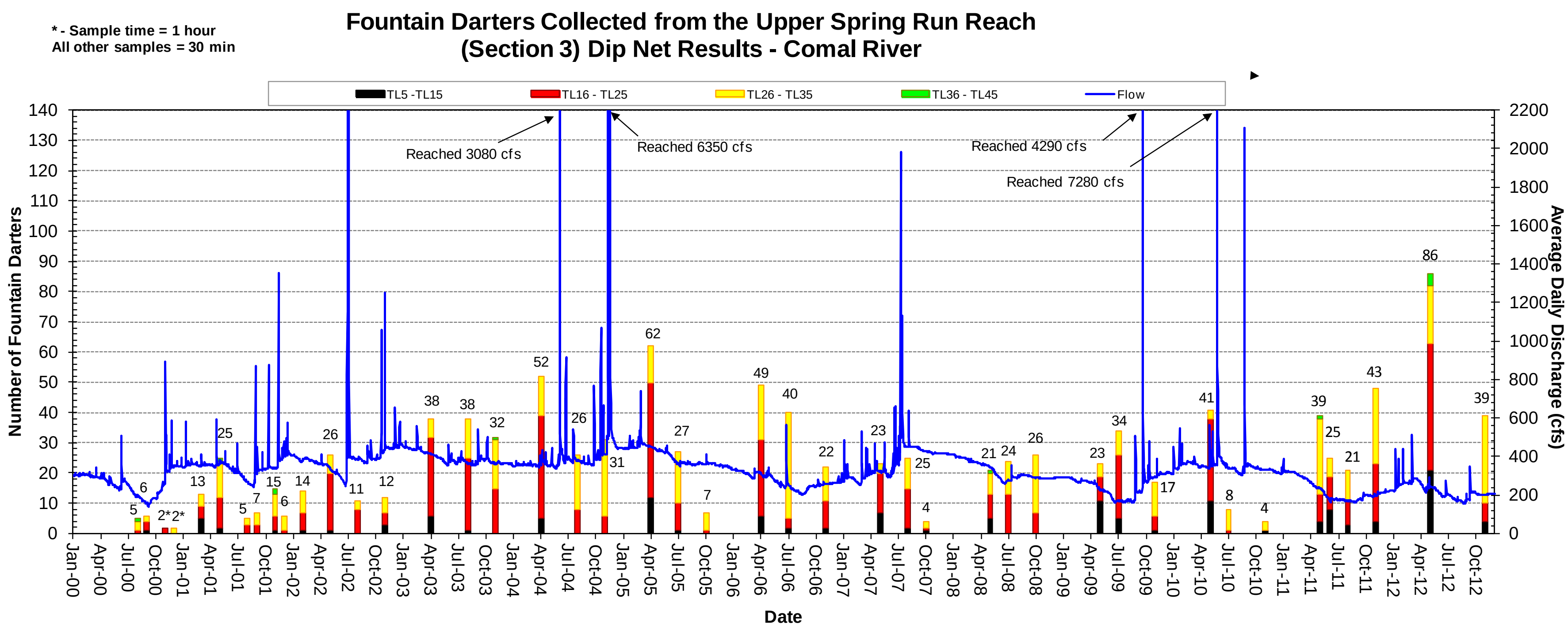


Figure 19. Number of fountain darters, by sample date and size class, collected from the Upper Spring Run Reach (section 3) using dip nets.

Figure 18 provides a good example of how long-term changes in vegetation community can affect fountain darter population dynamics. In 2005 the vegetation community of the Old Channel Reach switched from being dominated by high-quality filamentous algae to one dominated by non-native *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 7 to 48 and small darters are typically only collected in spring months. However, bryophytes have recently begun to establish in the Old Channel. If bryophytes become widespread in the Old Channel, it will likely lead to a rebound in the number of fountain darters collected in this reach.

Noticeable changes in numbers and size distributions of fountain darters have also been observed in dip net data from other sample reaches and are well correlated with changes in habitat availability. 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 (Figure 19). Similarly, a sharp reduction in the number of darters collected from the Upper Spring Run Reach occurred after the flood of June 2010, which scoured most of the vegetation from this reach. However, habitat conditions within this reach had improved considerably by 2012, and the spring 2012 sample had the largest number of darters ever collected in this reach (86).

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 sampling periods as well. This indicates that there is some reproduction occurring year-round, although perhaps on a limited basis and only in certain areas. These areas which exhibit year-round reproduction/recruitment are relatively close to spring upwellings and contain large amounts of bryophytes.

Presence/Absence Dip Netting

In 2012, presence/absence dip netting was conducted on the Comal River during the typical spring (May 21) and fall (November 5) sampling events. The percentage of sites with fountain darters started at 62% in spring and declined to 60% by fall (Figure 20). These percentages are similar to those observed previously (overall mean = 63%, range: 52 - 76).

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.

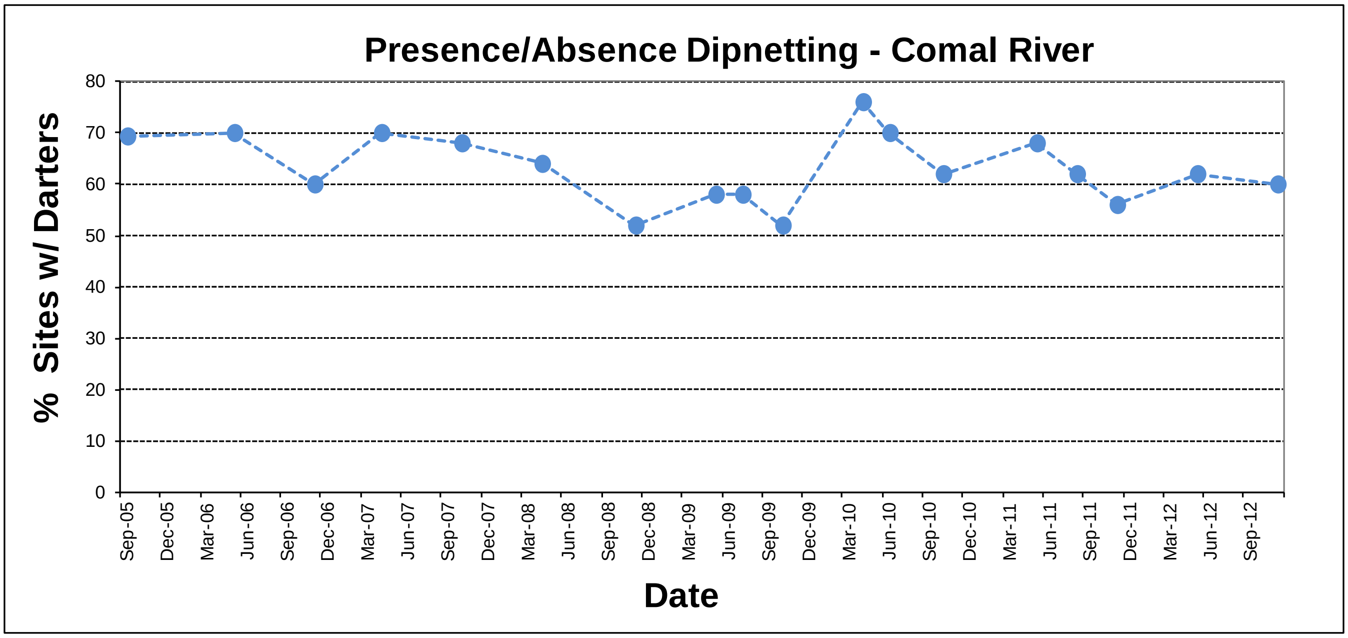


Figure 20. Percentage of sites (N = 50) in which fountain darters were present during 2005-2012.

Visual Observations

Fountain darters were again observed in the deepest portions of Landa Lake (depths greater than 2 m) during each of the two full sampling events in 2012. This is consistent with each SCUBA sampling effort in Landa Lake conducted since the adoption of this methodology in summer 2001 and documents the use of deeper water habitats within Landa Lake during all flow conditions observed to date. As documented in BIO-WEST (2011), the June 2010 flood event was the most severe disturbance observed in the SCUBA sampling area since the inception of the monitoring program. Recovery of that area occurred during 2011, but both percent aquatic vegetation and fountain darter numbers were still slightly below long-term averages. During 2012, percent aquatic vegetation rebounded to 70% (spring) and 60% (fall) with corresponding fountain darter counts of 67 and 46, respectively. SCUBA sampling continues to confirm the importance of aquatic vegetation composition and coverage relative to the overall densities of fountain darters in the Comal Springs/River ecosystem.

Comal Springs Salamander Visual Observations

Since spring 2010 (which saw the highest total salamander count in the Comal River), numbers of salamanders observed has declined, but exhibited a slight resurgence in 2012 (Table 7). Salamanders in the Spring Run 1 site saw the greatest increase from 6 in fall 2011 to 27 in spring 2012. Depths were greater in the spring run in 2012, and may have led to easier searching; however, there also appeared to be more fist-sized rocks present in the spring run, and less fine sediment. In addition, the left (facing downstream) section of the reach was covered in bryophytes which tend to harbor greater numbers of salamanders. Salamanders in Spring Run 3 dropped by 75% during the same time period. Salamanders in the spring run at Spring Island are still present, but stayed below the study average for both sampling efforts in 2012. The spring run continues to suffer from a lack of suitable habitat (fist-sized rocks), and occasionally is prone to scouring (like in 2010). While the East Outfall at Spring Island appears to have an abundance of these rocks, salamander populations remained below the study average in 2012. A decrease in the coverage of bryophytes may be contributing to the relative lack of salamanders.

Table 7. Total number of Comal Springs salamanders observed at each survey site during 2002 – 2012.

SAMPLE PERIOD	SPRING RUN 1	SPRING RUN 3	SPRING ISLAND SPRING RUN	SPRING ISLAND EAST OUTFALL	TOTAL BY SAMPLE
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
Spring 2011	11	10	1	2	24
Low-flow 2011	20	10	1	4	35
Fall 2011	6	20	1	3	30
Spring 2012	27	5	1	5	38
Fall 2012	20	10	3	5	38
Average	**23.6**	**12.2**	**3.2**	**9.8**	**50.9**

By fall, salamanders at Spring Run 1 decreased again, whereas they doubled in number at Spring Run 3. Although flows had decreased over this time period, it is unclear why these changes occurred. This exemplifies the variance inherent in such surveys and consequently shows how long-term studies like the present effort are needed in order to understand changes in salamander population dynamics.

Macroinvertebrate Sampling

To assess population dynamics and habitat requirements of the federally listed invertebrate species, two sampling techniques were used. Drift net sampling was conducted around spring openings as described in the Methods section. Results of this sampling are presented below. Additionally, continued regular monitoring of Comal Springs riffle beetles was conducted using the "cotton lure" methodology employed during previous years. Details of this methodology can be found in the Methods section, and results are presented below.

Drift Net Sampling

At least 9 taxa were captured from 144 hours of sample time at the three drift net sites in Comal Springs during 2012 (Table 8). Table 9 displays the physico-chemical data collected at these sites during sampling. *Stygobromus* spp. was the most abundant genus of organisms found on drift nets in the spring runs with *Lirceolus* (a genus of isopods) also quite commonly encountered. Elmidae (riffle beetles) were uncommonly observed on drift nets within the spring runs, but were much more abundant on cotton lures within the spring openings.

Table 8. Total numbers of troglobitic and endangered species collected in drift nets during May/June and November, 2012. 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)	14	23	16	53
Stygobromus russelli				
Stygobromus bifurcatus				
Stygobromus flagellatus				
Stygobromus spp.	132	219	346	697
All *Stygobromus*	146	242	362	750
Hadziidae				
Mexiweckelia hardeni	8	11	0	19
Sebidae				
Seborgia relicta	3	11		14
Bogidiellidae				
Artesia subterranea	1	1		2
Parabogidiella americana				
Ingolfiellidae				
Ingolfiella n. sp				
Isopoda				
Asellidae				
Lirceolus (2spp.)	46	56	6	108
Cirolanidae				
Cirolanides texensis			3	3
Insects				
Coleoptera				
Dytiscidae				
Comaldessus stygius		2 A		2
Haideoporus texanus	1 A	1 L		2
Dryopidae				
Stygoparnus comalensis				
Elmidae				
Heterelmis comalensis	1 A		2 L	3

Table 9. Results of water quality measurements conducted in 2012 during drift net sampling efforts at Comal Springs.

	Spring Run 1		Spring Run 3		West Shore Upwelling	
Date	May	Nov	May	Nov	May	Nov
Temperature (°C)	23.1	23.1	23.2	23.1	23.6	23.5
Conductivity (mS/cm)	0.6	0.6	0.6	0.6	0.6	0.6
pH	7.0	6.5	7.1	6.5	7.1	6.5
Dissolved Oxygen (mg/L)	5.5	5.6	5.6	5.8	5.4	5.6
Current Velocity (m/s)	0.3	0.3	0.2	0.3	0.2	0.05

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. In 2012, 749 Comal Springs riffle beetles were collected on cotton lures; the lowest total since 2003 (Table 10). Only 20 were collected along the Western Shoreline and 56 at Spring Island in spring. During sampling in spring, the water level dropped ~ 3 inches leaving part of each lure above the water line, and only slightly damp. As a result, the cloths attracted *Talitroides topitotum* (introduced terrestrial amphipods) instead of riffle beetles leading to their low numbers. Fewer riffle beetles were found at Spring Island because surface spring outlets have shifted locations due to the June 2010 flood, and riffle beetles may have moved. While riffle beetles were common at Spring Run 3 in spring, only half as many were observed in fall; however, they were abundant at both the Western Shoreline and Spring Island in November. Densities (#/rag) varied widely in 2012 across seasons (Figure 21). In May, only 8 beetles per rag was collected the lowest density since the beginning of the study. In November, densities (19/rag) were higher than the long term study average (15.1/rag). While these densities don't offer detailed analyses of population trends, they do provide baseline data for temporal comparisons of populations that can be assessed 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 – 2012.

