Comal Springs Riffle Beetle Habitat and Population Evaluation

Final Report
Variable Flow Study: Project 802, Task 13
Landa Lake, New Braunfels, Texas

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Executive Summary

BIO-WEST conducted three samples for riffle beetles in the Comal system to document potential areas where the Comal Springs riffle beetle (*Heterelmis comalensis*) might occur, but which had not been sampled in prior work. In addition, this study involved quantitative samples in an attempt to produce limited estimates of the *H. comalensis* population in areas sampled and to compare results with earlier work by D. Bowles of Texas Parks and Wildlife Department (TPWD). In that study, a maximum of 2.5 *H. comalensis* per m^2 was observed in spring run 3. Though the quantitative samples in this study were not gathered in the same random manner, it provides some means of comparison for the preferred habitat in which we focused our samples.

The first sample was conducted during summer 2001 (26-28 June) and primarily involved exploring the western shoreline of Landa Lake. That sample resulted in confirmation of the Comal Springs riffle beetles in a habitat far removed from the 3 spring runs in which it was previously believed to be restricted. The second sample occurred during fall 2001 (19-20 September) with additional sampling conducted during the first week of October. The result of this sample was to document the existence of Comal Springs riffle beetles in 2 areas of Landa Lake where springflow was clearly issuing from springs in the bottom substrate. In addition, quantitative samples were taken along the Landa Lake shoreline and in spring run 3; however, quantitative sampling was not as detailed as anticipated due to time constraints. The final sample occurred during winter (2-3 January 2002) and expanded on information gathered in the earlier samples, including additional quantitative sampling.

The first sample was focused entirely on exploring various habitats; thus no quantitative sampling was conducted. Our limited sampling during the second sample (fall 2001) resulted in an estimate of 2.0 adult *H. comalensis* per square meter in the shoreline habitat most distant from the spring runs, and 0.25 *H. comalensis* per square meter in spring run 3 (the latter is suspected to be underestimated). In the winter sample, we observed a similar number of adult *H. comalensis* in the shoreline habitat removed from the spring runs (2.0 per m^2), but more *H. comalensis* were observed in spring run 3 than in the earlier trip (2.0 per m^2).

From these findings, we can conclude that the Comal Springs riffle beetle is more widespread in the Comal Springs ecosystem than previously thought; it is not restricted to the spring runs. In fact, the population that was found along the shoreline habitat had similar densities of *H. comalensis* as that observed in spring run 3. These findings suggest that the habitat requirements for the species may not be as restrictive as is currently believed by the USFWS and others, but more study is needed during low-flow conditions. We did observe that the species was not typically found in areas where silt accumulated on top of the rocks, and were generally found only in areas where springflow was evident during the flow conditions that occurred during this study. Because low-flow conditions did not occur during the sampling protocol, we were unable to determine if the beetles remain in areas where springflow is reduced or ceases entirely with decreasing total springflow.

1.0 INTRODUCTION

The best scientific information currently available for the Comal Springs riffle beetle indicates that the species occupies a very narrow range and that the population is confined to areas highly susceptible to periods of low springflow. Bowles et al. (draft report 2000) observed that the Comal Springs riffle beetles occupy spring runs 1, 2, and 3, but are not found in spring run 4, the uppermost spring in the system and one that tends to have lower water velocities and silty substrates (Figure 1). The conclusion drawn by the authors was that the species requires significant springflow and are found only within the first three spring run areas. Based on this and other limited information regarding the range and habitat needs of the species, the USFWS has determined that to prevent "take" of the species requires constant springflow from Comal spring runs that, combined, are greater than 200cfs in the system (USFWS 1997). Unfortunately, the determinations of habitat requirements and range are based on limited observations, mostly conducted during periods of high flow (Bosse et al. 1988, Bowles et al. draft report 2000).

