Assessment of Instream Flow and Habitat Requirements for Cagle's Map Turtle (Graptemys caglei)

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INTRODUCTION

West Texas A&M University was contracted by the Edwards Aquifer Authority to conduct an assessment of the instream flow and habitat requirements for the Cagle's Map Turtle (Graptemys caglei) in the Guadalupe River. The team was to conduct independent research while working closely with the Project Management Team of the Guadalupe River Instream Flow (GRIF) Study.

The objectives of the study were to:

- Estimate relative abundance of Graptemys caglei.
- Correlate occurrences of Graptemys caglei with detailed physical morphometric maps of stream reaches within the main stream of the Guadalupe River.
- Develop field based habitat association of Graptemys caglei using instream flow methodologies and other techniques.
- Determine instream flow requirements of Graptemys caglei.
- Address water quality parameters and predict attenuation or degradation of water quality in stream segments.

West Texas A&M University was to submit a report containing data and detailed descriptions of Graptemys caglei habitat requirements and instream flow requirements and physical maps of the stream reaches inhabited by Graptemys caglei. All reports and maps were to be prepared in a manner that protects the species. This report and the comprehensive maps are being submitted to fulfill the requirements of the contract.

Graptemys caglei Haynes and McKown (Graptemys caglei; family Emydidae) is a recently described species of map turtle that is confined to riverine habitat in the Guadalupe-San Antonio River System of Texas (Haynes and McKown, 1974). Studies on Graptemys caglei include a chromosome study (Killebrew, 1977); an osteological comparison with Graptemys versa (Bertl and Killebrew, 1983); food habits (Porter, 1990); sex determination (Wibbels, Killebrew and Crews, 1991); coccidian parasites of Graptemys caglei and Graptemys versa (McAllister, Upton and Killebrew, 1991); radiotelemetry study (Craig, 1992); population and distribution (Babitzke, 1992); and population and nesting (Killebrew and Babitzke, 1996).

Graptemys caglei is currently found only in segments of the Guadalupe and San Marcos Rivers in Kerr, Kendall, Comal, Guadalupe, Gonzales, DeWitt, Hays, and Victoria Counties (Dixon, 1987; Killebrew, 1992; Killebrew and Porter, 1991; Porter, 1992). Surveys using time-constrained basking turtle frequency indices and mark-recapture studies indicate that Graptemys caglei is distributed in three river segments: (a) The upper Guadalupe River,(b) the middle Guadalupe River, and (c) the lower Guadalupe River (Figure 1). The total estimated population of Graptemys caglei in the Guadalupe river is 11,717 (Babitzke 1992).

The populations in the upper segment of the Guadalupe River (Figure 1), 253 river km (157 river mi) are unevenly distributed and minimal. Graptemys caglei is absent from Canyon Lake proper and virtually absent from Canyon Dam downstream to New Braunfels. Five impoundments on the Guadalupe River (Dunalp, Placid, Starke Park, McQueeny, and Meadow Lakes) occur between New Braunfels and Seguin and lack populations of Graptemys caglei. A review of the population data indicates that 11% of the population occurs in the upper segment of the Guadalupe River (Babitzke 1992).

The middle Guadalupe extends 226 river km (140 river mi) (Figure 1) and supports the primary population of this species. Early estimates indicated that from 60 to 70% of extant Graptemys caglei occur in the middle section of the Guadalupe River (Porter, 1992) while Babitzke (1992) estimated that 82% of the population occurred in the middle section of the river.

The lower Guadalupe River (Figure 1) in the vicinity of Victoria marks the southern extent of the distribution of Graptemys caglei. A review of the population data estimates indicates that only 7% of the Graptemys caglei population occurs in the lower portion of the Guadalupe River (Babitzke, 1992).

Habitat requirements for Graptemys caglei include a river bed consisting mostly of silt and gravel and gravel bars connecting long pool areas with a shallow average depth and a muddy, moderate flow (Killebrew 1991a). Basking habitats are provided by fallen logs, shrubs, rocks, and cypress (Taxodium sp.) knees (Haynes and McKown, 1974; Killebrew, 1992; Babitzke, 1992). Graptemys caglei is highly aquatic, and optimal habitat appears to include both riffles and pools (Haynes and McKown, 1974; Killebrew, 1991a; Killebrew, 1992; Babitzke 1992). Gravel bar riffles and transition areas between riffles and pools are areas of high aquatic insect prey species productivity and are considered important for Graptemys caglei foraging. (Killebrew, 1991a; Killebrew, 1991b). Recent radiotelemetry studies indicate that males may spend most of their time in these areas (Craig, 1992).

Haynes and McKown (1974) examined food items in several juvenile and adult males and two subadult females collected in July. They reported a diet of insects for both sexes (mostly caddisflies). Juveniles had also eaten large numbers of small gnat-like dipterans. The females had eaten caddisflies and snails. Lehmann(1979) reported both sexes as insectivorous, primarily consuming caddisflies and odonates (dragonflies and damselflies). The studies of Haynes and McKown (1974) and Lehmann(1979) involved small sample sizes and collections during a one or two month period.

Killebrew (1991b) described Graptemys caglei feeding ecology, including seasonal, size-specific, and sex-specific diet differences. This study took place near Cuero close to the middle of the species range. Adult males fed primarily on insects (81% of gastrointestinal contents by weight) while adult females fed primarily on mollusks (88% Asiatic clam (Corbicula fluminea) of gastrointestinal contents by weight)(Killebrew, 1991b). Male Graptemys caglei feed extensively on trichopteran (caddisfly) nymphs of the genus Nectopsyche (45% gastrointestinal contents by weight). Other insect prey taken by both sexes included mayfly, damselfly, and dragonfly nymphs and adults, stonefly nymphs, and spongillafly nymphs. Male juveniles fed on nearly equal quantities of snails and insects while female juveniles ate nearly equal quantities of Asiatic clams and insects (Killebrew 1991b).

Graptemys caglei exhibits distinct sexual dimorphism. The adult male carapace length averages from 7 to 12 cm, while those of females are generally larger and may reach lengths of up to 20 cm (Conant and Collins, 1991; Haynes and McKown, 1974; Killebrew and Porter, 1989; Killebrew and Porter, 1991).

Little is known regarding reproduction in this species. Haynes and McKown (1974) collected hatchling turtles from September through November and hypothesized that the Graptemys caglei nesting period occurs in late spring and early summer. Nesting habits in this species are not well known. Haynes and McKown (1974) reported that sand bars are virtually nonexistent in many reaches of the Guadalupe River and concluded that nesting habits in Graptemys caglei may differ from other species of Graptemys that often nest on sandbars. Killebrew and Babitzke (1996) indicated that nesting begins as early as late March and extends through August. Nest substrate varies, nests have been found in sand, sandy loam, clay loam and a sand gravel mix.

Graptemys caglei was listed in Texas as a threatened species on November 30, 2000 (Texas Register, TITLE 31. Chapter 65). The U.S. Fish & Wildlife Service has determined that the listing is warranted but has not proceeded with federal designation due to other listing priorities. As a result, Graptemys caglei is currently designated as a category 1 federal species.

On the federal candidate notice of review, category 1 designation means there is "substantial information on biological vulnerability and threats to support proposing to list as endangered or threatened." "Data are being gathered on habitat needs or critical habitat designations." This action is based on the following reasons: (1) Graptemys caglei has an extremely limited distribution; (2) within its current range, suitable habitat for Graptemys caglei is fragmented and becoming more scarce. Further losses of suitable habitat will result if impoundments and water diversions are constructed; (3) Graptemys caglei diet of aquatic invertebrates (particularly insects) may be adversely affected by altered instream flow, pollution and increased sedimentation; and (4) human depredation is occurring from intentional shootings and over-collection for the pet trade, zoos, museums, and scientific studies (Killebrew, 1991a; Killebrew, 1992).

MATERIALS and METHODS

The WTAMU team conducted over 381 miles of canoe and boat surveys along the Guadalupe River. The information was used to estimate the relative abundance of Graptemys caglei and to develop an action plan to accomplish the objectives of the project.

While conducting the surveys for relative abundance the following precautions were observed to prevent biasing the results:

- Surveys in recreational areas of the river were scheduled during mid-week to reduce the effects of human disturbances.
- Effects of seasonal and daily (weather) changes were reduced by performing the total census over a period of consecutive days during the same season (Giles, 1969).
- Notes were made on any changes that may have occurred during the survey. Field notes for the surveys were then compared to avoid unusual weather conditions.
- To prevent the loss or addition of more active periods when the animals may be observed in more abundance, surveys began and ended at approximately the same time each day.

Once the initial survey was completed, the WTAMU team returned to resurvey areas to verify findings. Once verification was completed the WTAMU team began surveying selected areas along the Guadalupe River to complete the requirements proposed by the Edwards Aquifer Authority.

I. Occurrences of Graptemys caglei

The Guadalupe River was divided into three regions: upper, middle, and lower (Figure 1). The divisions of the Guadalupe

River were selected based on biotic features. The upper and middle Guadalupe River division is approximately where the Balconian Biotic Province and Texan Biotic Province meet (Blair 1950). The division of the lower and middle Guadalupe River coincides with the beginning of the coastal plains within the Texan Biotic Province (Blair, 1950). Within these regions, locations of occurrences of Graptemys caglei were determined using a Sony GPS model IPS 360 and later transferred to digital morphometric maps using Arc View Geographic Information System software. The morphometric maps and the GPS coordinates of Graptemys caglei overlays were downloaded from data disks provided with the Arc View program. Copies of Well Hollow, Quadrangle Topographic Maps (7.5 minute series, U.S. Geological Society) were used as a field reference for the WTAMU team's site locations while conducting the basking surveys to determine relative abundance. Location coordinates were confirmed using the Sony GPS instrument.

II. Relative Abundance of Graptemys caglei

Relative abundance was determined using linear regression, basking counts and the index of conspicuousness (Howell, 1951). The linear regression analysis and index of conspicuousness were based on a capture-mark-recapture study and basking counts conducted from 1990 to 1999 within a 38.1 km (23.8 mile) stretch of the Guadalupe River (WTAMU study site). The capture-mark-recapture data was analyzed using the Jolley-Seber open population model (Pollock et al., 1990). The statistical computer program SPSS9 was used to calculate a zero regression using the Jolly-Seber (Pollock et al., 1990) population results and basking counts. Relative abundance was determined using the regression line equation and index of conspicuousness (Howell, 1951) and then compared for best fit.