Sample Period	Spring Run 3	West Shore	Spring Island	Total
January 03	65	7	47	**119**
March 03	32	5	10	**47**
September 03	10	15	42	**67**
November 03	16	9	18	**43**
May 2004	88	83	122	**293**
August 2004	169	143	90	**402**
November 2004	170	175	146	**491**
April 2005	119	121	121	**361**
November 2005	262	201	185	**648**
May 2006	256	195	160	**611**
November 2006	185	92	125	**402**
May 2007	59	161	119	**339**
November 2007	204	83	132	**419**
May 2008	155	139	156	**450**
November 2008	144	133	227	**504**
June 2009	136	226	74	**436**
December 2009	72	56	198	**326**
May 2010	53	110	20	**183**
November 2010	298	264	104	**666**
June 2011	255	245	121	**621**
November 2011	71	137	193	**401**
May/June 2012	142	20	59	**221**
November 2012	77	261	190	**528**
Total	**3038**	**2881**	**2659**	**8578**
Average	132.1	125.3	115.6	373.0

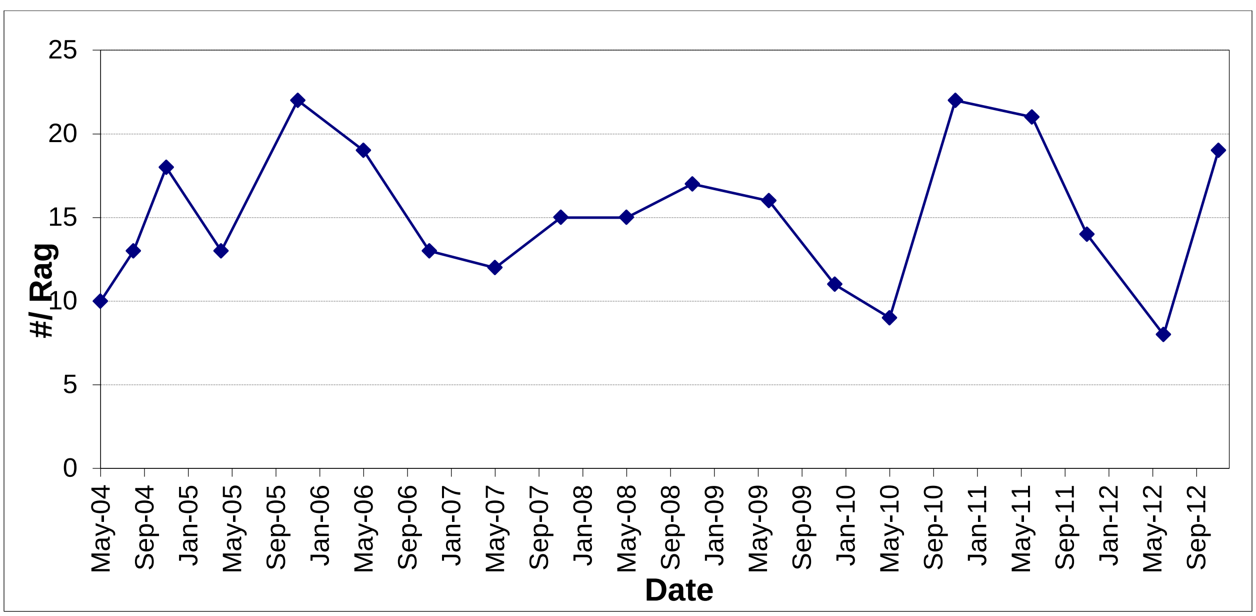


Figure 21. Combined density (#/cotton lure) of Comal Springs riffle beetles (*Heterelmis comalensis*) for each sampling date from 2004 – 2012.

REFERENCES

Arsuffi, T. L., B. G. Whiteside, M. D. Howard, and M. C. Badough 1993. Ecology of the exotic giant rams-horn snail, *Marisa cornuarietis*, other biological characteristics, and a species/ecological review of the literature of the Comal Springs Ecosystem of south central Texas. Final Report to the Edwards Underground Water District and City of New Braunfels. 97 pp.

BIO-WEST 2001. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal Springs/River Aquatic Ecosystem. Draft Report. Edwards Aquifer Authority, San Antonio, TX. 35p.

BIO-WEST 2002. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal Springs/River Aquatic Ecosystem. 2001 Annual Report. Edwards Aquifer Authority. 24 p. plus Appendices.

BIO-WEST 2003. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal Springs/River Aquatic Ecosystem. 2002 Annual Report. Edwards Aquifer Authority. 45 p. plus Appendices.

BIO-WEST 2004. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal Springs/River Aquatic Ecosystem. 2003 Annual Report. Edwards Aquifer Authority. 42 p. plus Appendices.

BIO-WEST 2005. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal Springs/River Aquatic Ecosystem. 2004 Annual Report. Edwards Aquifer Authority. 70 p. plus Appendices.

BIO-WEST 2006. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal River Aquatic Ecosystem. 2005 Annual Report. Edwards Aquifer Authority. 43 p. plus Appendices.

BIO-WEST 2007. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal River Aquatic Ecosystem. 2006 Annual Report. Edwards Aquifer Authority. 42 p. plus Appendices.

BIO-WEST 2008. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal River Aquatic Ecosystem. 2007 Annual Report. Edwards Aquifer Authority. 41 p. plus Appendices.

BIO-WEST 2009. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal River Aquatic Ecosystem. 2008 Annual Report. Edwards Aquifer Authority. 41 p. plus Appendices.

BIO-WEST 2010. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal River Aquatic Ecosystem. 2009 Annual Report. Edwards Aquifer Authority. 45 p. plus Appendices.

BIO-WEST 2011. Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal River Aquatic Ecosystem. 2010 Annual Report. Edwards Aquifer Authority. 51 p. plus Appendices.

Brandt, T. M., K. G. Graves, C. S. Berkhouse, T. P. Simon, and B. G. Whiteside. 1993. Laboratory spawning and rearing of the endangered fountain darter. Progressive Fish-Culturist 55: 149-156.

Dammeyer, N. T. 2010. Movement patterns of *Etheostoma fonticola* in a headwater stream. Master's Thesis. Texas State University – San Marcos.

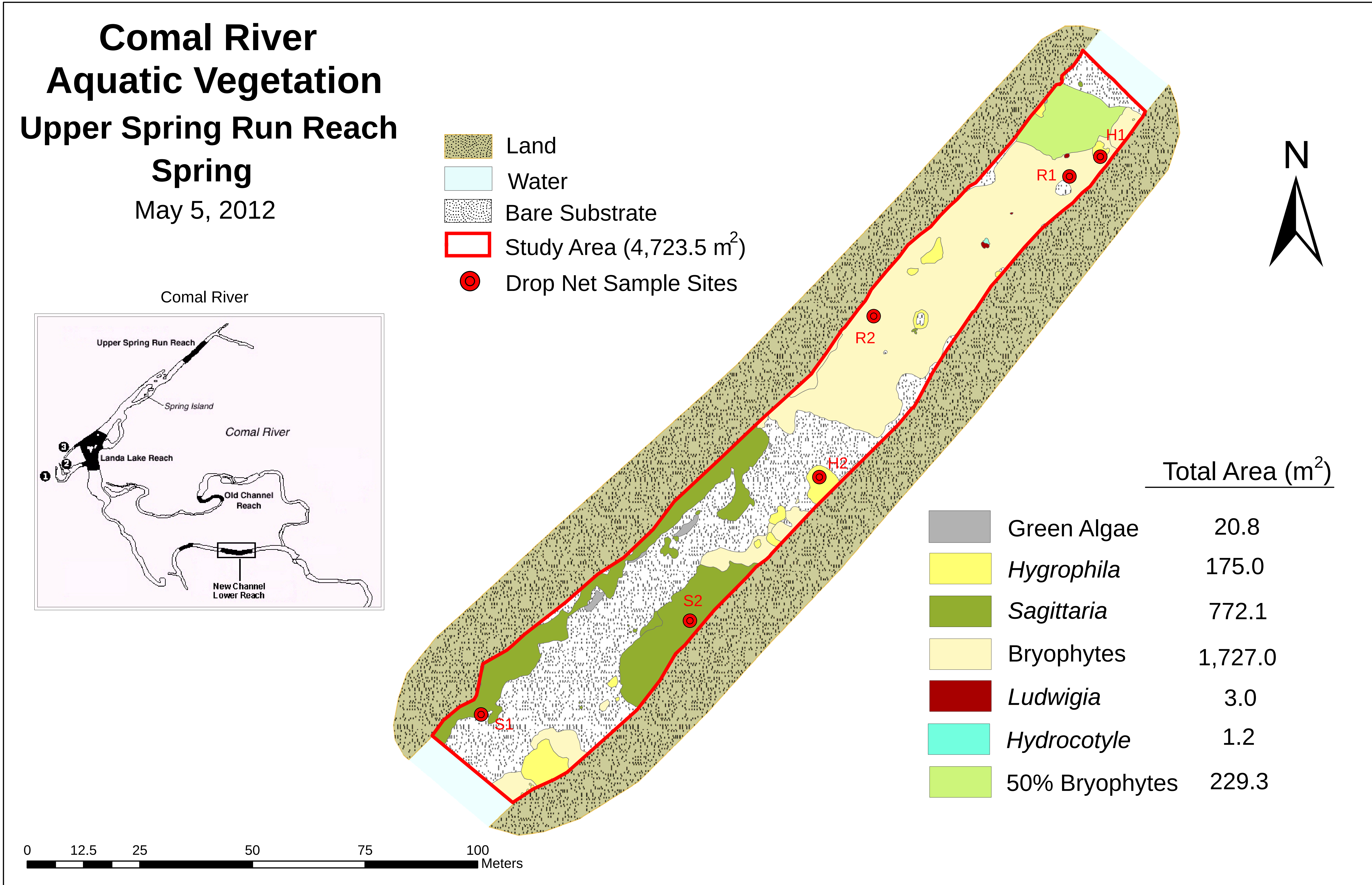
Horne, F. R., T. L. Arsuffi, and R. W. Neck. 1992. Recent introduction and potential botanical impact of the giant rams-horn snail, *Marisa cornuarietis* (Pilidae), in the Comal Springs Ecosystem of central Texas. The Southwestern Naturalist 37(2): 194 – 214.

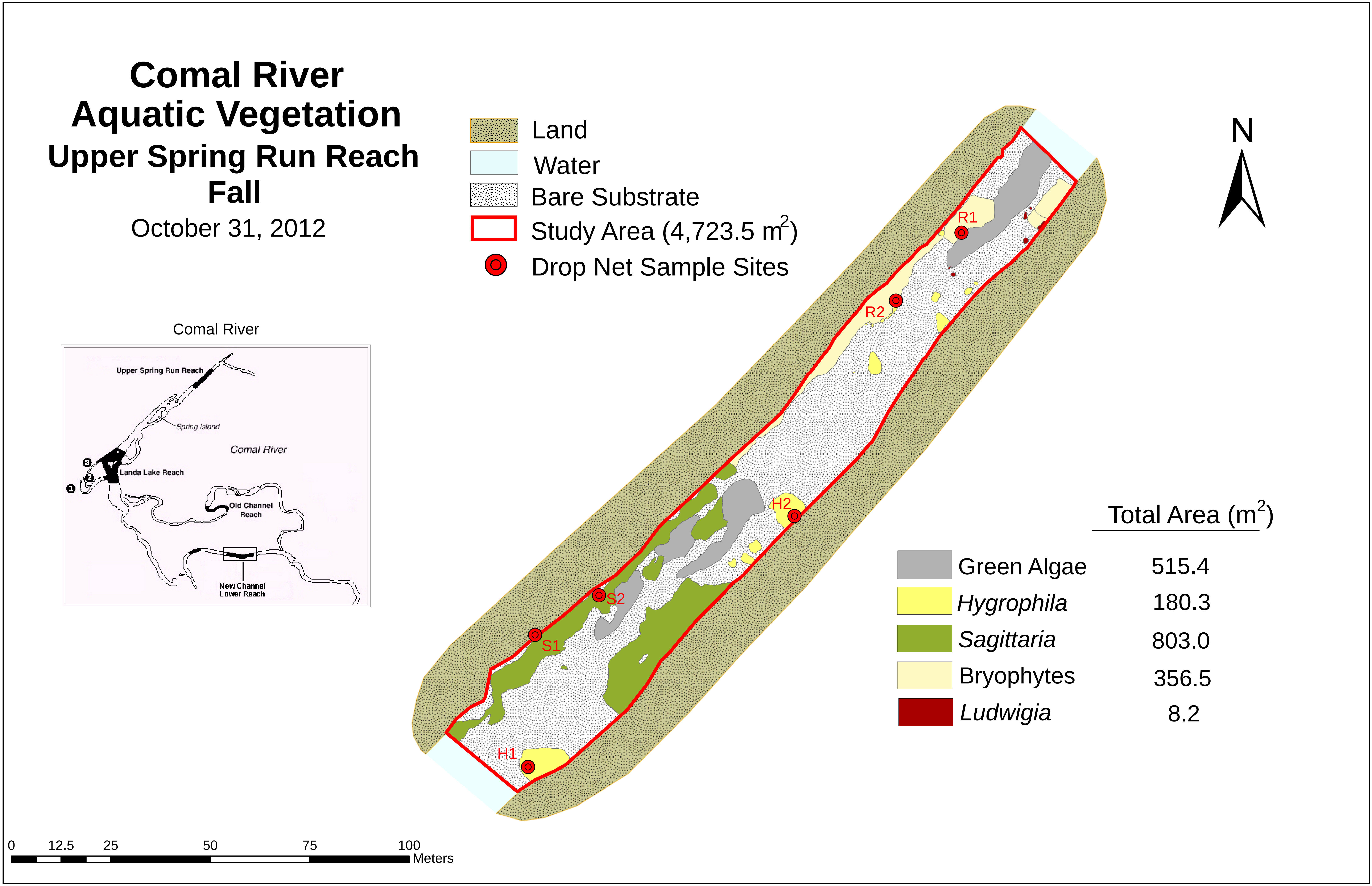
Phillips, C. T., M. L. Alexander, and A. M. Gonzales. 2011. Use of macrophytes for egg deposition by the endangered fountain darter. Transactions of the American Fisheries Society 140(5): 1392-1397.