The purpose of this study was twofold: to examine favorable habitat outside of the range of the Comal Springs riffle beetle as described by the USFWS and others, and to conduct limited quantitative sampling to evaluate population densities in areas where the beetles were found. The focus of our searches was initially the western shore of Landa Lake where smaller springs enter the system, but our sampling was extended to include areas within Landa Lake where springflow was evident from the bottom substrate and to areas around the privately-owned Spring Island. With the findings we present here, the currently accepted range of the species should be extended to include all of these areas, and the argument that the habitat requirements of the beetle are extremely restrictive should be reevaluated.

2.0 METHODS

BIO-WEST conducted three sampling efforts to verify the presence/absence of *H. comalensis* in various habitats within the Comal Springs ecosystem. The first sampling trip occurred from June 26-28, 2001. Three BIO-WEST employees, trained in the identification of the Comal Springs riffle beetle by Dr. David Bowles (TPWD), initially searched in Comal spring run 3 to become familiar with the current population of *H. comalensis* in that area and the relative densities of that species and the similar *Microcylloepus pusillus*. Following this, an extensive sampling of areas along the western shoreline of Landa Lake, focusing on areas where springflow was observed to be issuing from the shoreline, was conducted. Sampling involved intensive searches at each spring outflow where an attempt was made to turn every rock (ranging in size from small cobble of a few centimeters in width to much larger stones approaching 100 centimeters in width) to examine the underside for *H. comalensis* and *M. pusillus*. The location and number of individuals of each species were carefully recorded. In addition to turning rocks, some leaves and woody material in each habitat were examined for the presence of either species. As a supplement to the intensive search along the shoreline, some snorkeling was conducted in deeper areas where springflow was evident from the bottom substrate. The survey of these habitats for the beetles was qualitative in nature and designed to yield presence/absence data only.