III. Develop Habitat Association of Graptemys caglei

Based on survey results, the study site selected by WTAMU in 1985 was found to have the highest density of the species and was selected as the optimum model for habitat requirements of Graptemys caglei. Information accumulated during the distribution surveys when compared to the WTAMU site suggests occurrences of Graptemys caglei may be associated with water velocity, substrate, basking sites and willow trees (Salix sp.) The WTAMU team returned to four regions of Guadalupe River that exhibited selected relative abundance of Graptemys caglei to validate the proposed habitat characteristics. The river segment populations were categorized as; (High) population greater than 40 per kilometer, (Medium) less than 40 but equal to or greater than 26 individuals per kilometer, (Low) one or more but equal to or less than 25 individuals per kilometer and (Zero) no observed or predicted population. Within the upper Guadalupe River two areas were surveyed for habitat characteristics. The first area (location 4, Figure 2) was a 3.0 km segment of river with an isolated, low population (< 25/km). The second area (within location 4-5, Figure 2) was 1.0 km in length and contained a zero population. In the middle region of the Guadalupe River two additional areas were surveyed, one 2.7 km segment (within location 23-24, Figure 2) with a medium (26-40/km) population and a 3 km segment (within location 22-23, Figure 2) with a high (>40/km) population were surveyed for habitat characteristics. The river segments chosen for sampling varied in length because each segment was sampled until four run areas with joining pool and riffle areas were characterized. The data collected included: velocity, discharge, grade, substrate types, number of basking sites, and numbers of willow trees (Salix sp.) along the riverbanks. These variables were tested for relevance in determining the distribution of Graptemys caglei using the SPSS9 statistical computer program.

Water Velocity

Water velocity measurements were measured in six run areas within the selected low population area and in four run areas in each of the zero, medium and high population areas using a Rickly Hydrological AA Type flow meter and top setting rod. The procedures stated in the USGS EMD Manual Operation SOP, 5-21000-OPS, p. 10-22 were used as a guide to collecting the flow data; however, to increase accuracy the method was modified to include measurements at 1 meter increments for the width of the transect instead of following the three measurement method. Transects were established across the river at a point mid-way down the run to be measured. If the water depth at the increment was equal to or less than 2.5 feet, water velocity was measured at 0.6 of the total water depth. If water depth was greater than 2.5 feet two water velocity was measured at 0.2 of the total water depth and at 0.8 of the total water depth. Vertical measurements were averaged to determine water velocity for the increment. The water velocity at each meter increment long the transect was averaged to determine a mean water velocity for the run within the selected population areas.

The population estimates for the zero, low, medium and high areas were converted to a ratio of Graptemys caglei per meter. Within the sampled areas the number of Graptemys caglei per meter was assigned to each corresponding run according to length. To determine if water velocity was a relevant habitat requirement of Graptemys caglei, the population ratio and velocity were used to compute a polynomial regression at a 95% significance level. Water velocity was also used to calculate discharge for each run within the selected population area as a reference in determining influences of water movement on habitat preference of Graptemys caglei.

Grade was also measured for each run, riffle and pool within the selected population areas using a Berger Transit model no. 320 and a sokkia fiberglass leveling rod. Grade was recorded as the difference in elevation of the river channel at the beginning and end of each run, riffle and pool. Grade was measured for its influence on water velocity. Grade for the entire river segment in which the population resides was determined using 7.5 minute topographic contour maps. Grade (topographic relief) increases water velocity, as the topographical slope becomes steeper. Topography can also influence river channel width.

Substrate

Substrate type was determined at the same time that discharge and velocity were being sampled. For each 1 meter increment across the run, substrate was recorded as a percentage using a modification of the Wentworth scale: sand (1-2 mm), gravel/pebble (2-64 mm), cobble (64-256 mm), boulder (>256 mm), and solid stone. Percent substrate was determined by characterizing, at each increment sampled, the particle type at the base of the top setting rod/flow meter.

The population estimates for the low, medium and high areas were converted to a ratio of Graptemys caglei per meter. Within the sampled areas the number of Graptemys caglei per meter was assigned to each corresponding run according to run length. A multiple regression analysis was calculated and the nature of the relationship between substrate and Graptemys caglei population was determined.

Substrate was also sampled for benthic organisms, an important component in the diet of Graptemys caglei. Surber samples were collected at three different areas along a transect in the riffles within the selected population areas. The transect was divided into three segments across the riffles and a sample was collected in the middle of each segment. If the river conditions (velocity and depth) prevented sampling across an entire riffle area the portion available to sampling was divided into three segments and sampled. The aquatic organisms captured in the sample were placed in 70% isopropyl alcohol and later identified.

Sweep net samples were also collected in the selected population areas to determine alternate habitats that may be utilized by the food organisms preyed upon by Graptemys caglei. Herbaceous plants, along with their shoot or root systems, in contact with the water were sampled. The root system of woody vegetation was sampled by removing a portion of the roots system that was exposed by erosion and in contact with the water. The root systems were then examined for aquatic organisms.

Basking Sites

Basking sites were typically logs, stumps, tree branches, etc. that were visually estimated to be greater than 3 cm in diameter, (reference: U.S. Quarter Dollar) and at least 1 m from the bank. Basking sites were counted for each run, pool and riffle area within the four run river segment of the selected population area along the Guadalupe River. Two researchers would independently count the basking sites within the sampled area then compare the counts for accuracy. If the difference between the counts varied by more than 5% the area was resurveyed. To determine the significance of basking sites as a relevant habitat characteristic, the population estimates for the zero, low, medium and high areas were converted to a ratio of Graptemys caglei per meter and assigned to each corresponding riffle, run and pool according to their length. The basking site data was square root transformed to make the variances uniform for use in a parameteric test (Berthouex and Brown, 1994). Using the population ratios and number of basking sites, a linear regression was calculated with confidence intervals at a 95% significance level.

Willow Trees (Salix sp.)

Willow trees (Salix sp.) were counted for a 100 meter distance at 5 randomly chosen river segments within each of the selected population areas. The willow trees (Salix sp.) within a 5 meter distance from the river channel were counted with the assumption that the roots of these trees could extend into the river channel. Previous observations of isolated willow trees (Salix sp.) located at the bank/water interface with exposed root systems revealed that the roots extended approximately 5 meter upstream and downstream of the trees trunk. The exposed root system could provide habitat for prey identified in sweep netting. Willow tree (Salix sp.) counts were conducted by two researchers, independently, then compared for accuracy. If the difference between the two counts varied by more than 5% the area was resurveyed. A bushnell yardage pro 1000 was used to measure the 100 m increments and a table of random numbers was used to select the segments surveyed. The population estimates from the low, medium and high areas were converted to a ratio of Graptemys caglei per kilometer for the entire selected population area. The willow trees (Salix sp.) were square root transformed to make the variances uniform for use in a parametric test. Using the population ratio of Graptemys caglei per kilometer and average number of square root transformed willow trees (Salix sp.) per 100 m, a logarithmic transformation regression was calculated at a 95% significance level to determine relevance of willow trees (Salix sp.) as a habitat characteristic required by Graptemys caglei. The nature of the relationship was determined using an F-test.

IV. Water Quality Parameters

Historical water quality data was reviewed from the database of the Guadalupe/Blanco River Authority, Texas Natural Resource Conservation Commission and Edwards Aquifer Authority. Water quality data was searched for trends of increasing effluents, flocs (precipitating agents such as iron or aluminum salts), bacteria (coliforms), nitrates, phosphates and sulfates. This data was compared to the distribution and the relative abundance by placing the data on a map of the Guadalupe River with the distribution and relative abundance. The changes in chemical content of the water can then be compared to the changes in relative abundance of Graptemys caglei.

RESULTS

I. Occurrences of Graptemys caglei

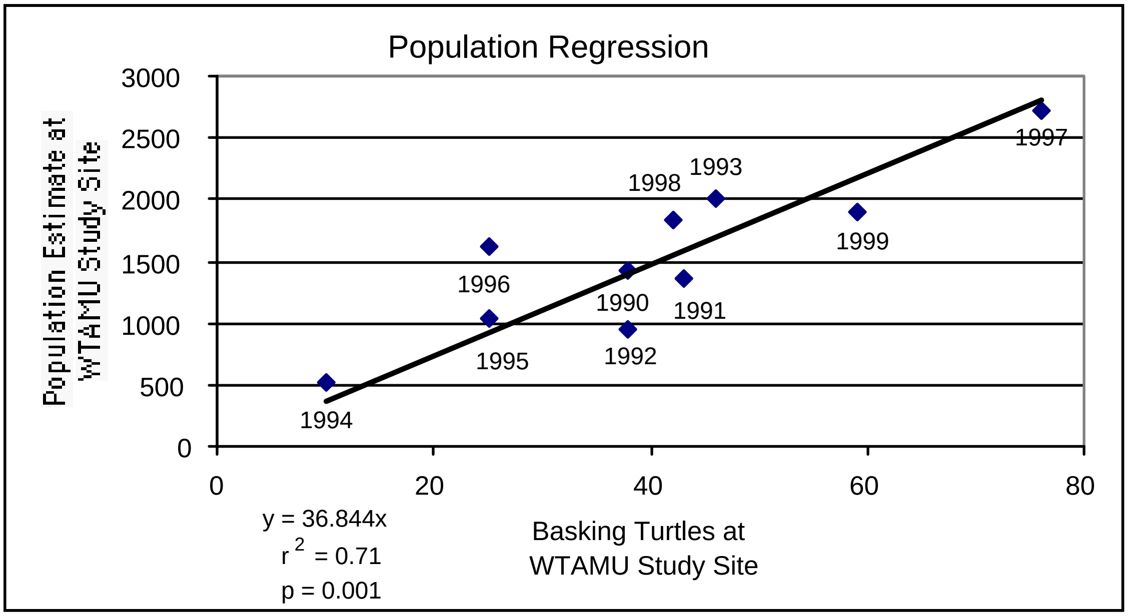
The Guadalupe River was separated into upper, middle and lower segments to locate and survey populations of turtles within those segments. The upper Guadalupe River is 253 km (157 miles) long and contains 1,434 individuals comprising 11% of the overall population (5.7 turtles per kilometer) (Figure 1). The middle area of the Guadalupe River is 226 km (140 miles) long and contains 10,067 turtles, which is approximately 75% of the population (44.5 turtles per kilometer) (Figure 1). The lower area of the Guadalupe River is 142 km (89 miles) in length and contains 1,967 turtles, which is approximately 14% of the total population (13.9 turtles per kilometer) (Figure 1).