U.S. Geological Survey (USGS). 12/2010. Provisional data for Texas. Location: http://tx.waterdata.usgs.gov/niwis/help/provisional.

APPENDIX A:
AQUATIC VEGETATION MAPS

Upper Spring Run Reach

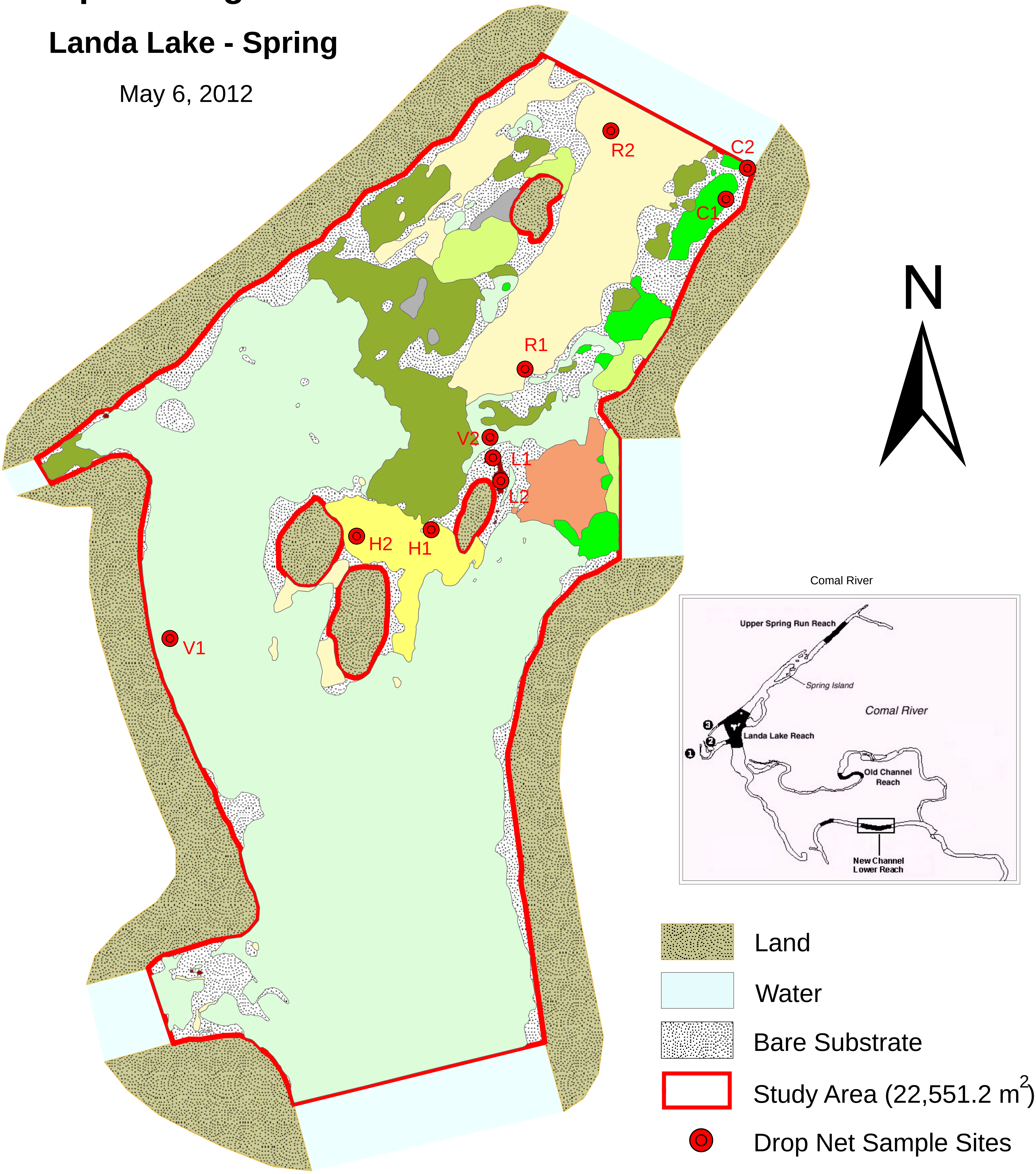

Comal River
Aquatic Vegetation
Upper Spring Run Reach
Spring
May 5, 2012
Land
Water
Bare Substrate
Study Area (4,723.5 m2)
Drop Net Sample Sites
Comal River
Upper Spring Run Reach
Spring Island
Comal River
Landa Lake Reach
Old Channel Reach
New Channel Lower Reach
H1
R1
R2
H2
S2
S1
N
Total Area (m2)
Green Algae 20.8
Hygrophila 175.0
Sagittaria 772.1
Bryophytes 1,727.0
Ludwigia 3.0
Hydrocotyle 1.2
50% Bryophytes 229.3
0 12.5 25 50 75 100
Meters


Comal River
Aquatic Vegetation
Upper Spring Run Reach
Fall
October 31, 2012
Land
Water
Bare Substrate
Study Area (4,723.5 m²)
Drop Net Sample Sites
N
Comal River
Upper Spring Run Reach
Spring Island
Comal River
Landa Lake Reach
Old Channel Reach
New Channel Lower Reach
R1
R2
H2
S2
S1
H1
Total Area (m²)
Green Algae 515.4
Hygrophila 180.3
Sagittaria 803.0
Bryophytes 356.5
Ludwigia 8.2
0 12.5 25 50 75 100
Meters

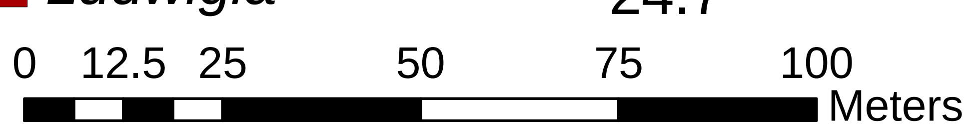
Landa Lake Reach

Comal River
Aquatic Vegetation
Landa Lake - Spring

May 6, 2012

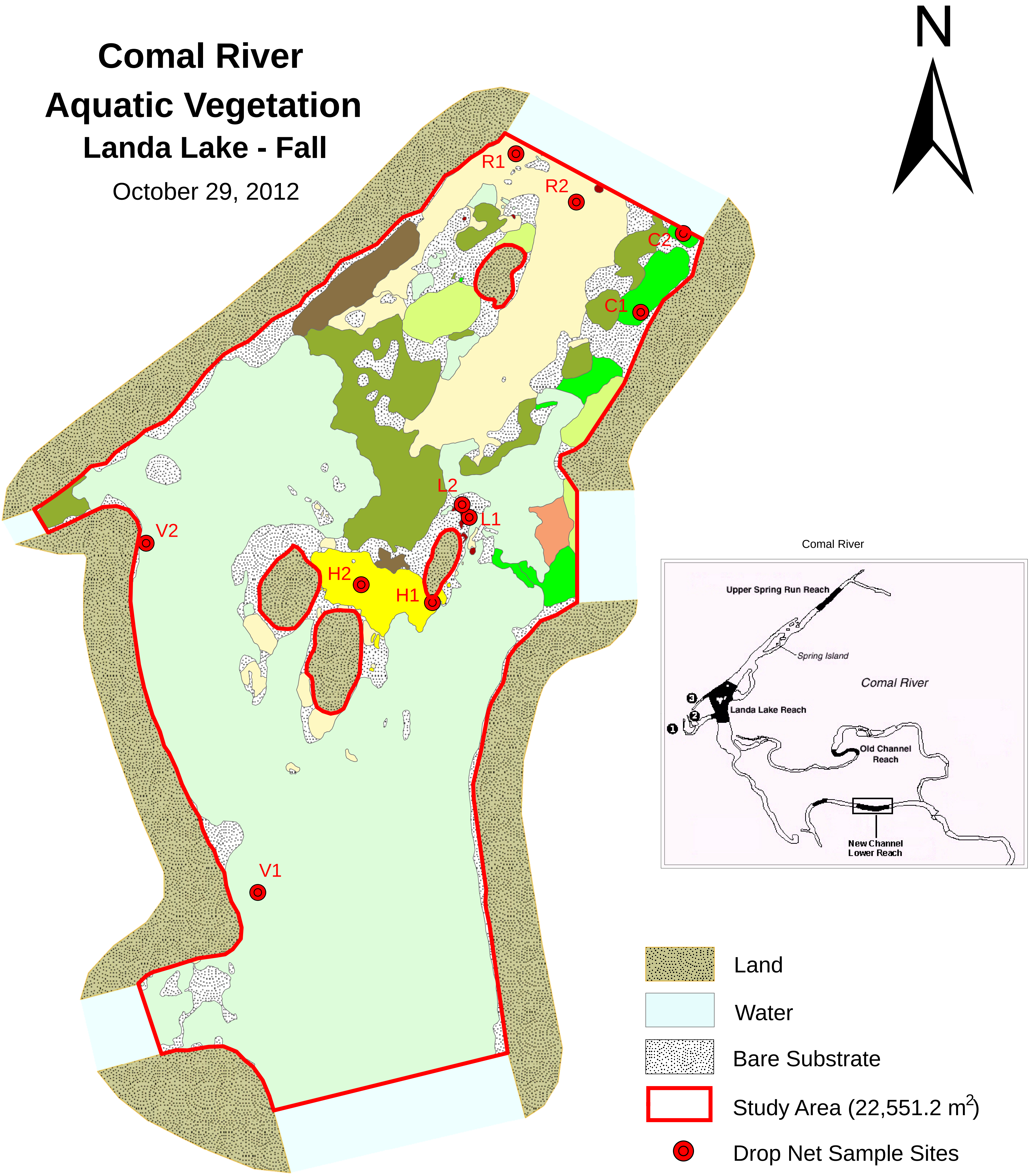


	Total Area (m^2)		Total Area (m^2)
Algae	87.5	*Nuphar*	483.1
Bryophytes	2,404.4	*Sagittaria*	1,988.0
Cabomba	445.8	*Vallisneria*	13,027.7
Hygrophila	575.5	*Vallisneria / Cabomba*	399.9
Ludwigia	24.7		

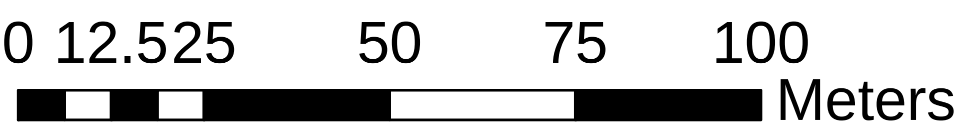


Comal River
Aquatic Vegetation
Landa Lake - Fall

October 29, 2012



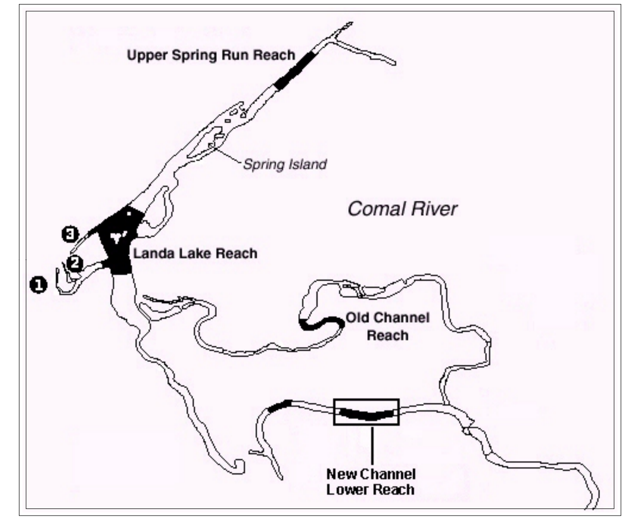
	Total Area (m^2)
Bryophytes	2,515.3
Cabomba	495.5
Hygrophila	459.6
Ludwigia	31.4
Sagittaria / Bryophytes	359.5
Nuphar	452.1
Sagittaria	1,710.4
Vallisneria	13,591.1
Vallisneria / *Cabomba*	120.2