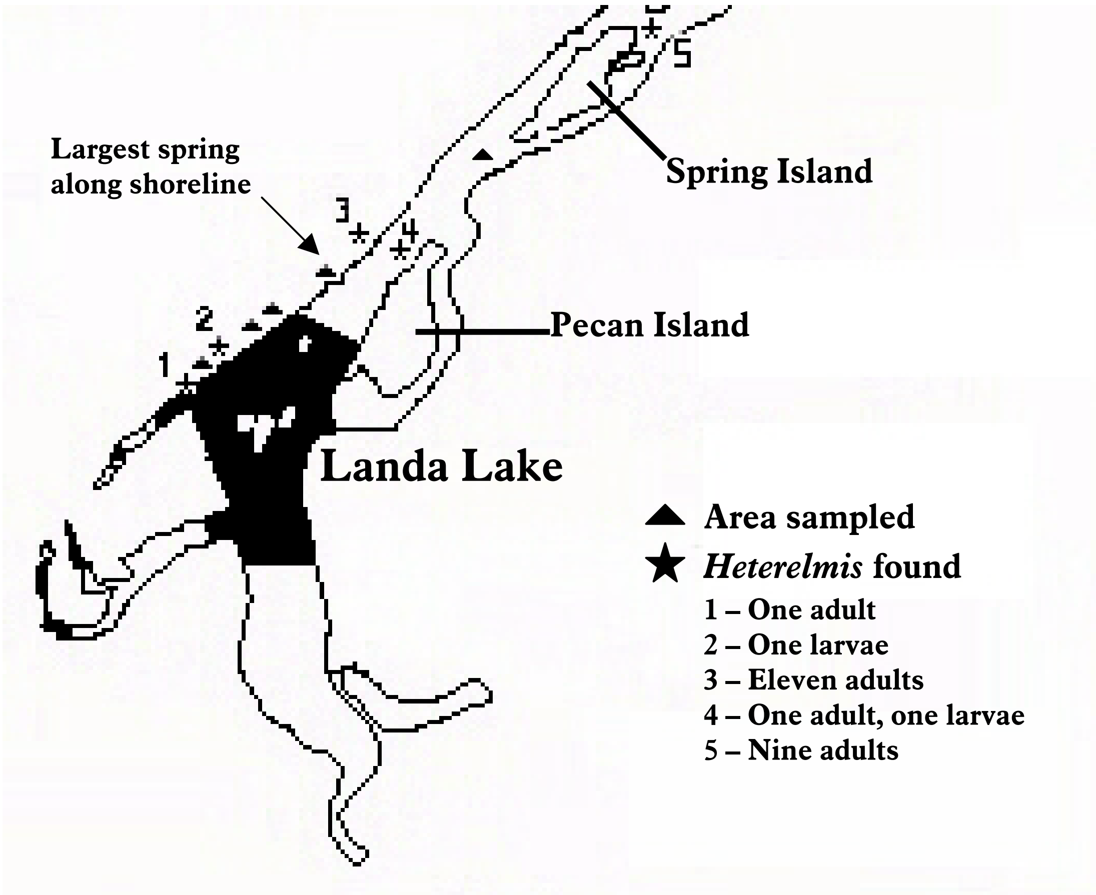

Figure 1. Areas sampled and specific locations of observations of *Heterelmis comalensis*. The largest spring along the western shoreline in Landa lake is indicated on this map, though only *M. pusillus* were found in this excellent habitat.

We anticipated using standard quantitative sampling methods in addition to the intensive survey methods described above, however, these were modified from our proposal. Dip nets were used to collect two samples; however, the time required to sort through the debris collected and the limited success of this method precluded its continued use. We determined that surber samples would not be feasible due to limited velocity of springflow from the shoreline spring openings, and using a square frame quantitative sampling tool was not conducted during this first trip due to time constraints. Standard water quality measurements were made at each sample location using a depth gauge, a Hydrolab, and a Marsh McBirney flowmeter, and photos were taken of each area where *H. comalensis* was found. A total of three adult and two larval *H. comalensis* were kept as voucher specimens.

The second sampling trip occurred during September 19-20, 2001. This sample also included an extensive search of habitats previously identified along the western shoreline of Landa Lake, with the focus on habitats where riffle beetles of either species where found previously. In addition, a 0.25 m^2 metal frame was used to make quantitative samples in the habitat where *H. comalensis* was found to occur in the previous sampling effort. The original intention of using a 1-m^2 frame was altered in order to allow for more samples and to focus on smaller areas with the smaller frame size. Taking these samples involved placing the square over suitable-looking substrate (relatively silt-free, adjacent to springs, etc…) where the beetles had been found before and searching all rocks within the frame. All rocks >3cm in length were examined for beetles, and any rock in which 50% or more was within the square frame was included. Quantitative samples with the same 0.25 m^2 frame were also conducted in spring run 3. It should be noted that the relative densities found during our sampling effort cannot be compared directly to that of Bowles et al. (2000) because our sampling methods were not random; they were targeted to areas where *H. comalensis* are more likely to be found. As before, standard water quality measurements were made at each sample location using a depth gauge, a Hydrolab, and a Marsh McBirney flowmeter.

During this trip, SCUBA gear was used to sample deeper areas within Landa Lake more extensively, and habitats above and below Spring Island were sampled. All sampling in these areas was focused around areas where springflow was evident from the bottom substrate. We also took video footage of spring run 3, areas in center of Landa Lake, and all habitats sampled along the shoreline on day 2.

The third sampling trip occurred during January 2-3, and 8, 2002. This sample event was nearly identical to the second trip with an extensive search of several habitats along Landa Lake's western shoreline with emphasis on habitats previously documented to contain *H. comalensis*. Quantitative samples were conducted in the same manner as before, and SCUBA gear was also used to sample the same general areas that were sampled in the previous trip.

2.1 Flow Conditions

Sample dates were chosen with the intent to sample during periods that have historically had specific springflow patterns that would be of interest to the study. The first sample date, early June, was chosen because flows are typically moderate, and this would reveal information on the true extent of the riffle beetle range during average springflow periods. The second sampling event was tentatively planned for late August or early September, when flows are typically much lower. The third sample was planned for mid-late November, when springflow has often been fairly low for some time, but is usually beginning to be supplemented with increased rainfall. Unfortunately, springflows were not typical during the planned sample periods.