Two trends occurred in the distribution of Graptemys caglei. First, in the upper Guadalupe River, Graptemys caglei are found in small isolated populations with the exception of location 11-12 (Figure 2). Second, in the middle and lower segments, the distribution is graded (Figure 2). Distribution within the segments identified as low, medium or high may have significant population variation within that segment. For example, between locations 20-21 and 21-22, both areas are listed as high populations; however, there are 43 turtles per km between locations 20-21 and 65 turtles per km between locations 21-22 (Figure 2). Both are placed in the high population category but have different population sizes.

II. Relative abundance of Graptemys caglei.

The relationship of basking Graptemys caglei to the population estimate (Graph 1) in the WTAMU study site strongly suggests a true correlation exists (i.e. we reject the null hypothesis H_o: Slope = 0) between basking turtles and population size at 95% significance levels (r^2 = 0.7608;p = 0.0001). The correlation of basking Graptemys caglei and population estimate within the WTAMU study site over a ten year period with comparable results supports the use of basking counts to determine populations in the Guadalupe River. Regression line 95% confidence intervals were calculated (± 15/km).

Graph 1. Graptemys caglei population and basking Graptemys caglei zero regression relationship.



The data in Graph 1 is from two populations of Graptemys caglei. When the capture-mark-recapture study was initiated, the WTAMU study site was a 21.5 km segment of Guadalupe River downstream from an abandoned hydroelectric dam that was in the process of being restored. The Guadalupe River was diverted around the dam while restoration was being completed. In the fall of 1992 restoration was completed and the dam became operational. The WTAMU study site was enlarged to include a 16.6

km segment of river above the dam to study the effects small impounds have on Graptemys caglei. The capture-mark-recapture study was initiated within this area during the summer of 1993. The hydroelectric dam appears to be a barrier to Graptemys caglei migration, therefore, creating two populations of Graptemys caglei within the WTAMU study site. Population estimates and basking counts from the upstream and downstream study sites were incorporated into the regression. Data collected every other year was used because the capture-mark-recapture study alternated from upstream to downstream study sites as the primary study site each year; however, several surveys were conducted in the alternate site each year to determine site status. Population estimates and basking counts from the upstream study site were 1994, 1996 and 1998 while estimates and counts during 1990-1993, 1995, 1997 and 1999 are from the downstream study site and both were used in the regression (Graph 1). Data suggests variation in basking counts and population estimates of Graptemys caglei in the upstream site is the result of the completion of the dam impounding water and resulting impoundment of water. The dam impounds water approximately 12 kilometers upstream and the depth of the water increased by 6 to 9 kilometers (20-30 feet) at the dam. The impounded water eliminated essential riverine habitat including but not limited to: riffle areas and shoreline vegetation (the habitat of aquatic insects composing the diet of Graptemys caglei); shoreline (for nesting sites); and logs, stumps, etc. (basking sites). Observations suggest these habitat characters are required for the existence of Graptemys caglei.

Loss of these habitat characteristics would result in the low population estimate and basking count in 1994. Over the next four years as the area recovered from the impounded water, new basking sites were accumulated and willow trees (Salix sp) repopulated the riverbanks. Water currents eroded the riverbanks exposing the root systems of existing willow trees (Salix sp) making habitat available to aquatic insects composing the diet of Graptemys caglei. Erosion and deposition created new nesting areas along the riverbanks. As this transformation took place Graptemys caglei would begin to repopulate the area, accounting for the increase in population size and basking counts in 1996 and 1998 (Graph 1).

The restored hydroelectric dam also varied the flow rate of the Guadalupe River in the downstream study site. Observations suggest that the variation in flow influenced the population estimates and basking counts in the downstream study site as well. Changes of 0.5-1 m in water level in the downstream site could occur within a few hours by releasing or impounding water. Rapid changes in water level can effect nesting and availability of food. Graptemys caglei females do not travel far from the waters edge to nest (Killebrew and Babitzke, 1996), frequent increases in flow rate could destroy nests by washing the eggs away or covering the eggs with water. Rapid decreases in flow rate exposes riffle areas, not allowing movement of mobile organisms and may destroy nonmobile or attached benthic insects which may compose the diet of Graptemys caglei.

Although influences of the hydroelectric dam on water flow began in December of 1992, the population remained stable in 1993. The population began to decrease after the capture period in 1993. Observations suggest the lower water flow of 1993 and frequent and rapid changes in water flow during 1994 are responsible for the reduction in population exhibited in 1995 (Graph 1). In 1997, the population estimate of Graptemys caglei was unusually large. Observations suggest, a drought across the Guadalupe River drainage basin in 1995 and 1996 reduced the amount of water released from dams upstream from the hydroelectric dam in the WTAMU study site. This reduced the amount and frequency at which water was released from the hydroelectric dam in the WTAMU study site. Although there was less water flow through the downstream study site it appeared to be a stable flow allowing the Guadalupe River to recover during 1995 and 1996 increasing the population of Graptemys caglei and resulting basking counts in 1997 (Graph 1). In 1997, increased water flow from rain and runoff across the drainage basin of the Guadalupe River increased and maintained the water level in the lower study site between 60 cm and 3 m above normal throughout the spring and summer. The high water flow reduced foraging in riffle areas and increased the scouring of the substrate, which reduced food availability and nesting success of Graptemys caglei by washing away nests and limiting quality nesting areas. During the late summer and early fall of 1997, the water flow returned to normal. However, during October of 1998 another large flood occurred which eroded large areas of riverbank and washed out willow trees (Salix sp.). Sediments deposited on the riffle areas reduced food availability and ultimately decreased the population of Graptemys caglei in 1999 (Graph 1).

The WTAMU team conducted basking surveys for 381 miles of the Guadalupe River, beginning at New Lake Ingram and ending at Tivoli, Texas. The population estimates from the zero regression and index of conspicuousness were similar. The index of conspicuousness was chosen to determine population in other areas because the estimated population from the index of conspicuousness is slightly lower. For example, if one basking Graptemys caglei was counted the regression line would result in an estimated 36 Graptemys caglei, while the index of conspicuousness would result in an estimated 33 Graptemys caglei. Thus the index of conspicuousness was used to prevent an overestimate of the population. Table 1 lists the index of conspicuousness, number of basking Graptemys caglei and population estimate based on the index of conspicuousness for each location along the Guadalupe River. The dates listed for locations 6,13,14 and 15 in Table 1 vary by one year because these locations were resurveyed. For example, location 6 and 13 had observed populations of Graptemys caglei in 1991 but during the survey in 2000 no Graptemys caglei were seen in these areas. To verify these observations the same locations were resurveyed in 2001. In the 2001 survey, one Graptemys caglei was observed basking in location 6 and three Graptemys caglei were observed basking in location 13. Locations 14 and 15 were resurveyed in

2001 because a change in weather conditions occurred during the survey in 2000 that could bias results.

Table 1. Distribution and abundance of Graptemys caglei. Index of Conspicuousness = 0.03.

Location	Date	# Basking	Population	Distance	Population/k
1	6/01/00	1	33	<1	Isolated
2	6/02/00	2	67	<1	Isolated
3	6/03/00	7	233	<1	Isolated
4	6/03/00	2	67	<1	Isolated
5	6/05/00	5	167	<1	Isolated
6	6/07/01	1	33	<1	Isolated
7	6/07/00	5	167	<1	Isolated
8	6/07/00	2	67	<1	Isolated
9	6/08/00	4	133	13.8	10
10	6/08/00			End Point	
11	6/14/00	11	367	20.5	18
12	6/14/00			End Point	
13	6/08/01	3	100	<1	Isolated
14	6/10/01	11	367	22.6	16
15	6/10/01	20	667	18.9	35
16	6/22/00	25	833	9.5	88
17	6/22/00	39	1300	25.7	51
18	6/24/00	41	1367	18.3	75
19	6/25/00	54	1800	57.3	31
20	6/25/00	21	1033	24.3	43
21	6/26/00	40	1333	20.5	65
22	6/27/00	41	1367	30	46
23	6/28/00	45	1500	40.6	37
24	6/28/00	14	14	26	18
25	6/29/00	0	0	76	0
26	6/30/00			End Point	

Populations of Graptemys caglei were considered to be isolated if a dam, low water crossing, or long segment of river separated basking Graptemys caglei. For isolated populations at locations 1-9 and 13, the distance is listed as less than 1 kilometer because basking Graptemys caglei were observed in an isolated area within less than a kilometer along the Guadalupe River.

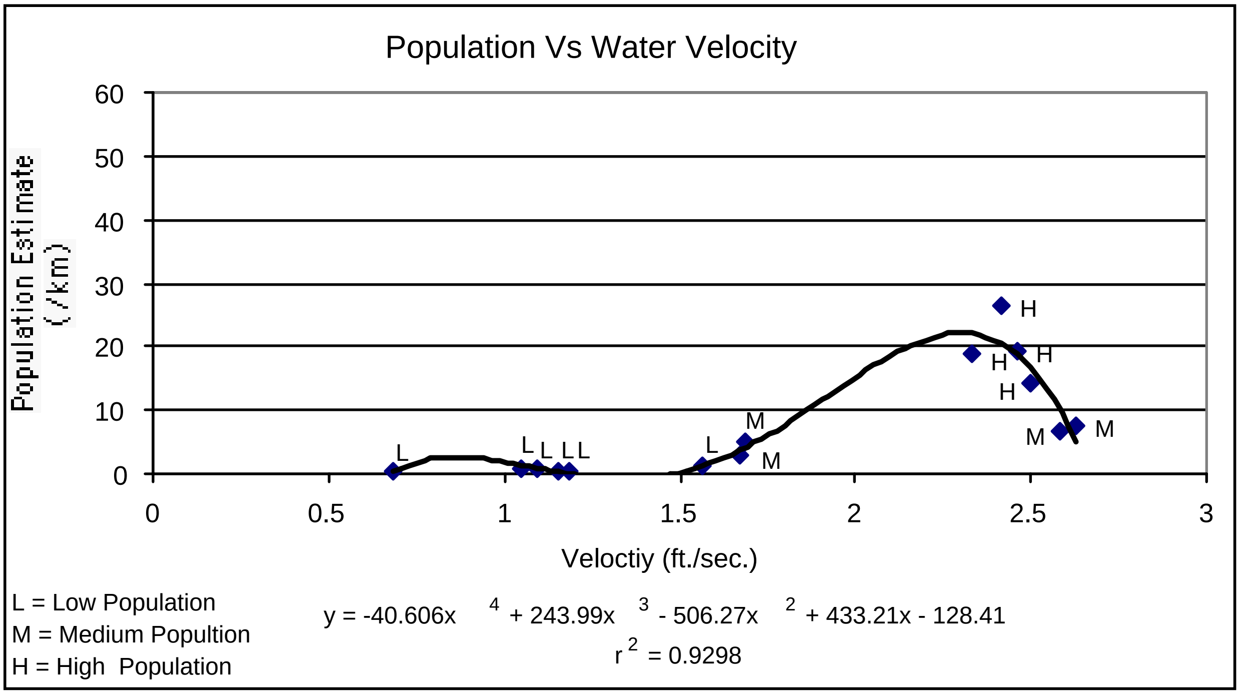
III. Develop habitat association of Graptemys caglei

It is important to understand that the habitat characteristic associated with Graptemys caglei cannot be used to determine relative abundance (Standards for the Development of Habitat Suitability Index Models, 103 ESM, Release No. 1-81). Populations can only be determined by counting basking Graptemys caglei or other direct measuring methods. Habitat characteristics should only be used to assess habitat potential of the area. Habitat characterization does provide a useful planning tool to evaluate potential habitat and potential for occurrences based on suitable habitat.