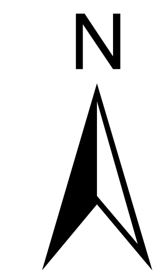


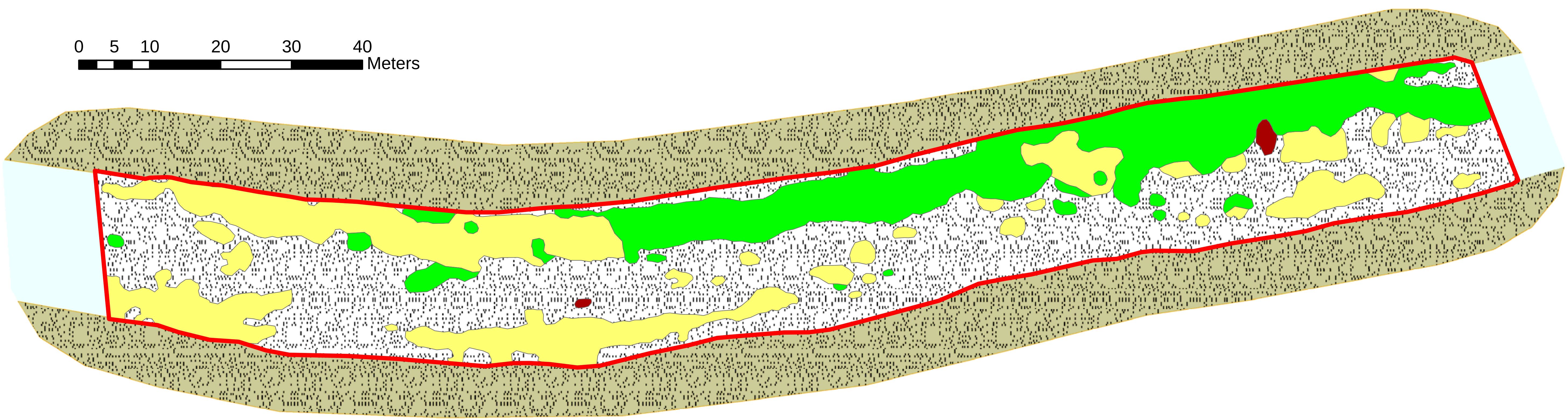
New Channel Reach

Comal River
Aquatic Vegetation
New Channel Lower Reach
Spring
May 21, 2012

Comal River





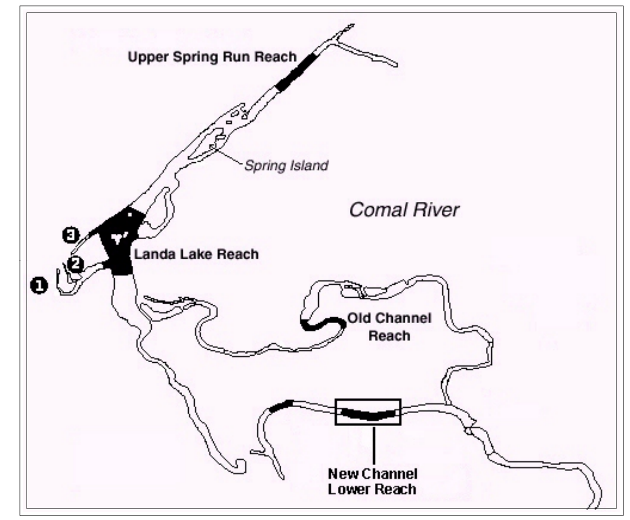


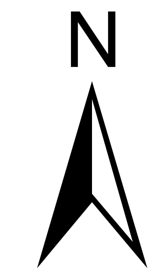
- Land
- Water
- Bare Substrate
- Study Area (4,177.8 m^2)

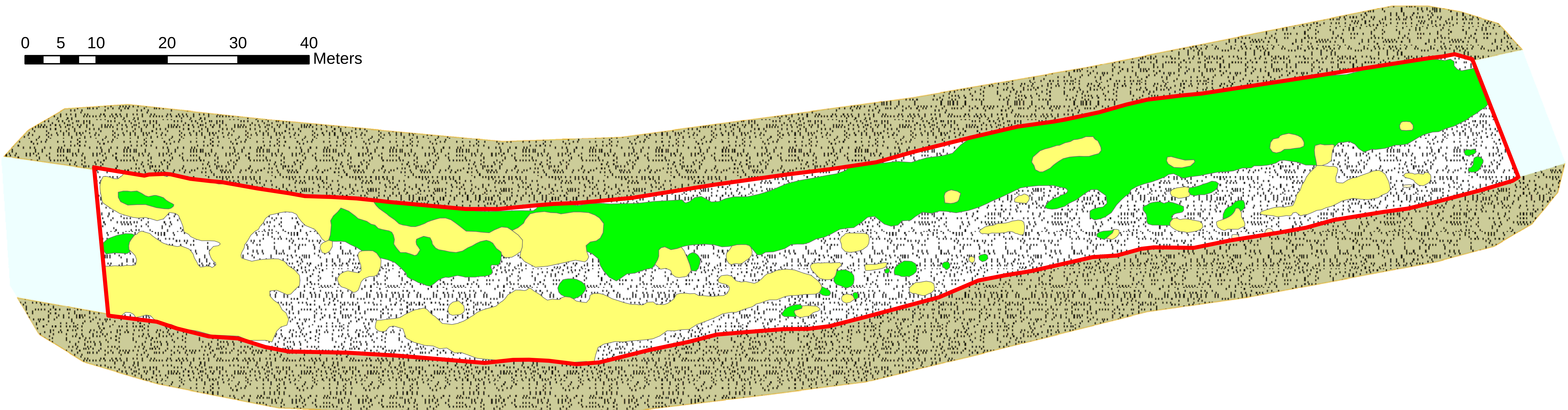
	Total Area (m^2)
Cabomba	930.7
Hygrophila	1,054.9
Ludwigia	13.0

Comal River
Aquatic Vegetation
New Channel Lower Reach
Fall
October 31, 2012

Comal River







		Total Area (m^2)
	Cabomba	1,409.6
	Hygrophila	1,159.7
	Bryophytes	1.7

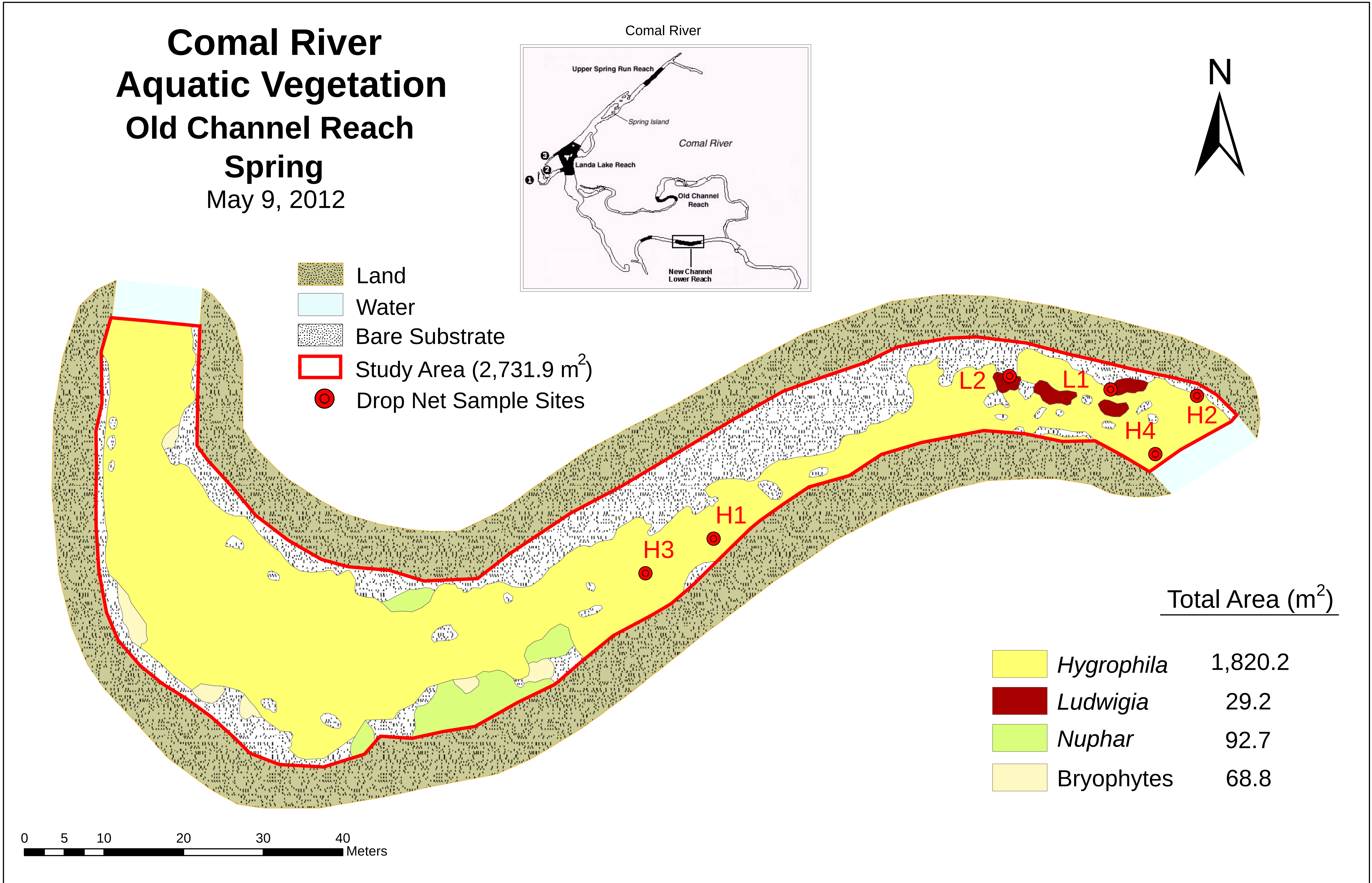
Land

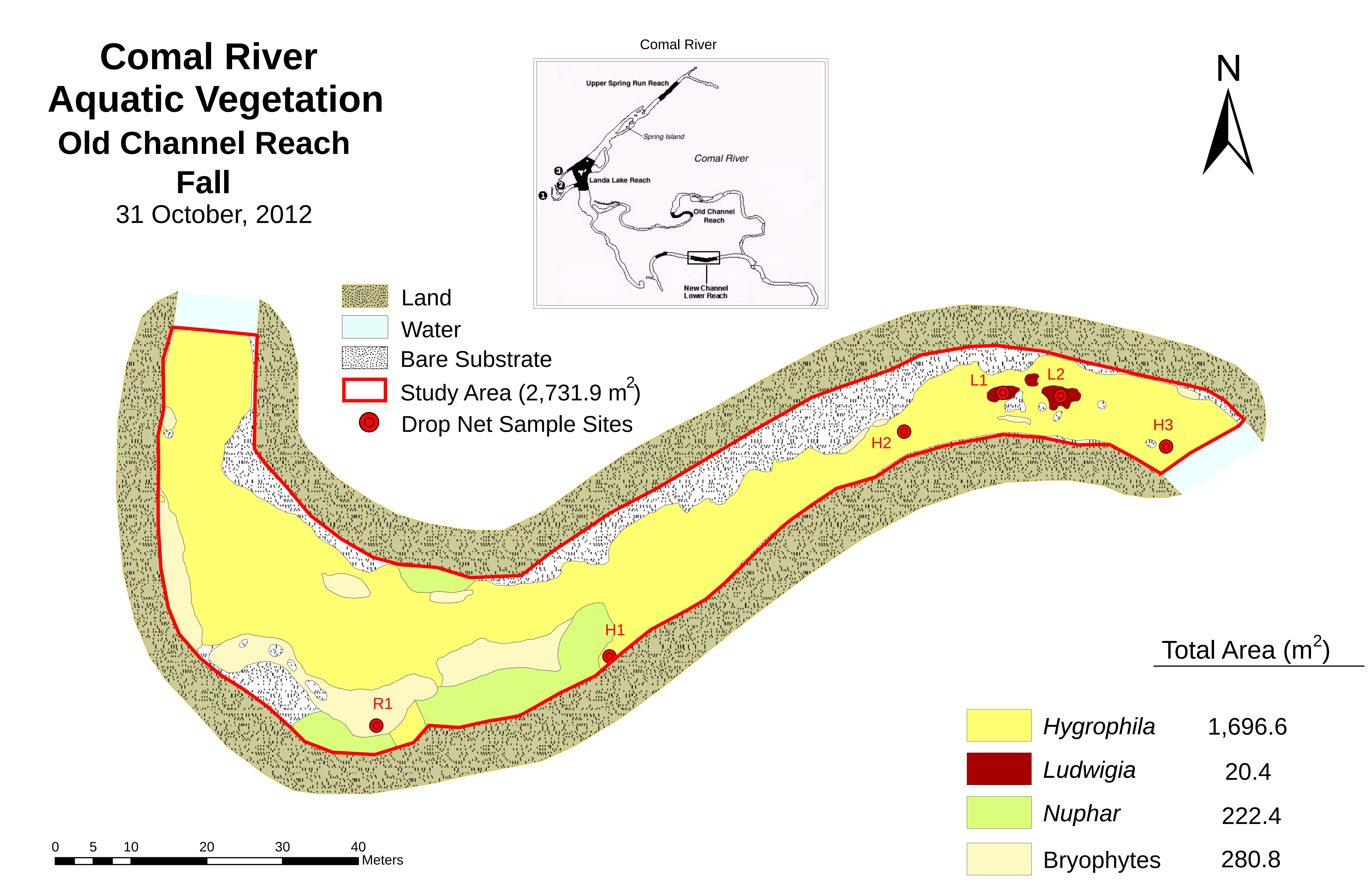
Water

Bare Substrate

Study Area (4,177.8 m^2)