The flow conditions during each of the first two samples were similar. The June sample occurred in the early stages of the summer drought while flow was still high from spring rains. Mean total flow over the sample period was 312-317cfs, slightly higher than the historical mean of 286cfs. The second sample was intended to occur during a period when flows are typically low in the early fall, after the cumulative effect of summertime drought conditions. While there was a fairly significant drought during the latter half of the summer, an unexpected and intense rainfall event occurred just prior to the planned sample period. Therefore, flows were higher than expected with a total springflow of 326-335cfs. The final sample occurred following a period of extensive rains including several individual rain events that caused unusually high spikes in the hydrograph; the total springflow during sampling was 375-389cfs.

3.0 RESULTS AND CONCLUSIONS

3.1 Summer Sample

Day One (6/26/01)

Both *H. comalensis* and *M. pusillus* were found during the initial survey of spring run 3 between the first and second bridges downstream from the springhead. Neither species was found exclusively on a particular size of rock, however, there did appear to be a tendency for *H. comalensis* to be found on larger stones. Leaves in the water column were also observed and several larvae of *H. comalensis* were noted on this substrate. A total of 20 adult and 4 larval *M. pusillus* and 6 adult and 8 larval *H. comalensis* were found in an length of about 30 ft of shoreline downstream from the first bridge (nearest the springhead) in spring run 3 in approximately 2 hours of sampling. Identification of the species was verified by J. Fries of the USFWS National Fish Hatchery and Technology Center in San Marcos who positively identified two voucher specimens of each species taken from the reach.

Day Two (6/27/01)

Exploration of the western shoreline of Landa Lake was conducted this day, beginning at the mouth of spring run 3 along the region where there is an influence of the flowing water from the spring run and moving north. The first area sampled did not have any noticeable springflow from the springs along the shoreline. This length of shoreline was approximately 30 feet and would be most likely to have incidental occurrence of a species that drifted down from areas in the spring run (Site 1; Figure 1). We found a single adult *H. comalensis* at the mouth of the spring run (the upstream-most edge of shoreline sampled, where springflow still had a marked influence). Further north along the shoreline (moving away from spring run 3) there are several areas where springflow could be seen issuing from the shoreline and from openings under the lake itself. We sampled each of these areas and found *M. pusillus* in most locations. In addition, *H. comalensis* was observed in two locations along this shoreline in habitats that differ dramatically from what has been previously described as the habitat requirements for the species. These two areas were not influenced by the spring flow in any spring run and were found adjacent to small spring openings with relatively little springflow (~0.20 m/s or less from each). Locations and total number of individual riffle beetles observed along this shoreline are as follows:

- 30 ft downstream from where the adult *H. comalensis* was found (at mouth of spring run 3) a single *M. pusillus* larvae was found on relatively small cobble underneath a boulder overhang.
- 75 ft further north along the western shoreline of Landa Lake (moving away from spring run 3) two *M. pusillus* larvae and a single *H. comalensis* larvae were found on small cobbles (Site 2; Figure 1). This area did not have noticeable springflow issuing from the side (shoreline), but some springflow was evident from the substrate.
- 100 ft further north, two adult *M. pusillus* were found on small cobble at spring opening.
- 60 ft further north, two adult *M. pusillus* were found on rocks.
- 290 ft further north, 11 adults and 2 larval *M. pusillus* were found in a large spring opening issuing from the side. Springflow was measured at ~0.50 m/s here. Subsequent sampling the following day revealed zero *H. comalensis*, despite the apparently favorable conditions for the species.

In the center of Landa Lake, around silt-free spring openings with rocks 13 *M. pusillus* adults were found in two searches totaling ~1 hour.

Day Three (6/28/01)

A series of small springs issuing from the shoreline just downstream (~50 ft) from the "No Trespassing" wire that separates Landa Lake from the privately owned shoreline upstream were sampled (Site 3; Figure 1). A first attempt to sample this area resulted in a single *H. comalensis* adult within 20 min. of sampling. A subsequent and more thorough search yielded 4 additional adult *H. comalensis* and 2 adult *M. pusillus*. The 2 *M. pusillus* were found downstream of the area where all of the *H. comalensis* were found. The two species did not appear to overlap in this area.