Water Velocity

The relationship of water velocity to population in a polynomial regression (r^2 = 0.929) provides a good fit and standard error of estimate suggests water velocity is influential as a habitat characteristic of Graptemys caglei. The polynomial regression line in Graph 2 suggests Graptemys caglei can inhabit areas with low water velocities but these areas will only support small populations. As water velocity increases the population of Graptemys caglei also increases until the optimum velocity at approximately 2.4 feet per second.

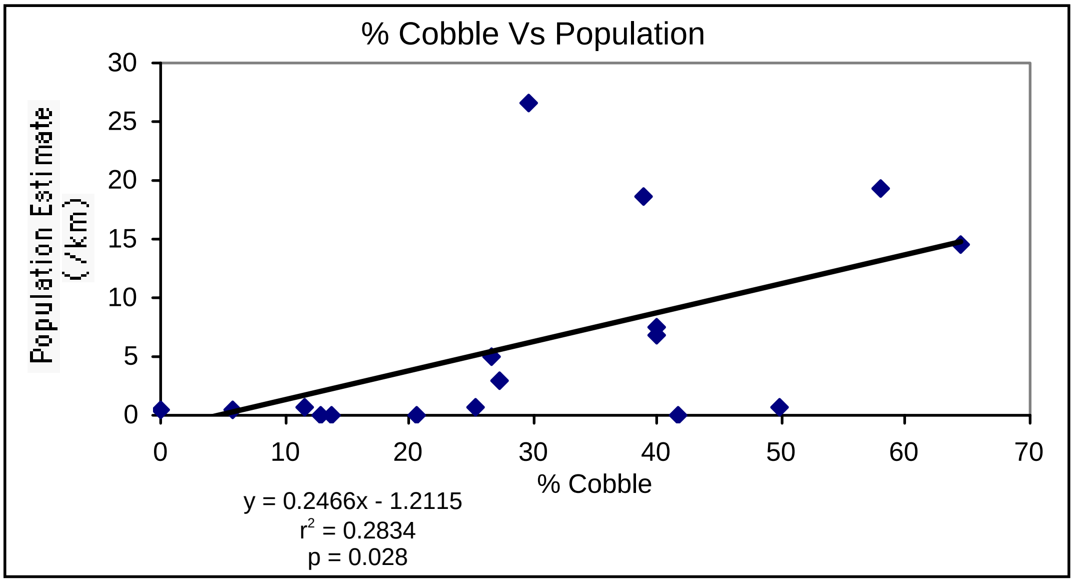
Graph 2. The relationship of Graptemys caglei population and water velocity.



Substrate

Substrate types were compared in a multiple regression as a stepwise comparison. The substrate types that were not significant at the 95% significance level were eliminated by the comparison. Cobble sized (64-256 mm) substrate was the only substrate that was significant at 95% significance levels. The relationship of percent cobble to population (Graph 3) was tested and found to be significant at the 95% level (i.e. we reject the null hypothesis H_o: Slope = 0) (r^2 = 0.283; p = 0.028), suggesting substrate is an important habitat characteristic in determining the occurrence of Graptemys caglei.

Graph 3. Linear regression relationship of percent cobble to Graptemys caglei population.



Zoobenthos and Substrate

Surber and sweep net sampling was conducted to obtain a qualitative representation of the zoobenthos within the selected population areas. A total of 18 families of insects, 2 families of mollusks and 2 families of gastropods were represented in the surber and sweep net analysis of the four selected population areas. The families represented in the high population area (WTAMU study site) are listed in Table 2. The surber and sweep net samples conducted at the remaining selected population areas were compared to the sample collected in the high population area (WTAMU study site) (Table 2).

Table 2. Families collected in Surber and Sweep net analysis.

Location	Surber Samples	Sweep Netting
WTAMU STUDY SITE	Corbicula	Leptoceridae
	Ecdyuriidae	Coenagrionidae
	Sialidae	Libellulidae
	Velidae	Nepidae
	Pyralidae	Ecdyuriidae
	Elmidae	
	Hydropsychidae	
	Leptoceridae	

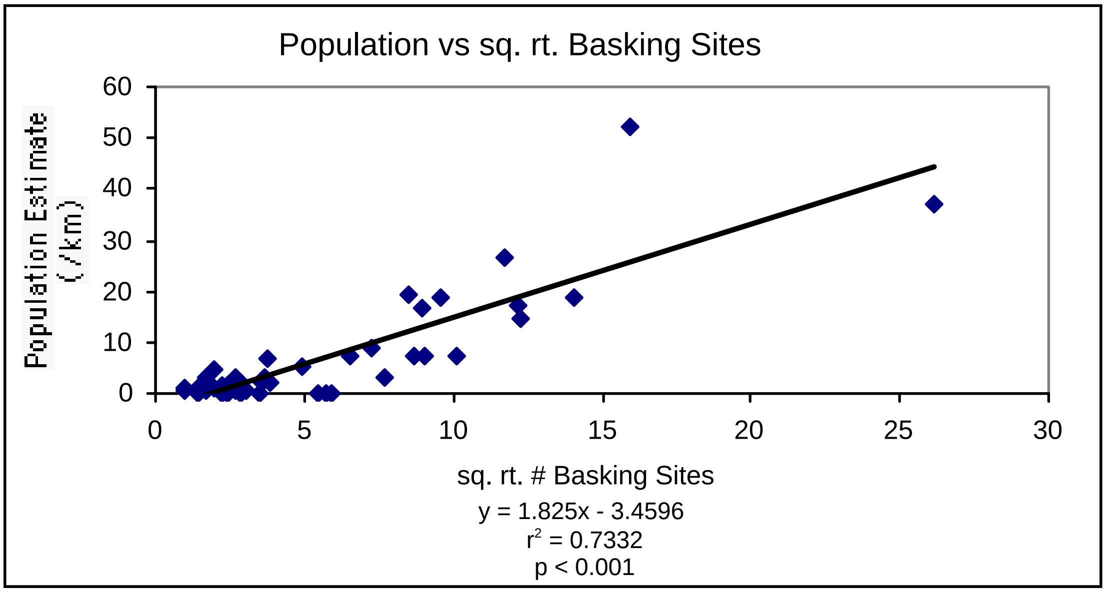
The surber and sweep net analysis from the low population area contained many of the same representative insect families as the WTAMU study site except the families Velidae, Pyralidae and Leptoceridae were absent. The family Leptoceridae is an important family because it composes approximately 45% of the male Graptemys caglei diet (Porter, 1990). The medium population area contained the same representative families as the high population area (WTAMU study site).

The surber and sweep net samples from the zero population, when compared to the WTAMU study site lacked Velidae, Pyralidae, Libellulidae, Nepidae, Ecdyuriidae and Leptoceridae. Again, the family Leptoceridae is absent from the sample which composes approximately 45% of the male Graptemys caglei diet (Porter, 1990).

Basking Sites

The linear regression relationship of basking sites to population (Graph 4) is significant as well (i.e. we reject the null hypothesis H_o: Slope = 0) beyond the 95% significance level ($r^2 = 0.733$; $p < 0.001$). Basking sites are considered an essential habitat characteristic for the occurrence of Graptemys caglei. The number of basking sites were square root transformed; therefore, the actual number of sites can be determined by squaring the number of basking sites along the x-axis of Graph 4.

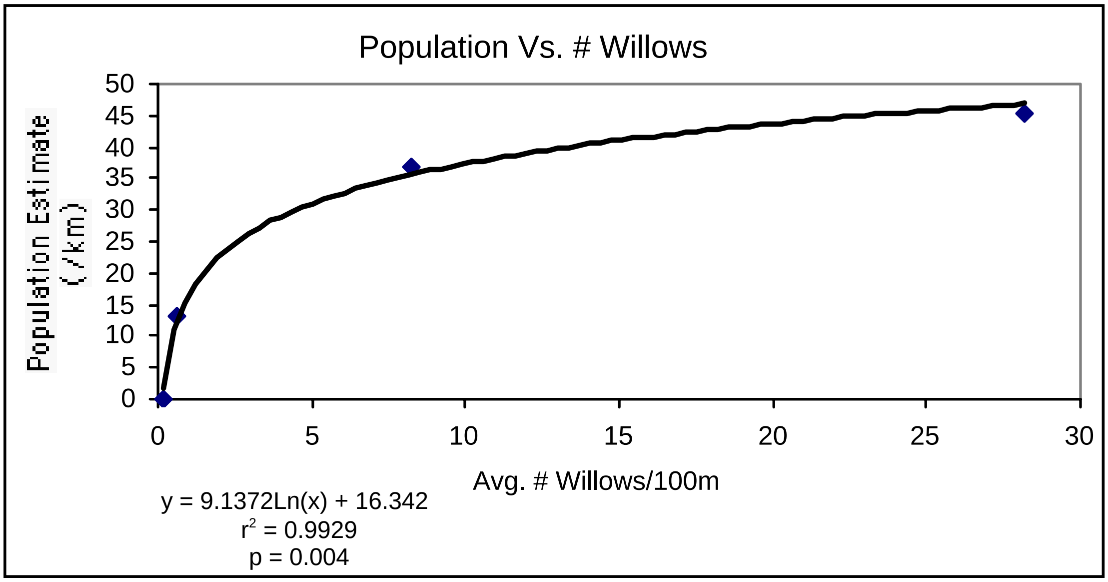
Graph 4. Linear relationship of Graptemys caglei population to transformed basking sites.



Willow Trees (Salix sp.)

The data was evaluated using a log-regression to determine a relationship of willow trees (Salix sp.) to population. The relationship is illustrated in Graph 5 (r^2 = 0.993) suggesting that a true correlation exits (i.e. we reject the null hypothesis H_o: Slope = 0). Willow trees (Salix sp.) are considered an important habitat characteristic for the occurrence of Graptemys caglei. The log-regression suggests that once a certain number of trees are present, the population of Graptemys caglei will no longer increase regardless of increasing tree density.