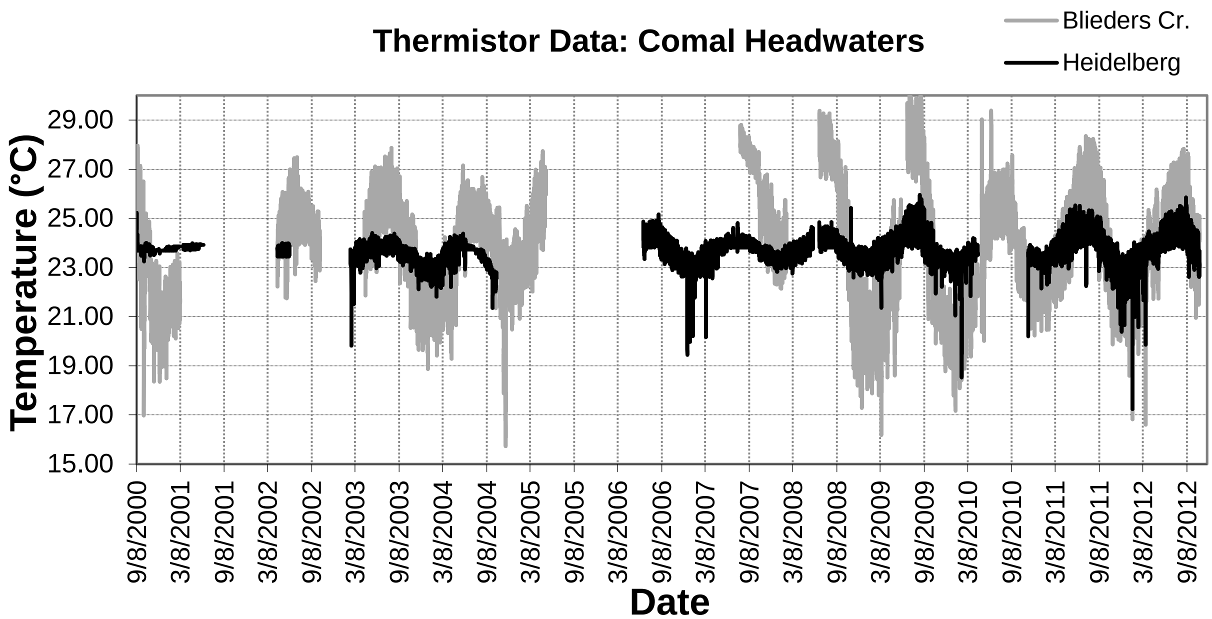
Old Channel Reach


Comal River
Aquatic Vegetation
Old Channel Reach
Spring
May 9, 2012
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
L2
L1
H2
H4
H1
H3
Total Area (m2)
Hygrophila 1,820.2
Ludwigia 29.2
Nuphar 92.7
Bryophytes 68.8
0 5 10 20 30 40
Meters

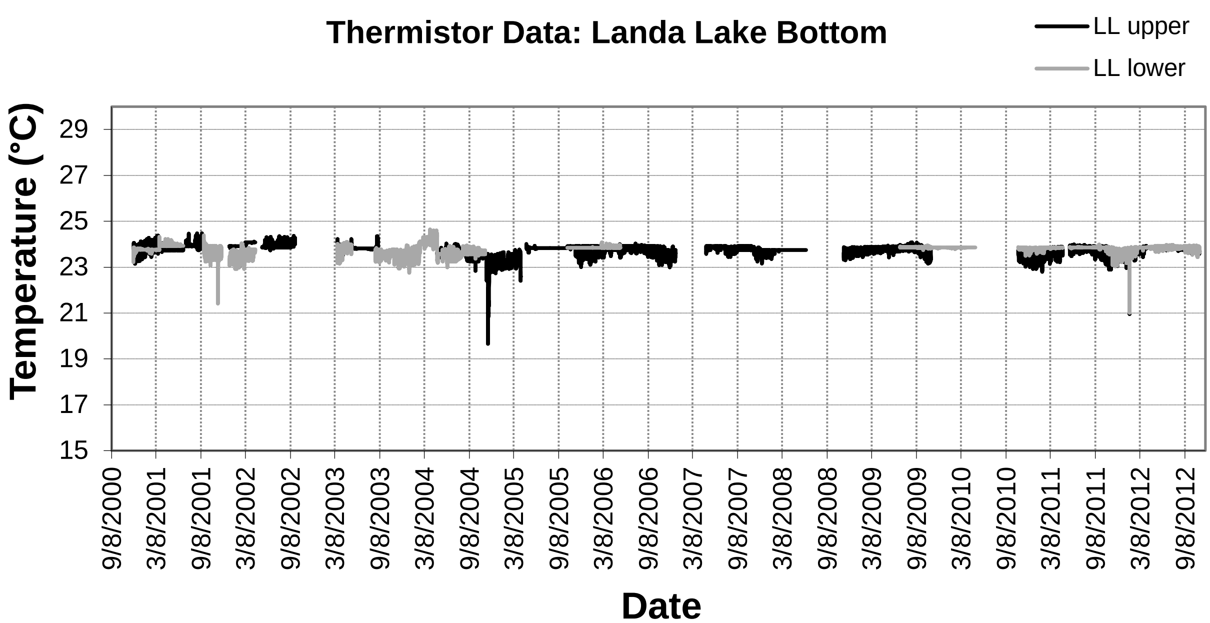

Comal River
Aquatic Vegetation
Old Channel Reach
Fall
31 October, 2012
Comal River
Upper Spring Run Reach
Spring Island
Comal River
Landa Lake Reach
Old Channel Reach
New Channel Lower Reach
N
Land
Water
Bare Substrate
Study Area (2,731.9 m²)
Drop Net Sample Sites
L1
L2
H1
H2
H3
R1
Total Area (m²)
Hygrophila 1,696.6
Ludwigia 20.4
Nuphar 222.4
Bryophytes 280.8
0 5 10 20 30 40
Meters

Appendix B:
Data and Graphs

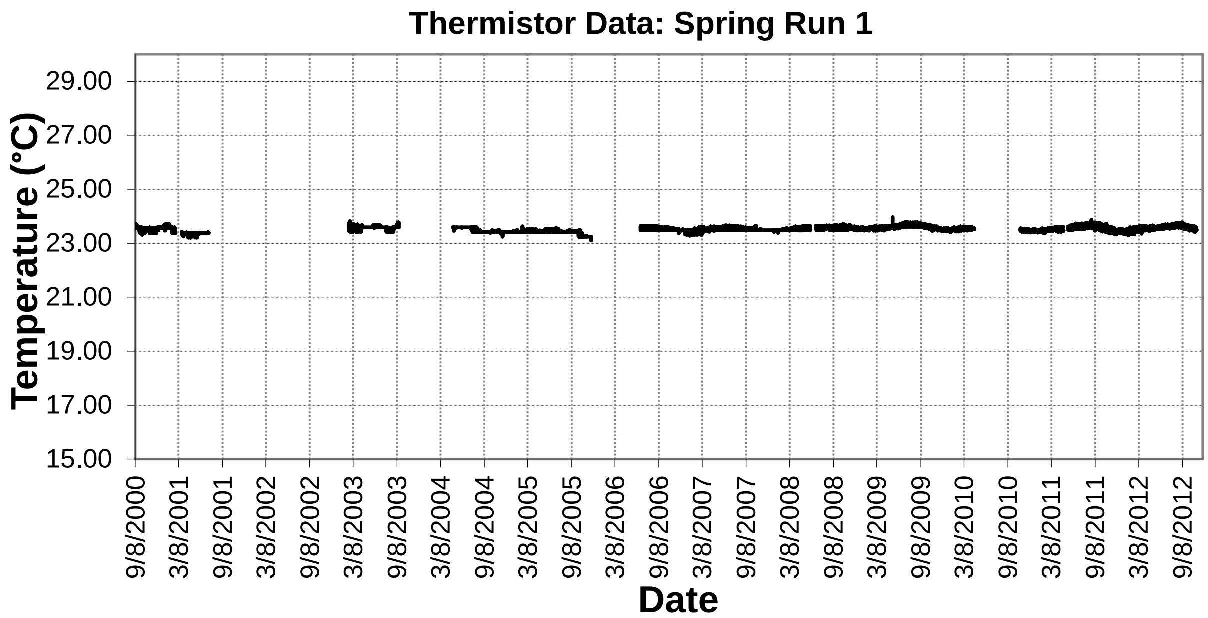
Water Quality Data
and
Thermistor Graphs

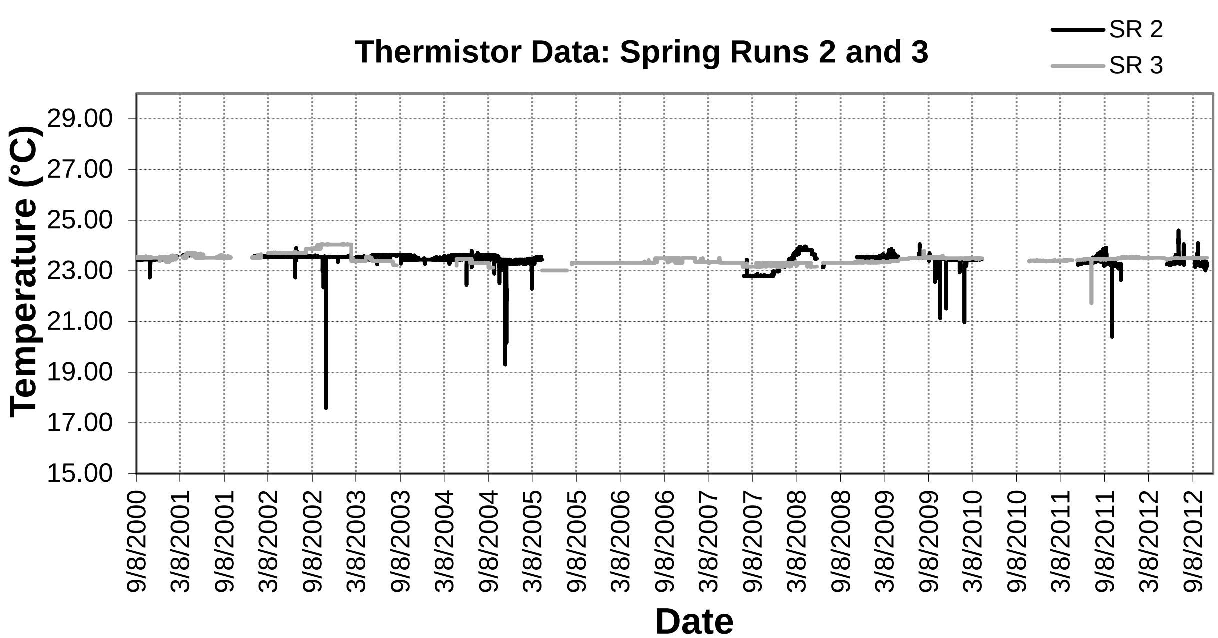


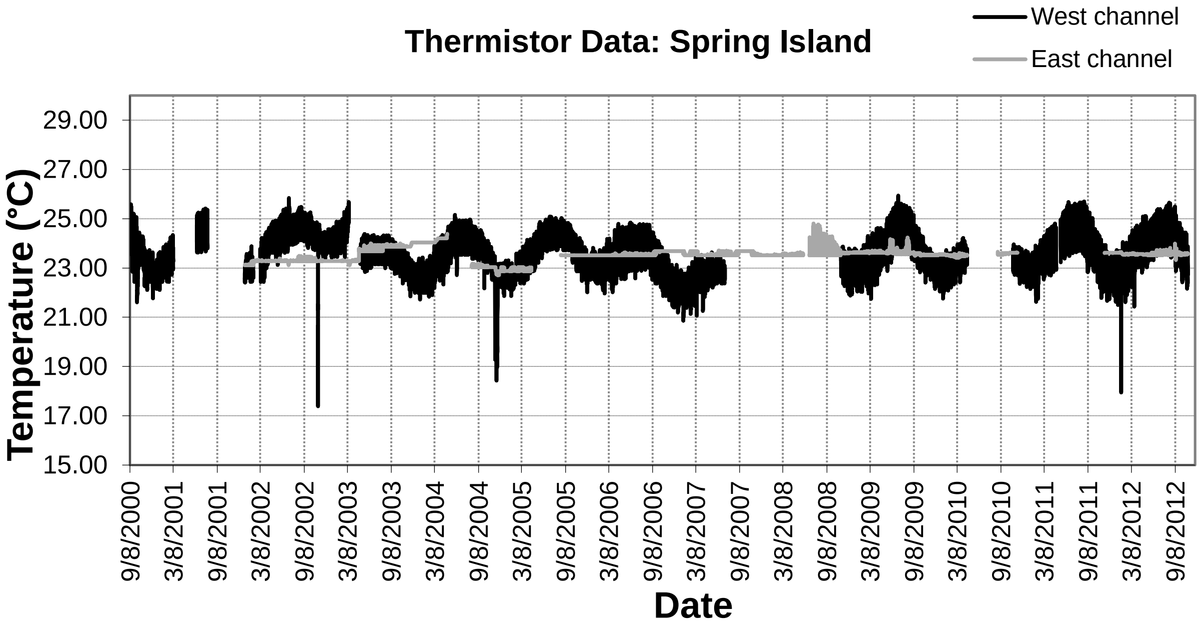
Thermistor Data: Comal Headwaters
Blieders Cr.
Heidelberg
Temperature (°C)
29.00
27.00
25.00
23.00
21.00
19.00
17.00
15.00
9/8/2000
3/8/2001
9/8/2001
3/8/2002
9/8/2002
3/8/2003
9/8/2003
3/8/2004
9/8/2004
3/8/2005
9/8/2005
3/8/2006
9/8/2006
3/8/2007
9/8/2007
3/8/2008
9/8/2008
3/8/2009
9/8/2009
3/8/2010
9/8/2010
3/8/2011
9/8/2011
3/8/2012
9/8/2012
Date