Graph 5. Log-transformed relationship of Graptemys caglei and willow trees (Salix sp.).



DISSCUSSION

I. Relative abundance of Graptemys caglei

The capture-mark-recapture program at the WTAMU study area was conducted from May 1985 to March 1999 and represents over 16,229 survey man/hours. This data was used to establish the relative abundance of Graptemys caglei within the Guadalupe River. Field research for the Edwards Aquifer Authority began on May 2000 and ended in February 2002 representing over 1,312 survey man/hours.

The total estimated Guadalupe River population of Graptemys caglei calculated in July 2001 was 13,468. The total estimated population calculated in July 1991 was 11,717 (Babitzke, 1992);

however, it is important to note that four areas of the Guadalupe River surveyed in 2000 and 2001 were not included in the July 1991 surveys because of monetary and time constraints placed on the survey team. These four locations were 1, 2, 3 and 15-16 (Figure 2), all contained a population of Graptemys caglei in July 2000.

To determine population changes from 1991 to 2000, the error variance due to deviation of the y-values (Population Estimates) must be accounted for. The error variance was previously listed as ± 15/km. Therefore, to determine if an area has increased or decreased in population from the 1991 survey to the 2000-2001 surveys, the difference must be greater than ± 15/km Graptemys caglei for the selected area. Population changes that were observed from 1991 to 2000 included one potential population decrease (location 17-18), one population increase (locations 23-24) and one diminished population (within location 12-13). One unusual population distribution pattern encompassing an increasing and a decreasing population (locations 19-22 and 13-14) (Figure 2) was also noted.

Location 17-18 (Figure 2) was estimated to have a population of 77/km in July of 1991 while in June of 2000 the population estimate decreased to 51/km. Major changes in riverine habitat from 1991 to 2000 were not observed. Locations 17-18 should be monitored for continued population decreases and resurveyed to determine factors influencing a possible population decline.

Location 23-24 (Figure 2) had an estimated population of 16/km in July 1991 and in June 2000 the population estimate increased to 37/km. Major changes in riverine habitat from 1991 to 2000 were not observed; however, this area should be monitored for continuing change.

Within location 11-12 a 7.5 km segment of river exhibits a diminished population (Figure 2). This area did not meet the requirement of error variance to exhibit a change; however, this area is of concern. This area was estimated to have a population of 36 Graptemys caglei; however, during surveys conducted in June of 2000 and September of 2001 no basking Graptemys caglei were observed. This segment of river was not highly developed in 1991 and the riverine habitat was mostly undisturbed. Riverine habitat is still present in this river segment but there has been a large increase in the development of housing.

Two segments of river in close proximity, locations 19-20 and 21-22 (Figure 2) exhibited an unusual distribution. The July 1991 survey of the Guadalupe River from location 19-20 (Figure 2) had an estimated population of 17/km and location 21-22 (Figure 2) was estimated to have 120/km. In June 2000, the estimated population of Graptemys caglei from location 19-20 increased to 35/km and location 21-22 decreased to 65/km. Major changes in riverine habitat from location 19-20 were not observed; however, at location 22, a dam restoration occurred. In 1991 this dam was nonfunctional and the Guadalupe River was diverted around the dam until restoration was completed. Restoration was completed in 1993. The dam was closed and began to impound water.

In the middle segment of the Guadalupe River, the stretch of river between locations 13-14 (Figure 2) requires additional study. Graptemys caglei was not observed in this 19 km section of the Guadalupe River during four separate surveys; one each in 1991 and 2000; and two in 2001. This is unusual because the riverine habitat in this area is the same as the WTAMU study site and there are no barriers to migration.

Surber samples conducted in 2000 near location 13 yielded one Gastropod shell. In 2001 surber samples and willow root system samples were conducted at three sites downstream from location 13 to location 15 (Figure 2). The first sample was collected approximately 7 kilometers downstream from location 13. Only one family of trichopteran (Helicopsychidae) and one family of mayfly (Caenidae) was collected from the riffles in this area. Helicopsychidae is a pollution tolerant family of trichopteran (Mackay, 1979). Samples of willow tree (Salix sp.) root systems contained no trichopterans; however, it did contain a member of the family Agrionidae. The second sample site was approximately 16 km downstream from location 13. Surber samples at this location contained the same two families (Helicopsychidae and Caenidae) as the first surber sample. However, small numbers of Leptoceridae were found in the willow tree (Salix sp.) root systems. The cobble, gravel and pebble size rocks that compose the riffle areas in this stretch of river had white chalky sediment covering them during low discharges. The sediment is similar in color and constancy of the floc material that has been observed by the WTAMU team below wastewater discharges. The material was not observed above the Geronimo Creek confluence. The concentration of sediment is gradually reduced as one travels further downstream. The first Graptemys caglei observed basking is approximately 19 km downstream from location 13. The third surber sample was conducted 26 km downstream from location 13 (Figure 2). Surber samples in this area yielded the family Leptoceridae that composes the largest percentage of aquatic insects in the diet of Graptemys caglei in the WTAMU study site (Porter, 1990). Other benthic organisms included representatives from the families collected at the WTAMU study site with the exceptions of Velidae, Pyralidae, Coenagrionidae and Nepidae. The pollution tolerant family Helicosychidae (Mackay, 1979) was the most abundant family in the surber sample. Samples of the willow tree (Salix sp.) root systems also yielded a small number of Leptoceridae. Major changes in riverine habitat were not observed in this area; however, this area should be monitored for continuing change because of the unusual distribution of Graptemys caglei and potential influence of water quality.

II. Develop habitat association of Graptemys caglei

While habitat characteristics associated with Graptemys caglei cannot be used to determine relative abundance. The habitat characteristics provide a useful planning tool to identify potential suitable habitat, potential areas of avoidance to be used in stream discharge control and discharges to improve or maintain habitat. Areas can also be identified that can be managed to improve critical habitat characteristics to mitigate other habitat loses. Habitat suitability provides a basis for determining which habitat characteristic might be limiting habitat suitability and a method to predict habitat improvement.

Water Velocity

Killebrew (1991b) and Babitzke (1992) both noted that Graptemys caglei was absent from Canyon Lake, Lake Dunlap, Meadow Lake, Lake Placid, Starkie Park and the main body of Lake McQueeny. An absence of Graptemys caglei within these lakes suggests, that the species requires flowing water as a habitat requirement. Impoundments flood vast areas of riverine habitat and diminish the flow rate of the river. The loss of lotic water and increased depth of water over the gravel and cobble bars may reduce the suitability of habitat for the prey items.

Graph 2 suggests that populations of Graptemys caglei can inhabit areas with low water velocities. However, as water velocity increases the population appears to increase as well, up to approximately 2.4 feet per second, after which the population declines. Increases in the water velocity may be a result of catchment area, grade, channel width, and volume. Optimum water velocity for Graptemys caglei appears to occur at approximately 2.4 feet per second (Graph 2). Extremely high water velocity can directly influence Graptemys caglei by restricting activities such as swimming, foraging for food, finding mates and maintaining a home range. Extremely high water velocity may also indirectly affect vital habitat characteristic needed for the survival of Graptemys caglei. For example, Graptemys caglei is an insectivore feeding on insect nymphs and adults that require water flow for survival. High water velocities and discharges provide a scouring effect to remove accumulated sediments and algae from the riffles areas. This improves substrate quality and the associated abundance of aquatic insects for foraging Graptemys caglei. Higher water velocities and discharge typically erode the soil banks washing trees, branches and other debris into the river channel to be utilized as basking sites and cover or will displace existing basking sites and deposit them further downstream, thus cycling basking sites from area to area. The suspended soil particles and particulate matter associated with high water velocities and discharge from the catchment area runoff also reduce the transparency of the water giving Graptemys caglei added protection from predators. Extremely high velocities such as those found in the upper reaches are indicative of steep grades and conditions that may not support other requisite characteristics such as basking sites and willow embellishment.

In the middle and lower Guadalupe River (Figure 1) the water level is highly variable. This variability is not only the result of a large catchment area but is also directly affected by discharge of dams and water control structures located along the river. Fluctuations in discharge within the WTAMU study site due to discharges from impoundments have been observed to cause a raising and lowering of the water level by 0.5-1 m daily and on several occasions extreme fluctuations of 3-4 m have occurred.

Such variable increases and decreases can occur within hours and can be maintained for several days. These fluctuations can greatly influence nesting and availability of food.

Females excavate the nest 2-11 m from the waters edge and from 0.5-1 m above water level (Killebrew and Babitzke, 1996). If nesting were to occur prior to high water fluctuations the nests could be washed away due to the shallow depth (4.5-11 cm) of the egg chamber (Killebrew and Babitzke, 1996). The fluctuating water could also flood the nesting areas reducing availability of prime nesting sites causing the females to choose unprotected sites increases egg loss due to predation. For example, low water discharge increases open beach area and reduces concealment of the nesting female and nest. High discharges may also increase predation by confining the nesting females to only a few nesting sites increasing the number of nests per area increasing the probability of predation. Additionally, sex determination in this species is temperature dependent (Wibbels, Killebrew and Crews, 1991). Thus, nesting in unfavorable areas could expose the nest to differing edaphic and physical factors changing incubation temperature and disrupting the normal male to female ratio of the species.

Food availability can also be reduced by the fluctuating discharges. If the fluctuation occurs quickly, the substrate creating the riffle areas can be exposed before the aquatic organisms can react to the change, stranding them on the exposed substrate and ultimate desiccation. Surveys of these exposed areas during discharge fluctuations have revealed large numbers of dead aquatic organisms, including insect adults, nymphs, mollusks and gastropods.

Substrate

The insects that compose the diet of Graptemys caglei are nymph forms, which inhabit the riffle areas of the Guadalupe River. Surber samples conducted in the cobble-sized rocky substrates of the riffle areas contain the largest quantity and diversity of aquatic nymphs forms. The cobble-sized rocks are used as attachment sites for nymphs and adult insects. Cobble-sized rock provides a relatively stable substrate in higher flows and a suitable attachment site for nymphs and adult insects and for cover. The cobble rock is also important to aquatic insects, nymphs and other aquatic organisms that do not attach to the rock, but instead rely on the microhabitat created on the underside of rock. The study team observed fractured pulvoritic limestone in some areas, while classified as "cobble" the soft stone does not form a round cobble. The soft material produces very fine lime silt and an eroding surface that does not support insects. The resulting precipitate forms a silt like covering over the fractured rock decreasing the value of the substrate. It was noted that in some areas with a similar type of limestone, hard limestone cobble was imported into the river by small tributaries.

Porter (1990) reported that the male Graptemys caglei diet is composed primarily of insect nymphs (80.5%) of the order Trichoptera. These insects are found in great abundance on gravel bars within the study area at Cuero. The remainder of the male's diet is composed of gastropods (16%) and isopods (1.9%) (Porter, 1990). Female Graptemys caglei eat insects (2.8%), plant material (7.8%) and pelecypods (88.5%), primarily the asiatic clam Corbicula fluminea (Porter, 1990). Craig (1992) performed a radiotelemetry study on Graptemys caglei and found that males spend over 50% of their time on areas between gravel bars and pool areas (transition areas), while female Graptemys caglei spend 86.6% of their time in pool areas. This difference in habitat utilization by male and female Graptemys caglei is probably due to prey item preference.

Basking Sites

Cagle and Chaney (1950) indicated that the number of basking sites may attract turtles to a particular area. Boyer (1965) suggested that basking was necessary for turtles to maintain their home range and are also used for rest stations for turtles inhabiting swift rivers. Cagle (1950) suggested basking would allow turtles to regulate body temperature to increase digestive rates. He also reported that, if captive turtles were prevented from basking they would develop fungal infections on the carapace and plastron. Cagle (1950) and Neil and Allen (1954) suggested that basking would allow the turtles body to dry helping to eliminate plant and animal parasites. Boyer (1965) reported basking behavior as “best developed in the family Emydidae” (Graptemys caglei) and that the family also has “the strongest basking tendencies and the development of this habit may have contributed to their success." Cagle (1952) observed that turtles of the genus Graptemys inhabited areas where their feeding area and basking sites are in close proximity.

Willow Trees (Salix sp.)

Surber samples conducted in riffle areas within the WTAMU study site during prolonged and fluctuating low water periods yielded few species of trichopterans from the cobble substrate. Visual surveys of the exposed, dry cobble near the waterline during low discharge revealed many abandoned trichopteran cases, exoskeleton of many species of aquatic insects and shells of numerous gastropods and mollusks. The loss of this vital habitat during low discharge stages and the continued presence of Graptemys caglei suggests that alternate habitats are utilized by trichopterans and other aquatic organisms. Observations and surber samples indicated that benthic organisms inhabiting the riffle areas appeared to die-out during rapid onset of low discharge stages. Sweep net samples of submerged herbaceous vegetation shoot and root systems within the water along the bank of the river yielded numerous aquatic organisms but few were trichopterans. However, sampling of the submerged willow tree (Salix sp.) root system yielded large numbers of trichopterans of the family Leptoceridae. The members of this family are free swimming forms that do not attach their cases to a substrate but hold to the substrate with their legs. This family also prefers to inhabit vegetation but will also occur in riffle areas (Mackay, 1979). This probably contributes to their success for three reasons, first, if rapid fluctuations occur in water level the trichopterans inhabiting the root system can easily relocate as the water level decreases. Whereas, members of this family inhabiting a riffle area could be trapped by the particles composing the substrate preventing them from relocating as the water level decreases. Second, sediments that could potentially cover the substrate of riffle areas settle and are transported by the water column. This reduces the amount of sediment at the water's surface keeping cleaner water in contact with the root systems near the surface. Third, if the river water does have sediment throughout the water column the water current will keep the sediment in movement so it does not accumulate on the root systems.

Leptoceridae composed the largest percentage of trichopterans and prey items in the diet of Graptemys caglei (Porter, 1991). The willow tree (Salix sp.) roots systems appear to provide vital habitat for the preferred food items of Graptemys caglei. Trichopterans were also found in the root systems of other vegetation along the shore but only in small numbers. The willow tree (Salix sp.) root systems are larger and less dense than the root systems of other plants along the bank. Thus, willow tree (Salix sp.) roots may not trap as much silt or sediment. The willow tree (Salix sp.) root system is extensive, preventing the willow trees (Salix sp.) from washing away, as easily as herbaceous vegetation, providing a more stable habitat. Cypress (Taxodium sp.) and sycamore trees (Platanus sp.) are also numerous along the bank-water interface of Guadalupe River.

However, based on the sampling results, trichopterans do not use these root systems as habitat. These root systems are adapted to trap soil, preventing erosion so the tree will not wash away during floods. These root systems are very dense and trap large amounts of silt that could suffocate the trichopteran nymphs. Oak (Quercus sp.) and pecan trees (Carya sp.) are also observed along the riverbank. Sampling of these root systems revealed few trichopterans but the presence of nymphs of damselflies, mayflies, and dragonflies. The root systems of oak (Quercus sp.) and pecan (Carya sp.) are smaller in diameter and denser than the willow (Salix sp.) root systems. While the preference of trichopterans for willow roots is apparent, the cause for this attraction is unknown. Willow tree (Salix sp) root systems located in lotic water have higher densities of trichopterans suggesting water velocity and discharge are important for trichopterns to inhabit the root systems. Lotic water reduces sediment buildup in the root systems preventing suffocation of the nymphs and maintains nutrients within the water column preventing it from settling out as in lentic systems.

The middle Guadalupe River contains the largest population of Graptemys caglei and has the highest concentrations of willow trees (Salix sp.). The willow trees (Salix sp.) growing at or near the waters edge have their root systems partially exposed by water erosion creating undercuts and vertical banks. In these areas, willow tree (Salix sp.) root systems, were exposed for the entire vertical exposure of the bank creating trichopteran habitat during low or high discharges. Willow trees (Salix sp.)

also exhibit a unique characteristic that trunk or branches in constant contact with the water will develop adventitious root systems at the water contact zones that are also utilized as habitat by the trichopteran nymphs. These adventitious roots float up and down with rising and falling water levels. This feature may provide important feeding habitats shortly after flooding events.

Impoundments

The small lakes found along the middle to lower Guadalupe River segments were found to have variable populations of Graptemys caglei. Lakes such as Dunlap, Placid, McQueeny, Starke Park, Meadow and Canyon Lake have zero populations while three other lakes along the Guadalupe River have moderate to high populations of Graptemys caglei. The presence of willow trees (Salix sp.) and unaltered shorelines may explain the occurrence of Graptemys caglei in these three impoundments. These three impounded areas lack features typically found in lotic systems such as riffle areas, and substrate suitable for lotic species often found in Graptemys caglei diet. The willow trees (Salix sp.) may offer an alternate substrate for common prey organisms in the impoundment. All three of these impoundments contain populations of Graptemys caglei and contain high densities of willow trees (Salix sp.) along the shoreline of the lake. The shorelines of these three impoundments have experienced only limited modifications and development. Unlike the other impoundments along the Guadalupe River, there are a few houses and campgrounds along these impoundments. The houses and campgrounds that occur there are separated by large open areas and are set back away from the river. Thus, the shoreline is relatively unaltered, except for wooden boat docks. The impoundments also have a large number of fallen trees, log jams, or stumps that can be utilized as basking sites.

Lakes Dunlap, McQueeny, Placid, Starke Park and Meadow Lake also lack features typically found in lotic systems such as riffle areas, and substrate suitable for lotic species often found in Graptemys caglei diet. However, these lakes do not contain dense populations of willow trees (Salix sp.). Housing developments, camping areas, and picnic areas have altered a significant percent of lake shoreline by replacing soil banks with concrete, metal and wooden retaining walls. These modifications preclude suitable nesting habitat and establishment of root systems in contact with water. Trees along the water’s edge have been removed allowing a more esthetic view of the river and to prevent damage to the retaining walls. The floodplain beyond the shoreline has been altered by replacing native vegetation with domestic grasses, concrete and wooden walkways, boat ramps, decks, patios, etc. These alterations remove nesting habitat and increase potential disturbance by humans, domestic pets and urban wildlife, which eliminates the seclusion needed for nesting. These impoundments are also usually cleared of suitable basking sites such as fallen trees and stumps which are considered boating hazards.

Observations also suggest surface area (size) of the impoundment is important for survival of Graptemys caglei. The dams of the three impoundments with populations of Graptemys caglei are small, flooding only a few hundred meters of riverine habitat near the dam. The remaining river area is moderately wider and deeper so lotic water is present in a large portion of the lakes and numerous basking sites are found throughout the lakes even in the open water near the dams. The combination of willow tree (Salix sp.) root systems for prey items habitat and lotic water to keep the roots free of sediment increases the feeding habitat for Graptemys caglei in these lakes. This is especially important since the elimination of riffle areas has reduced available habitat for prey items of Graptemys caglei. In contrast large lakes such as Canyon Lake flood vast areas eliminating lotic water. In many areas of Canyon Lake the shoreline is composed of steep canyon walls that are highly susceptible to erosion and vegetation and soil removal which prevents growth of willow trees. There are some areas along the lake's shoreline where willow trees (Salix sp.) are growing in contact with the water, however the gentle slope of these shorelines do not allow exposure of the root systems. Basking sites are located only in the headwaters of the lake.

Behavioral Influences on Distribution

Graptemys caglei is a highly aquatic species (Haynes and Mckown, 1974) that confines itself to the water for protection from predators, to prevent desiccation and for foraging. Analysis of recapture data and a radiotelemetry study suggests that Graptemys caglei has variable home ranges. Male Graptemys caglei have an average home range of 1300 m with the extremes being 520 m and 2700 m, while females had an average home range of approximately 1400 m with the extremes being 230 m and 4,100 m (Craig, 1992). Thus, Graptemys caglei move significant distances within the river channel; however, they are not noted for traveling across land. Graptemys caglei will emerge from the water to bask on structures that protrude from the water's surface but which remain within the confines of the riverbank. The females of the species will leave the water to nest but remain within a few meters of the waters edge and returns to the water immediately after depositing eggs (Killebrew and Babitzke, 1996). Within the WTAMU study site a small dam separates the area into two segments. Specimens tagged above the dam and below the dam have remained in their original capture segment, even though Graptemys caglei could easily bypass the dam by leaving the water and crossing a 10-15 m area of riverbank. This behavior may account for the isolated populations in the upper Guadalupe River. Structures (natural or man-made) transecting the river could be a potential barrier if Graptemys caglei is required to leave the water to bypass the structure.

Floods also do not appear to disperse the species downstream. Within the WTAMU study site, tagged specimens were recaptured at the same location as their original capture after large floods. For example, during the flood of October 1998 the

Guadalupe River was estimated to have crested at 49 feet and was approximately three miles wide at certain areas within the WTAMU study site. However, the tagged specimens within the study site were recaptured at their original capture sites after water levels returned to normal.