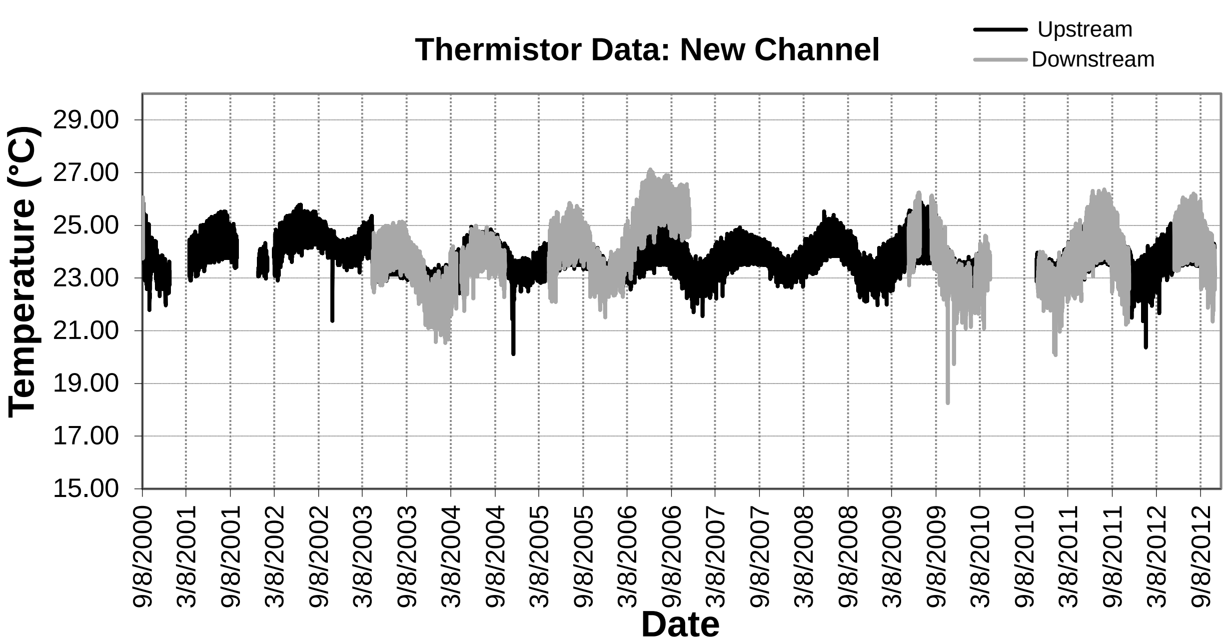


Thermistor Data: Landa Lake Bottom
LL upper
LL lower
Temperature (°C)
29
27
25
23
21
19
17
15
9/8/2000
3/8/2001
9/8/2001
3/8/2002
9/8/2002
3/8/2003
9/8/2003
3/8/2004
9/8/2004
3/8/2005
9/8/2005
3/8/2006
9/8/2006
3/8/2007
9/8/2007
3/8/2008
9/8/2008
3/8/2009
9/8/2009
3/8/2010
9/8/2010
3/8/2011
9/8/2011
3/8/2012
9/8/2012
Date

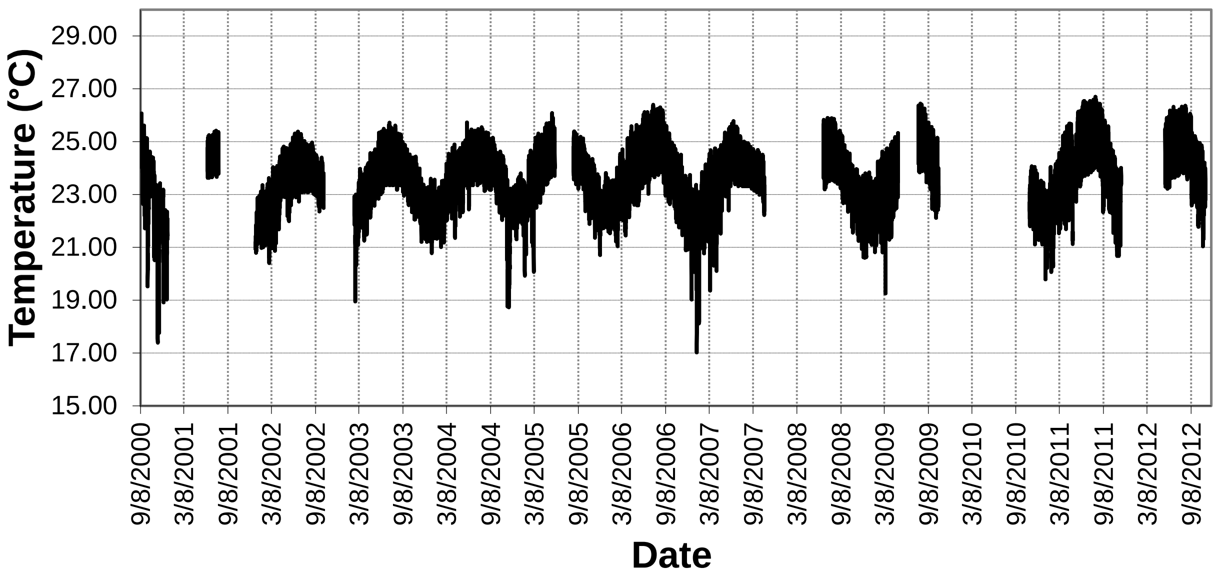

Thermistor Data: Spring Run 1
Temperature (°C)
29.00
27.00
25.00
23.00
21.00
19.00
17.00
15.00
9/8/2000
3/8/2001
9/8/2001
3/8/2002
9/8/2002
3/8/2003
9/8/2003
3/8/2004
9/8/2004
3/8/2005
9/8/2005
3/8/2006
9/8/2006
3/8/2007
9/8/2007
3/8/2008
9/8/2008
3/8/2009
9/8/2009
3/8/2010
9/8/2010
3/8/2011
9/8/2011
3/8/2012
9/8/2012
Date


SR 2
SR 3
Thermistor Data: Spring Runs 2 and 3
Temperature (°C)
29.00
27.00
25.00
23.00
21.00
19.00
17.00
15.00
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
3/8/2011
9/8/2011
3/8/2012
9/8/2012
Date

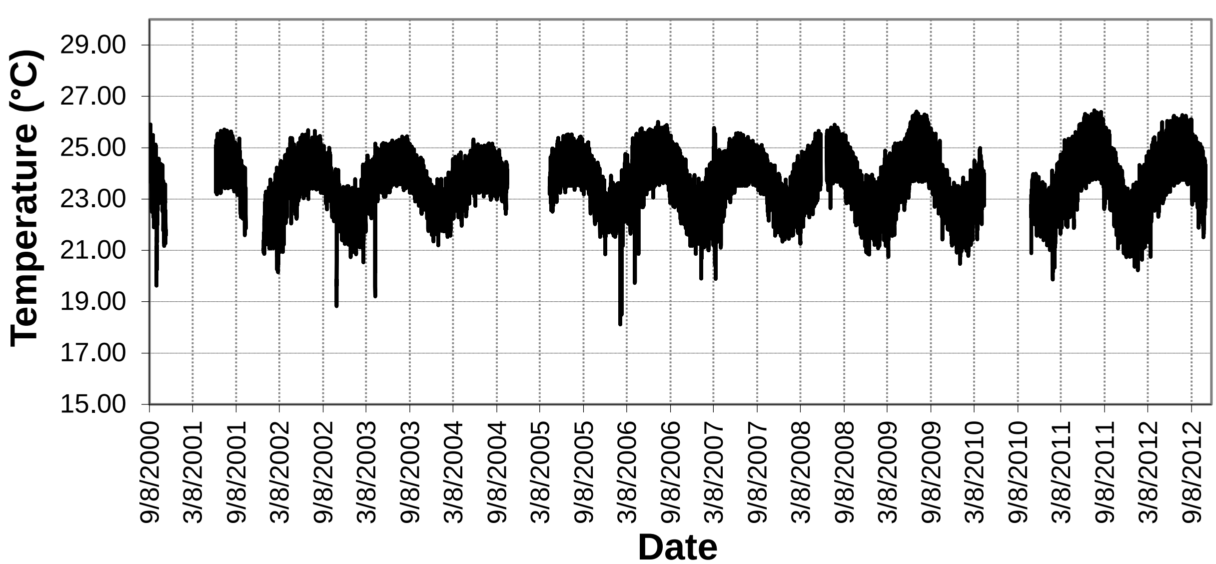

Thermistor Data: Spring Island
West channel
East channel
Temperature (°C)
29.00
27.00
25.00
23.00
21.00
19.00
17.00
15.00
9/8/2000
3/8/2001
9/8/2001
3/8/2002
9/8/2002
3/8/2003
9/8/2003
3/8/2004
9/8/2004
3/8/2005
9/8/2005
3/8/2006
9/8/2006
3/8/2007
9/8/2007
3/8/2008
9/8/2008
3/8/2009
9/8/2009
3/8/2010
9/8/2010
3/8/2011
9/8/2011
3/8/2012
9/8/2012
Date


Thermistor Data: New Channel
Upstream
Downstream
Temperature (°C)
29.00
27.00
25.00
23.00
21.00
19.00
17.00
15.00
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
3/8/2011
9/8/2011
3/8/2012
9/8/2012
Date