The apparent restriction or preference of Graptemys caglei to a specific home range even during large fluctuations in water flow raises questions about the feasibility of relocation of the species to repopulate an area. Relocation studies of Graptemys caglei have not been conducted but is an important issue that should be addressed, since there are many existing and projected barriers on the Guadalupe River that could potentially, reduce the probability Graptemys caglei would naturally repopulate an area.

IV. Water Quality Parameters

The objective of this component was to determine if Graptemys caglei distribution and population density was being influenced by either naturally occurring or anthropogenic changes in water quality. One approach (a) was to correlate the water quality data found in those river segments with moderate to high populations of Graptemys caglei and the water quality found in segments with zero to low populations of Graptemys calgei to determine if water quality parameters were influencing Graptemys caglei occurrence and density. An approach (b) was to evaluate the river based on the habitat characteristics identified in this study to identify those segments with apparently suitable habitat but which lacked predicted Graptemys caglei populations. The objective of both studies was to identify any water quality characteristics that might influence potential Graptemys caglei habitat suitability.

Historical water quality data was reviewed from the data-base of the Guadalupe/Blanco River Authority and the Texas Natural Resource Conservation Commission. The WTAMU team also collected a limited number of samples for analysis. The team selected two years of quarterly data to evaluate in detail which was collected at twelve stations, starting at Station 12578 and extending to Station 13700. The data was collected by the GBRA between October 1999 and July 2001. This data was reviewed and compared to Graptemys caglei population density maps. The review was limited to the stations sampled by the GBRA and the parameters typically included in the quarterly sampling. Parameters selected for comparison included fecal coliforms, conductivity, turbidity, temperature, dissolved oxygen, Nitrate-N, Phosphorus, Chloride, Sulfate, E. coli, and Chlorophyll a.

Four stations were identified as being located in segments of the Guadalupe River with medium to high relative abundance of Graptemys caglei. Eight stations were identified as being located in segments identified as having either no observed Graptemys caglei or low populations. Quarterly sampling events were selected which were either on the same date or very close to the date of the base sampling event. Water quality characteristics were then compared to the changes in relative abundance of Graptemys caglei. The eight quarters of data for each parameter were reviewed and the maximum, minimum and average values were determined. This provided an indication of extreme conditions as well as average or typical conditions. The maximum values found in the medium/high population stations were then compared to the maximum values found in the low/zero population stations. The process was repeated for the minimum parameter values and the average values. For example, the maximum fecal coliform values identified in segments having moderate/high populations (n=4) was then compared to the maximum values found at the 8 stations with zero/low populations (N=8). A two-sample t-Test, assuming unequal variances, was used to test the null hypothesis that the means were equal in both populations of data at the 95 percent confidence level.

Results

Approach A: ***Review the water quality data from those river segments with zero to low and moderate to high populations of Graptemys caglei to determine if water quality parameters could be correlated to Graptemys caglei occurrence and density.*** Table 3 lists the minimum and maximum values found at each station. (Stations with high/moderate populations have not been identified in the table to protect the specific locations of the medium/high density areas for the species. Specific locations of the populations will be provided using unique segment codes that can be used to identify the appropriate sampling station.) Additional data were reviewed from the TNRCC data base as well as other historic data collected by the GBRA. While an impressive amount of water quality data exists for the Guadalupe, it is difficult to find comparable sampling events that all fall within the same time period. This is understandable considering the length of the survey area and the time that it takes to collect water samples and the required field data. Table 3 is intended only to provide an overview of the typical variations in water quality. The analysis of the data should be considered as preliminary and does not represent a comprehensive evaluation. Preliminary analysis of the data, as presented, indicates that Graptemys caglei currently exists in the Guadalupe River in a wide range of water quality parameters. A comparison of the selected water quality parameters found in segments of medium/high populations was not significantly different from that found in segments with low/zero populations. Table 4 shows the t Stats and P(T<=t) one-tail value for each comparison. Table 5 shows the average values for each parameter at each sampling station. Table 6 shows the t Stats and P(T<=t) one-tail value for each comparison of the average values between medium/high and low/zero population segments of the river. This evaluation compares current population estimates, in total numbers of individuals, to recent water quality survey data (quarterly sampling events over two years) and does not address any ongoing long-term changes in population structure.

Approach B: ***Evaluate the habitat characteristics identified in the study and identify those segments with apparently suitable habitat but which lack predicted Graptemys caglei populations.*** In three segments of the river apparent suitable habitat exists for Graptemys caglei but predicted populations were not found in the 2000-2001 surveys. These areas existed between locations 13 and 14, the upper portion of the segment between locations 19 and 20 and the upper portion of the segment between locations 25 and 26.

In the area between locations 13 and 14, suitable habitat exists but no Graptemys caglei occur in the segment. This area lies directly below Seguin and below the Geronimo Creek confluence. This stream segment receives treated wastewater effluent and during low flow velocities it appears that a precipitate accumulates on the substrate. Surber samples described above indicated reduced benthic production and diversity.

The upper portion of the segment between locations 19 and 20 lies directly below the confluence of the San Marcos River and the city of Gonzales, Texas. A large recreational park is located along the Guadalupe River in the upper section of this segment. Graptemys caglei exist in the upper area but are not found in the numbers predicted based on habitat availability.

The upper portion of the segment between locations 25 and 26 lies just below Victoria and at the beginning of a major industrial complex. The industrial facilities lie adjacent to the river and many use the river for process water. The water is typically pumped from the river and returned after use.

Discussion: Three stream segments were identified that, based on the presence of suitable habitat, lacked predicted populations of Graptemys caglei. In all cases the stream segments lie below either municipal and/or industrial outfalls. Below Geronimo Creek and the outfall from the City of Sequin a fine precipitate was found on the substrate. Benthic organism density and diversity was reduced in the area. Surber sample results revealed that as the sediments decreased downstream, both benthics and Graptemys caglei populations increased. The traditional water quality parameter list is effective in monitoring nutrient loading and potential for fecal and waste contamination but the list does not address a wide array of inorganic and organic chemicals that could have an effect on the stream ecosystem such as pesticides and herbicides used on lawns and recreational areas. Additional research is needed to determine why benthic diversity and abundance and Graptemys caglei populations decrease below these areas. Other factors such as disturbance by recreational activities, shooting and periodic habitat disturbance by construction in the streambed and the use of temporary coffer dams should be addressed.

Table 3. Comparison of Minimum and Maximum Measurements.

Station	FColiMin	FColiMax	CondMin	CondMax	TurbMin	TurbMax	TempMin	TempMax
12578	34	1144	456	830	27	250	10.93	31.52
16579	18	2000	347	637	13	97	13.44	31.49
12590	8	900	382	629	5	63.5	17.53	31.67
12592	1	14200	448	621	5.6	35	10.07	32.48
15110	1	76	378	577	4.9	17	15.98	31.61
15149	1	44	469	563	5.3	25	12.06	29.77
12596	1	170	399	583	3.7	8.3	12.1	28.07
12570	4	1350	527	729	2.5	15.5	9.8	25.55
12653	4	372	528	585	0.06	2.5	22.49	25.85
12658	12	224	384	433	3.3	5.5	10.31	28.07
12598	0	21	349	459	7.94	8.88	10.96	30.32
13700	31	282	465	562	1.1	29.9	14.27	29.11
Station	DOMin	DOMax	NitrateMin	NitrateMax	Pmin	PMAx	ClMin	ClMax
12578	6.39	12.34	1.36	3.48	0.26	0.7	34	116
16579	13.44	31.49	0.13	0.4	0.13	0.4	16.6	50.2
12590	7.26	13.28	0.8	1.7	0.06	0.33	22.9	38.2
12592	7.69	13.48	0.308	1.76	0.06	0.22	21.6	42
15110	7.14	10.38	0.08	1.9	0.05	0.13	19.3	41.2
15149	7.65	10.88	0.64	1.4	0.04	0.2	19	28.3
12596	7.74	11.03	0.83	1.97	0.02	0.15	15.9	27
12570	5.99	13.22	0.23	1.4	0.03	0.07	17.5	45.8
12653	9.1	10.72	1.32	2.08	0.01	0.044	16.9	19.7
12658	8.52	13.78	0.088	1.2	0.01	0.032	12.7	16.9
12598	7.59	12.83	0.01	0.66	0.01	0.11	15.4	22.3
13700	7.54	12.38	0.15	1.57	0.01	0.09	16.9	26

Table 3 Continued. Comparison of Minimum and Maximum Measurements.

Station	SulfateMin	SulfateMax	EColiMin	EColiMax	ChlaMin	CjlaMax
12578	45.2	96	32	800	1	11.7
16579	16.6	50.2	18	1600	1	17.1
12590	5	35.2	8	900	1	6.1
12592	21.6	42	2	360	1	11
15110	7.6	36.2	1	56	1	9
15149	23.8	30.1	1	20	1	18
12596	19.2	27	2	88	1	1.7
12570	4.2	109	4	462	1	13
12653	20.4	25	4	100	1	1
12658	19.2	33.3	8	188	1	1.1
12598	16.9	22.4	0	12	1	4.5
13700	19.2	26.4	4	196	1	2.9

Table 4. t-Test: Two Sample Assuming Unequal

variances for Minimum and Maximum Measurements

Parameter	Minimum		Maximum	
	t-Stat	P(T<=t)	t-State	P(T<=t)
Fcoli	1.077	.153	.917	.213
Cond.	1.471	.086	.879	.202
Turb.	.905	.197	.751	.235
Temp.	.090	.456	1.561	.081
DO	.600	.281	.629	.273
Nitrate	1.036	.163	.054	.478
P	.558	.295	.418	.342
Chloride	.031	.487	.575	.289
Sulfate	1.268	.120	.932	.191
Ecoli	.771	.220	.125	.451
Chloro a	#NUM*	#NUM*	.590	.285

*Values and Means were identical.

Table 5. Parameter Average Values for 8 Quarters

Station	Fcoli	Cond	Turb	Temp	DO	Nitrate	P	Cl	Sulfate	Ecoli	Chla
12578	223.5	689.3	66.4	23.2	8.2	2.2	0.31	71.9	58.7	159	5.2
16579	320	564.3	31.3	23.6	9.2	0.9	0.26	38	32.7	244.5	6.14
12590	142.1	547.5	20	23.1	9.1	1	0.13	43.4	28.1	128.6	3.3
12592	65.4	546.9	14.7	23.6	9.1	1	0.11	32.2	30.2	56.3	4.1
15110	19.6	473.1	10.8	23.2	9.5	0.86	0.1	28.9	24.4	16.4	4.5
15149	12	520.1	9.1	22.9	9.7	0.96	0.095	23.87	25.6	7.4	6.1
12596	45.6	511	6	22.3	9	1.3	0.07	20.3	24	29.4	1.1
12570	243.4	627.3	5.3	22.9	10.6	0.74	0.052	28.6	57.3	105.8	4
12653	90.4	559.1	1.4	23.93	10.22	1.7	0.038	19	22.5	38.3	1
12658	73.7	409	4.1	17.4	10.7	0.4	0.034	15.8	23.9	50.6	1.1
12598	4.1	389	3	21.81	9.6	0.26	0.016	17.5	19.6	1.9	1.6
13700	101	480.9	10.8	21.1	9.1	0.94	0.05	22	18.1	65	1.6

Table 6. t-Test: Two Sample Assuming Unequal Variances Average of Measurements.