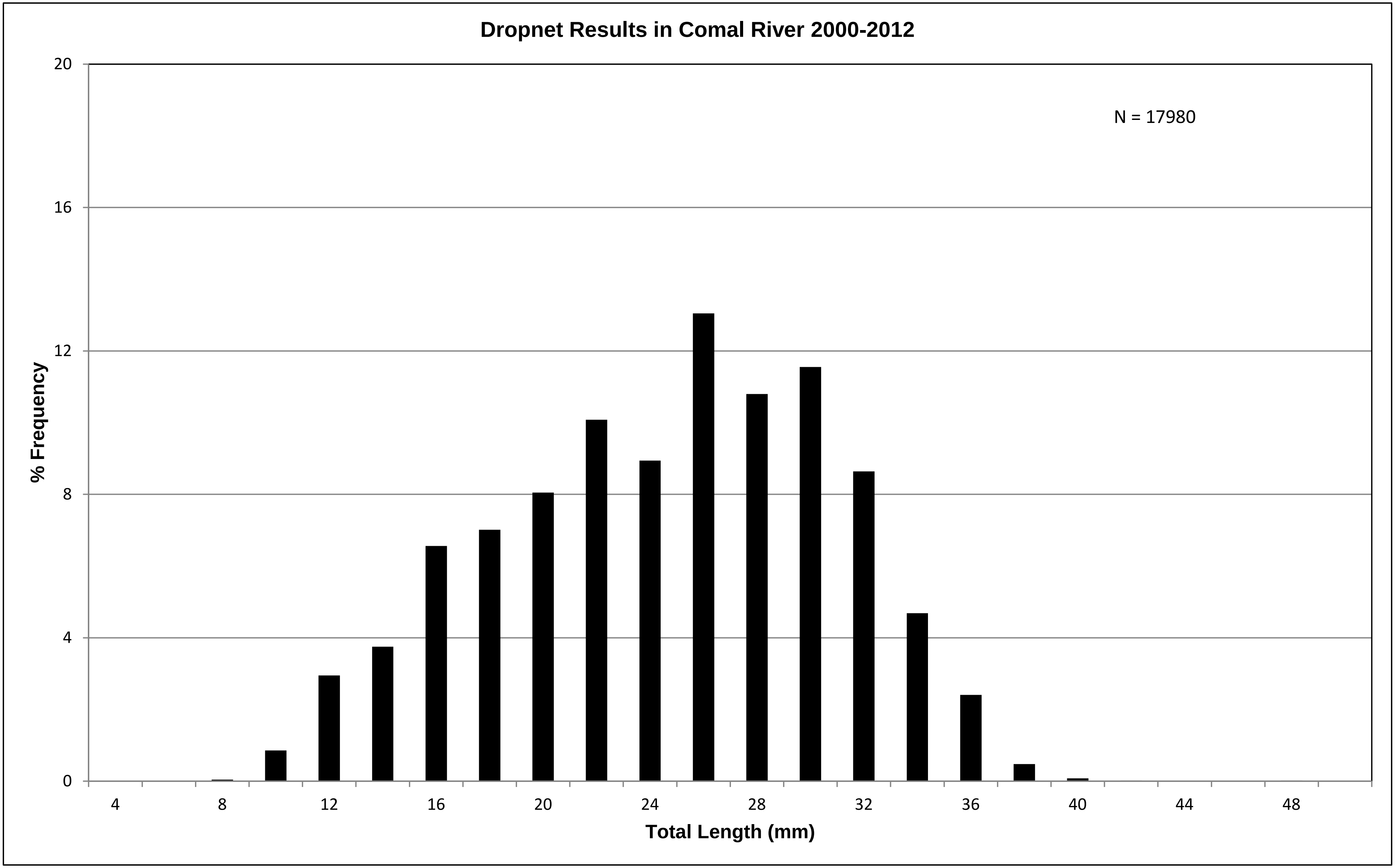
Thermistor Data: Other Place



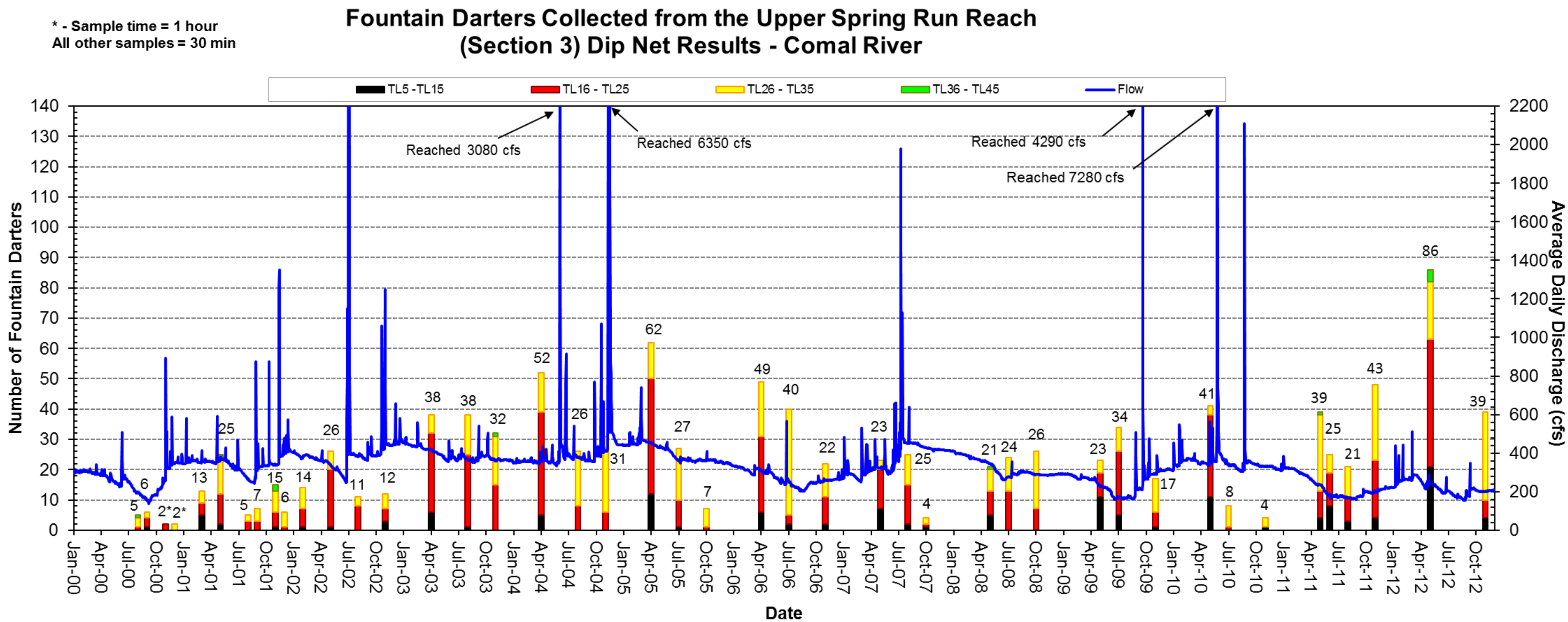
Thermistor Data: Old Channel

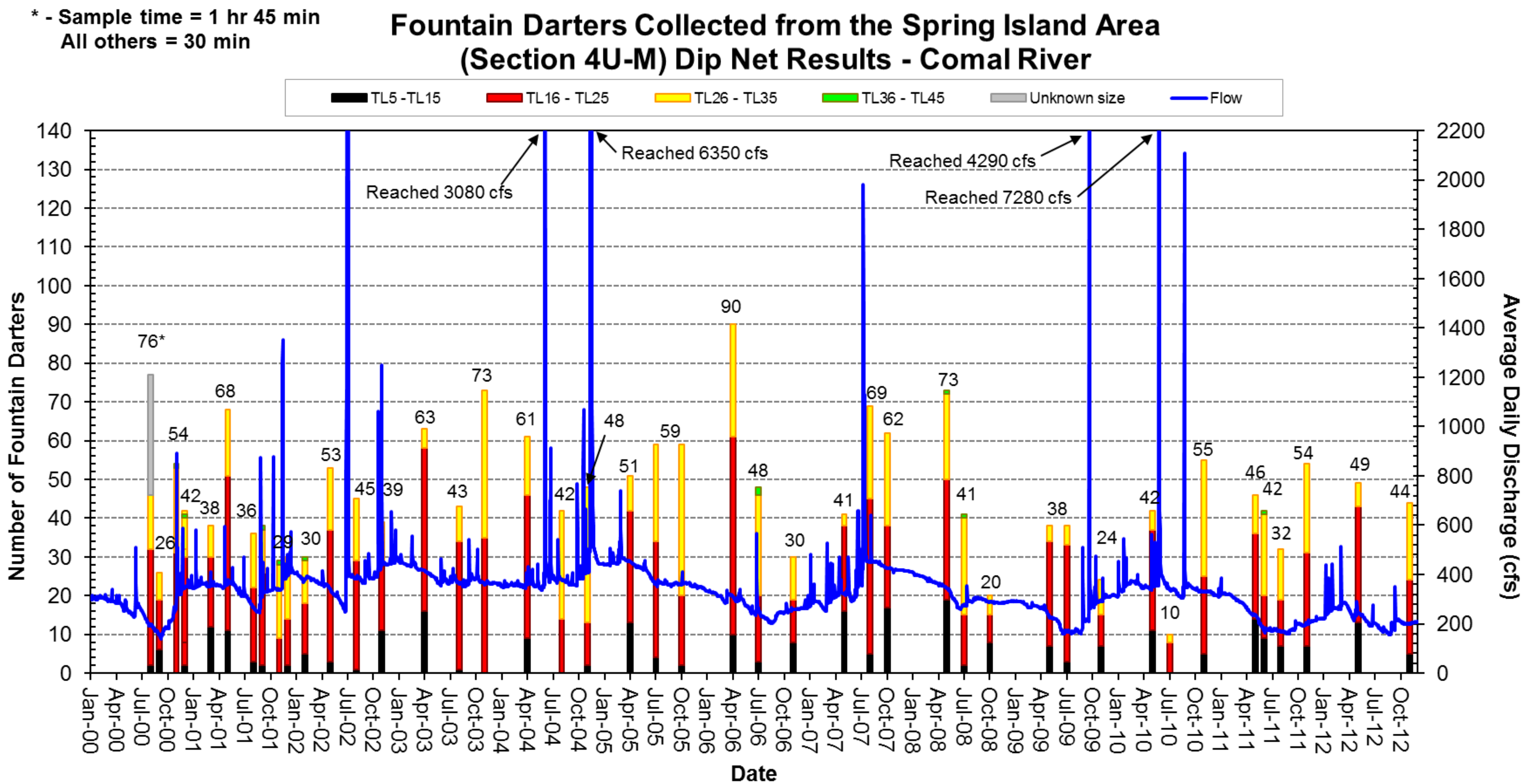


Drop Net Graph

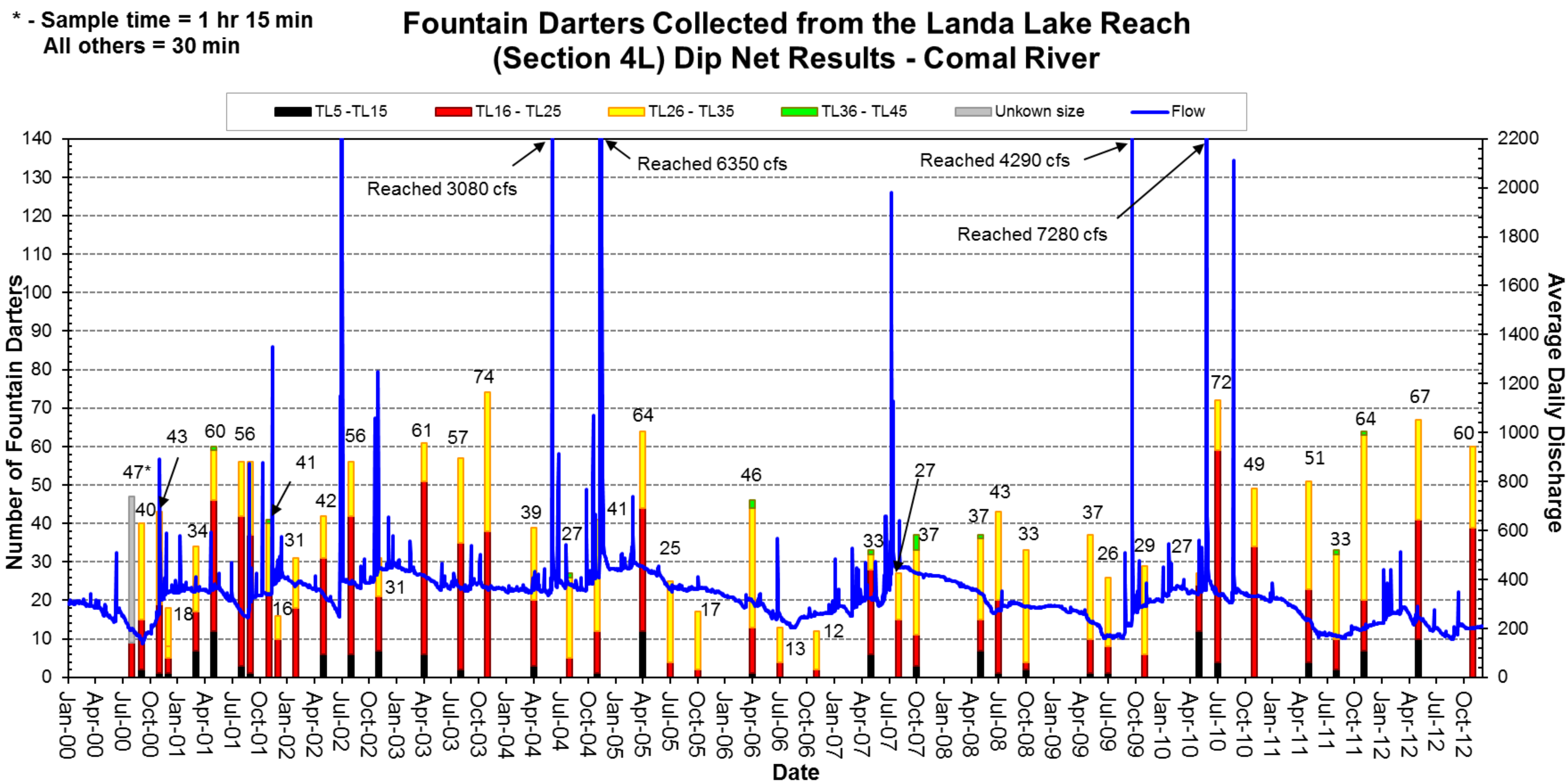

Dropnet Results in Comal River 2000-2012
N = 17980
% Frequency
0
4
8
12
16
20
4
8
12
16
20
24
28
32
36
40
44
48
Total Length (mm)

Dip Net Graphs

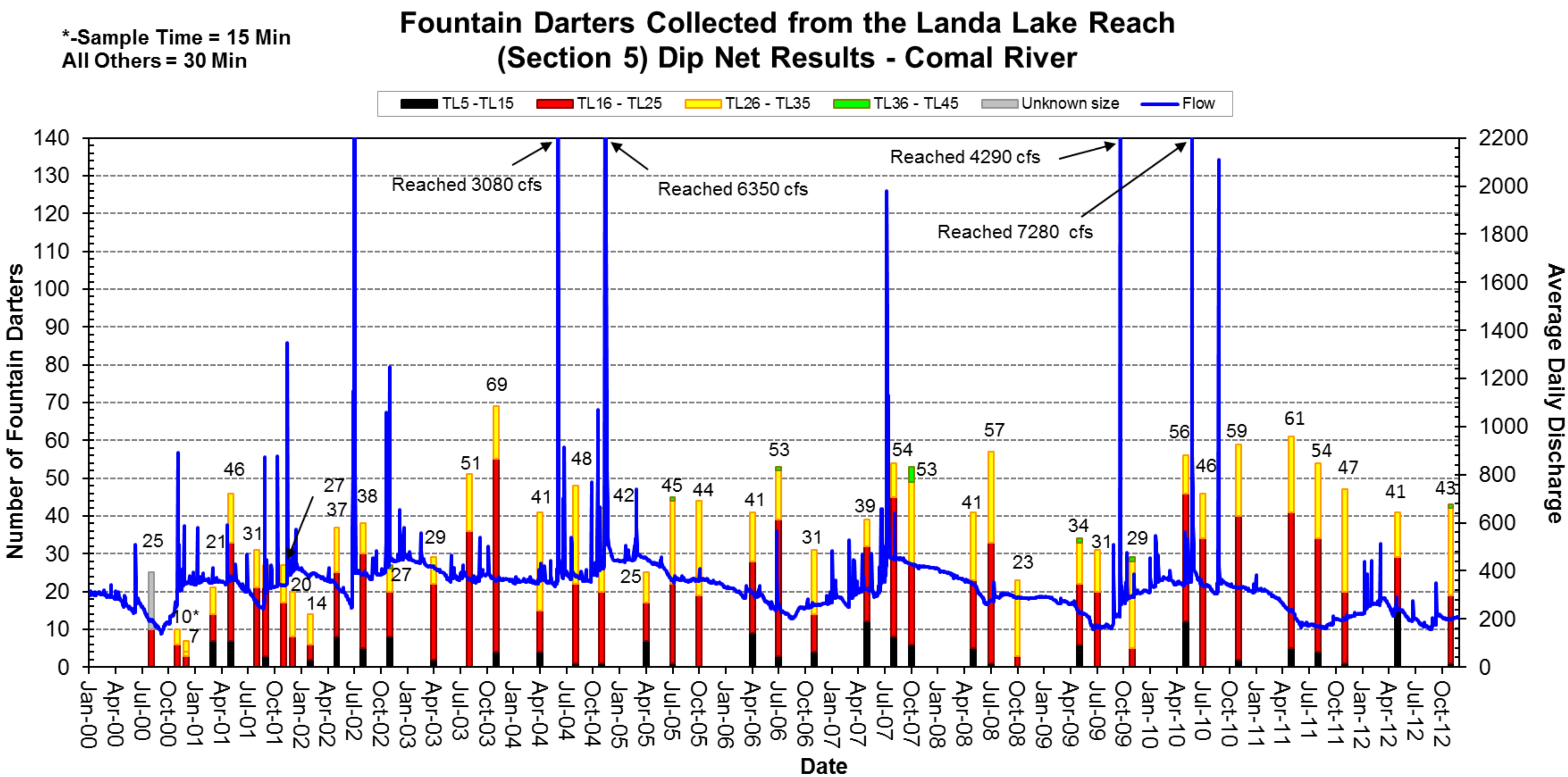

* - Sample time = 1 hour
All other samples = 30 min
Fountain Darters Collected from the Upper Spring Run Reach
(Section 3) Dip Net Results - Comal River
TL5 -TL15
TL16 - TL25
TL26 - TL35
TL36 - TL45
Flow
Reached 3080 cfs
Reached 6350 cfs
Reached 4290 cfs
Reached 7280 cfs
Number of Fountain Darters
Average Daily Discharge (cfs)
Date