Parameter	Average	
	t-Stat	P(T<=t)
Fcoli	1.125	.143
Cond.	1.045	.163
Turb.	.500	.315
Temp.	.589	.299
DO	.319	.380
Nitrate	1.213	.126
P	.406	.347
Chloride	.009	.496
Sulfate	.942	.187
Ecoli	.485	.319
Chloro a	.084	.468

Recommendations

The population studies conducted in this project address current populations based on a relatively short observation period. Additional studies on the population structure of the species would provide additional insight into the health of the population. These studies could now be focused in areas of noted population decline or low population density.

Several sections of the Guadalupe provide suitable habitat but do not support predicted populations of Graptemys caglei. While traditional water quality parameters do not indicate a water quality effect, the current list of water quality parameters does not address constituents that can have a dramatic effect on the species and its food base. Additional study is needed on those stream segments that lie below the known municipal and industrial outfalls.

The EAA project has supported evaluation and determination of habitat and instream flow characteristics that can influence Graptemys caglei populations. While this information can be very useful in resource and project management and planning, the full development and verification of habitat suitability indices (HSIs) and a habitat suitability model for Graptemys caglei would provide a more defensible and quantitative planning tool. The HSIs are established based on 0-1.0 indices with 1.0 being ideal conditions and 0.0 being very poor habitat or absence of habitat. Habitat Units (HUs) can be calculated by multiplying the HSI X area of habitat to be assessed. This tool can then be used to make planning decisions based on gains or loses of HUs under the various planning alternatives. The process can also be used to select and manage mitigation areas or management areas. The process can also support Endangered Species Assessments and negotiations under the Endangered Species Act in the event that the species is listed. The individual HSIs provide the decision-maker with a basis for determining which variables need to be managed or improved to improve the habitat as well as the expected outcome of the management actions. As such, properly developed HSIs and Habitat Suitability Models can support decisions in project siting, selection of project alternatives, mitigation strategy, mitigation area selection and management of post-mitigation project areas. Considering the level of understanding gained in this and in other studies, WTAMU is confident that the HSIs and the Habitat suitability model as well as the studies suggested above could be fully developed and verified with a relatively small additional effort considering the potential benefits of such studies.

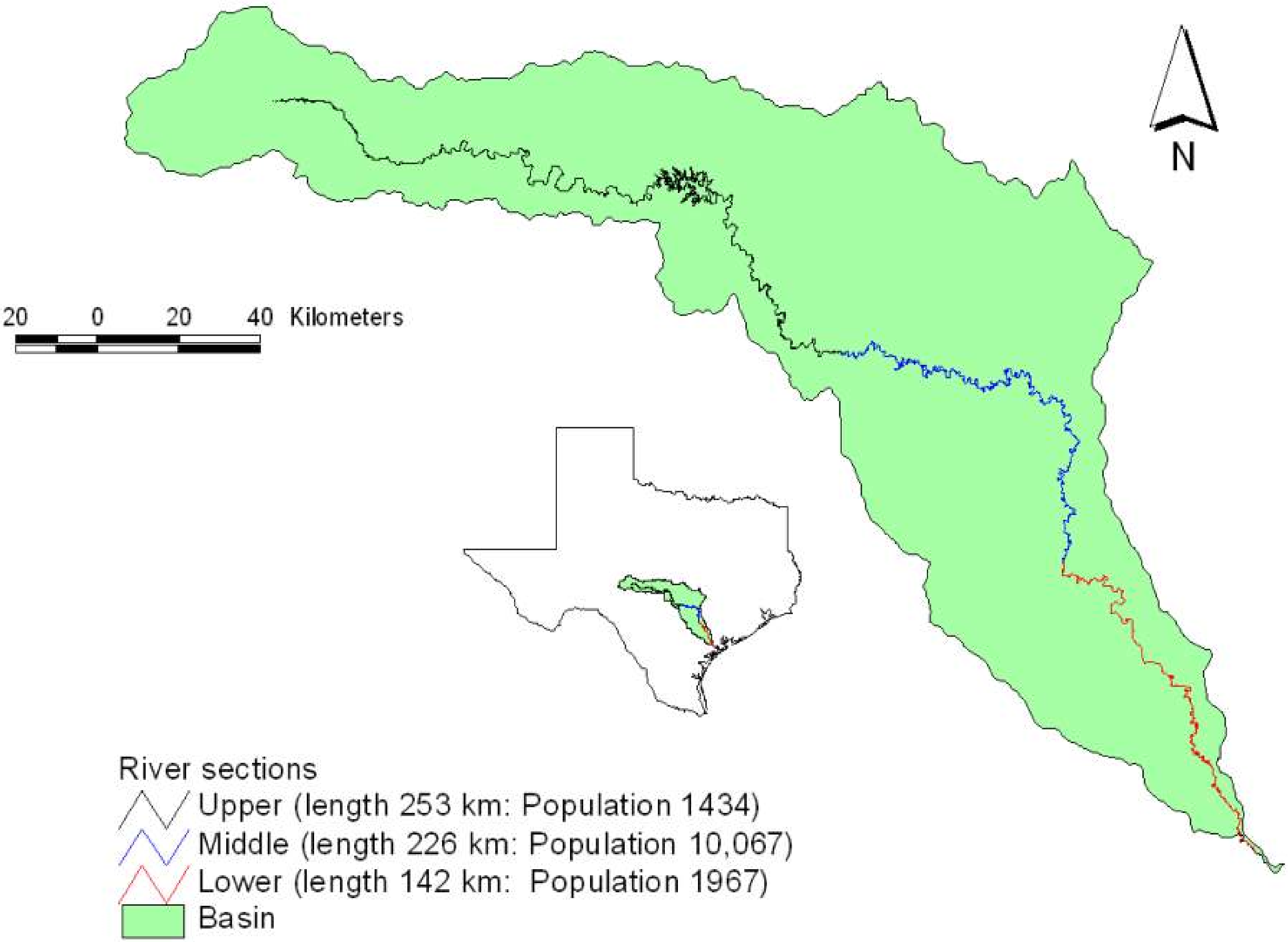


Figure 1. Division of the Guadalupe River.

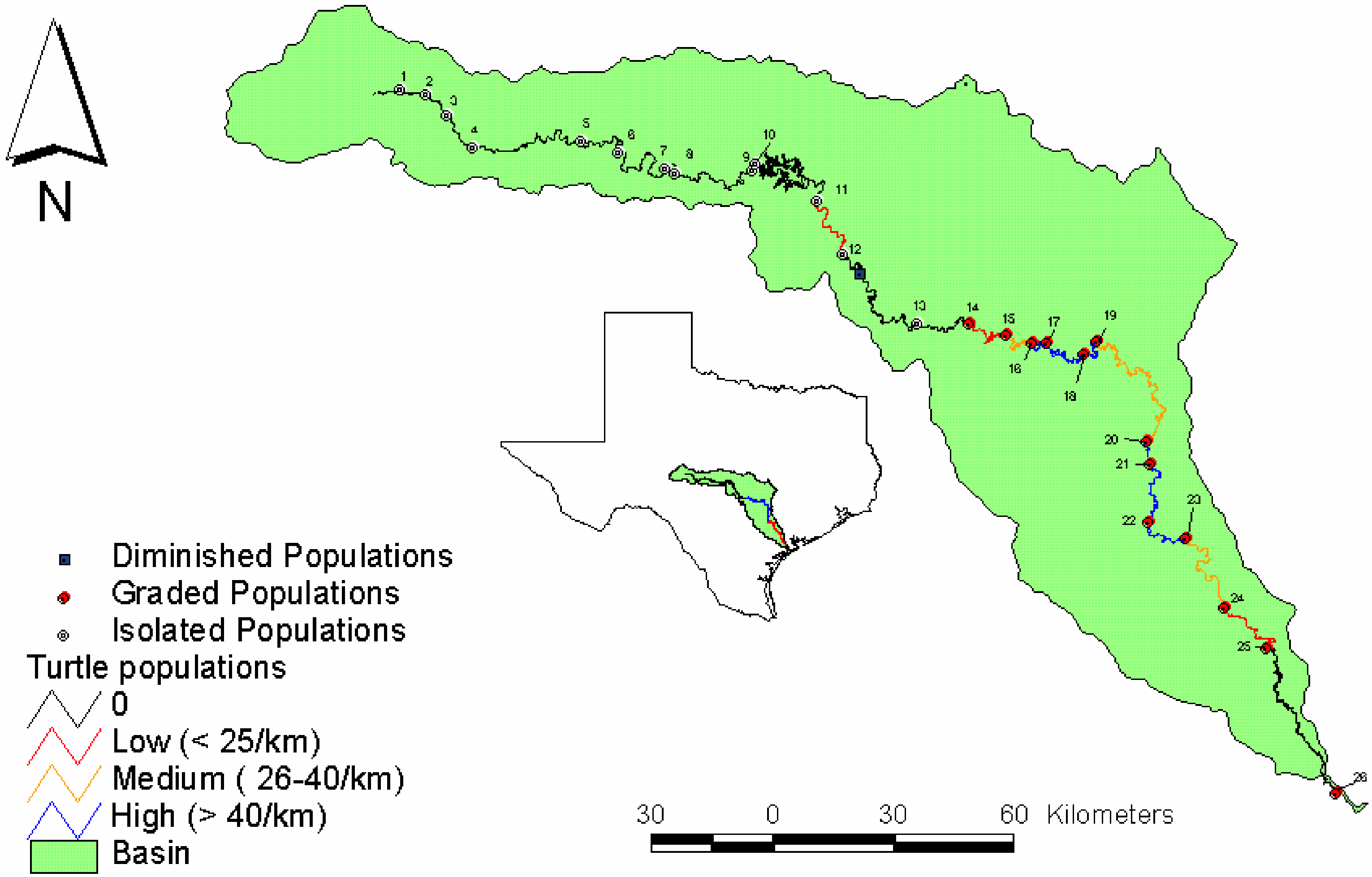


Figure 2. Populations of G. Caglei along the Guadalupe River.

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