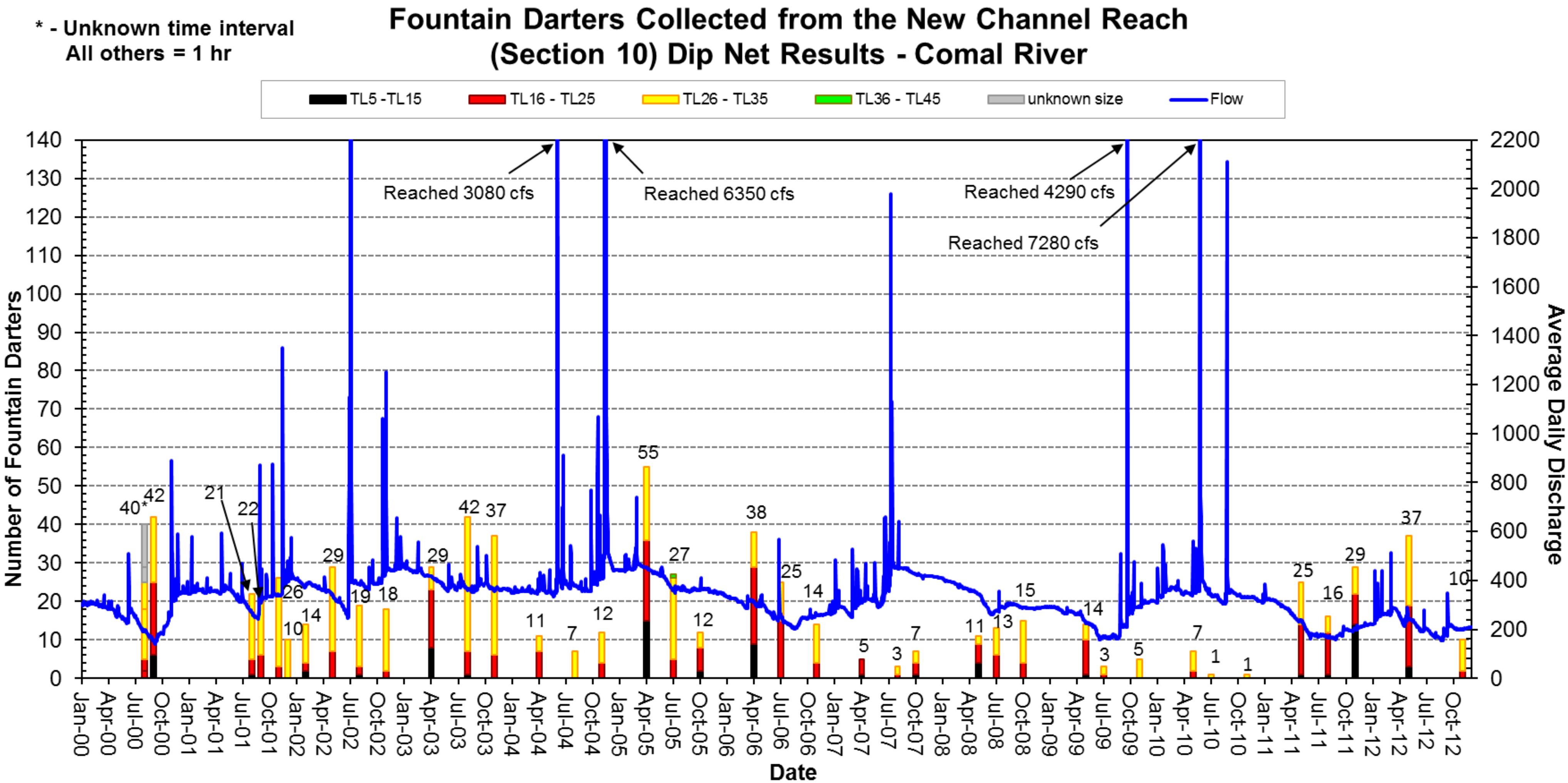


* - Sample time = 1 hr 45 min
All others = 30 min
Fountain Darters Collected from the Spring Island Area (Section 4U-M) Dip Net Results - Comal River
TL5 -TL15
TL16 - TL25
TL26 - TL35
TL36 - TL45
Unknown size
Flow
Reached 3080 cfs
Reached 6350 cfs
Reached 4290 cfs
Reached 7280 cfs
Number of Fountain Darters
Average Daily Discharge (cfs)
Date
76*
54
42
38
26
68
36
29
30
53
45
39
63
43
73
61
42
48
51
59
90
48
30
41
69
62
73
41
20
38
24
42
10
55
46
42
32
54
49
44

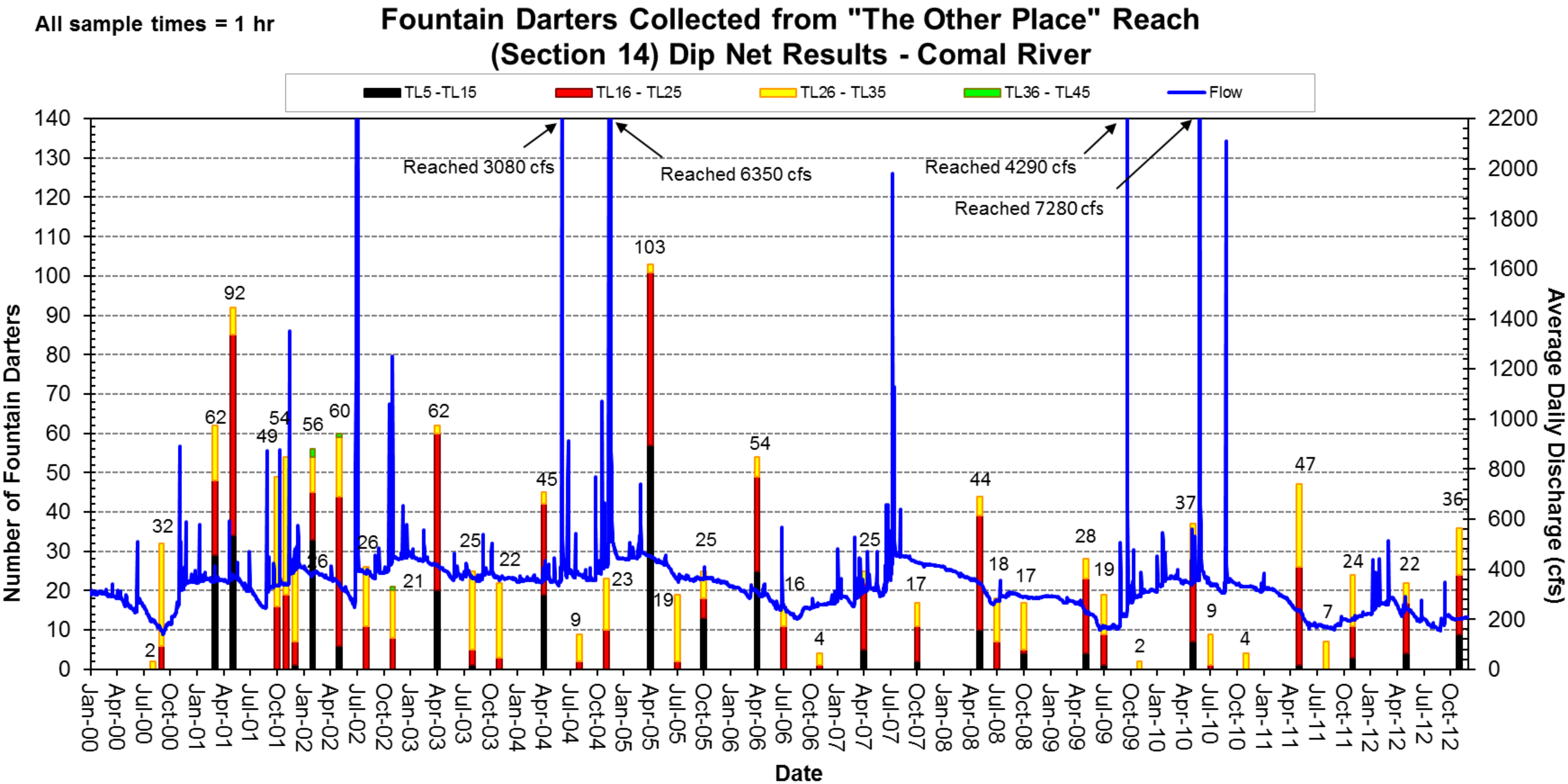

* - Sample time = 1 hr 15 min
All others = 30 min
Fountain Darters Collected from the Landa Lake Reach
(Section 4L) Dip Net Results - Comal River
TL5 -TL15
TL16 - TL25
TL26 - TL35
TL36 - TL45
Unkown size
Flow
Reached 3080 cfs
Reached 6350 cfs
Reached 4290 cfs
Reached 7280 cfs
Number of Fountain Darters
Average Daily Discharge
Date

*-Sample Time = 15 Min
All Others = 30 Min

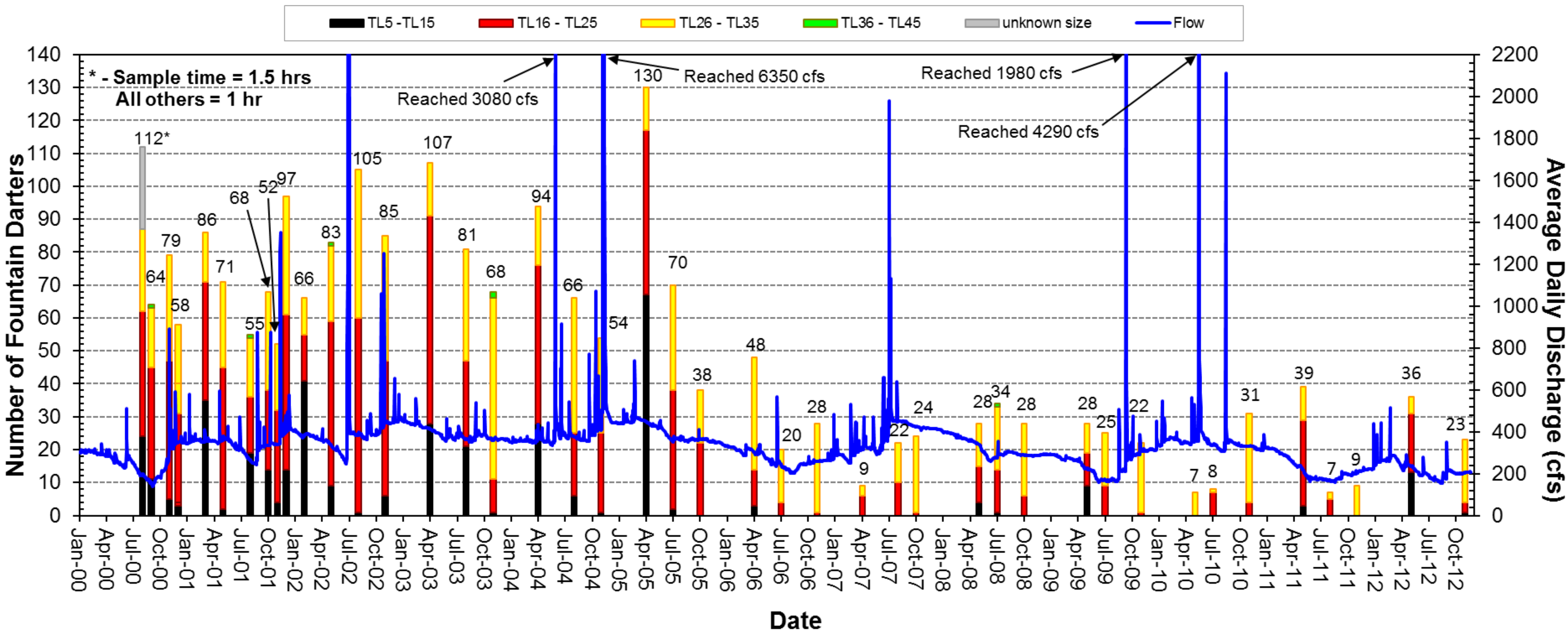



* - Unknown time interval
All others = 1 hr
Fountain Darters Collected from the New Channel Reach
(Section 10) Dip Net Results - Comal River
TL5 -TL15
TL16 - TL25
TL26 - TL35
TL36 - TL45
unknown size
Flow
Reached 3080 cfs
Reached 6350 cfs
Reached 4290 cfs
Reached 7280 cfs
Number of Fountain Darters
Average Daily Discharge
Date
40*
42
21
22
26
10
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
25
16
29
37
10
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
Jan-11
Apr-11
Jul-11
Oct-11
Jan-12
Apr-12
Jul-12
Oct-12

All sample times = 1 hr



Fountain Darters Collected from the Old Channel Reach (Section 16) Dip Net Results - Comal River



Appendix C:
Drop Net Raw Data
(Not Available Online)