In addition to the above findings, more *M. pusillus* (6 adults, 3 larvae) were found the area adjacent to the large springs where several were found the day before; but no other *H. comalensis* were observed.

A thorough sampling of the spring on Spring Island (privately owned) resulted in only 2 adult and 1 larval *M. pusillus*. This sampling occurred in the spring run only (spring run 6) and did not include areas in deeper water where springflow was evident from the bottom (sampled in the subsequent trip).

3.2 Fall Sample

Day One (9/19/01)

SCUBA equipment was used on this first day of sampling to conduct a more thorough search of areas in the deeper parts of Landa Lake that exhibit springflow from the substrate (bubbles issuing from the ground). A search of likely areas in about 4-5 feet of water (for about 1-hour) resulted in 47 larval (found primarily in aggregates on just a few rocks) and 23 adult *M. pusillus* (Site 4; Figure 1). Also found among the abundant *M. pusillus* was 1 larval and 1 adult *H. comalensis*. Though rocks were turned in a relatively large area encompassing various habitat types (including areas with Riccia on top of substrate with springflow), the two species of riffle beetles appeared to be restricted to areas clear of silt and free of vegetation with some flow issuing from the substrate.

Day Two (9/20/01)

A majority of the sampling that occurred on this day was focused on the habitat were 5 adult *H. comalensis* were found during the summer sample. An additional 6 adult *H. comalensis* were found in this area, but zero *M. pusillus* (adult or larvae) were found. Quantitative samples were conducted here using the 0.25 m^2 frame with total of 6 samples resulting in 3 of the 6 adult *H. comalensis* being observed. That translates into an estimate of 2.0 individuals per square meter. Individuals were not found in the two samples conducted in slightly deeper water and with a greater amount of silt on top of the rocks. The 3 individuals found in these quantitative samples were near spring openings, in shallow water, and under silt-free rocks. The other 3 individuals were found during a thorough search of an adjacent habitat just downstream of this area.

Two additional sites along the western shoreline that corresponded to the next most downstream areas that were sampled in the previous trip were also sampled on this day (Figure 1). The first site (Largest spring along shoreline; Figure 1) was where a significant amount of springflow was observed (velocity estimated at 0.45 - 0.50 m/s) and yielded 4 adult and 2 larval *M. pusillus* after approximately 1 hour of searching. The next site down yielded no riffle beetles of either species after 30-45 min of searching.

Quantitative samples with the same 0.25 m^2 frame were also conducted in spring run 3. A total of 4 samples yielded 15 adult and 3 larval *M. pusillus* and 1 adult *H. comalensis*. These samples were not representative of previous conditions, however, as the first two samples yielded zero riffle beetles, which may have been due to a larger than normal amount of sediment on top of the rocks from recent heavy rains. The latter two samples were relatively clear from sediment buildup as is normally observed on all rocks in this area. The resulting densities should be noted with caution (3.75 adult *M. pusillus*, 0.75 larval *M. pusillus*, and 0.25 adult *H. comalensis* per meter squared). Most likely, the true density of both populations in this area is higher than we observed on this date.

An attempt was made to characterize the area along the western shoreline where quantitative samples were taken by measuring depth and making an estimate of flow from several measurements taken at spring openings. Depth was taken for samples in spring run 3, however, the influence of the streamflow generally overshadowed that of lateral flow from shoreline spring openings. The velocity measurements were variable due to extremely shallow conditions and multi-directional flow associated with a spring opening and the rocks that are found around them, however, all measurements of water velocity tended to be 0.20 m/s or less. Water depth ranged from 0.2 to 0.6 ft in depth, with most habitat occurring within 1-2 ft of the shoreline. Outside of this range, the influence of springflow was minimal and silt deposition markedly increased. Water depth of samples in spring run 3 ranged from 0.1 to 0.6 ft.

Days Three and Four (10/1-10/2/01

Additional sampling was conducted using snorkel gear in the upper spring run reach where spring run 5 enters the river and above and below Spring Island (site of spring run 6) where springflow was obvious from the substrate (Figure 1). The upper spring run site did not have any apparent springflow from the substrate, however, the area searched was heavily influenced by the flow of spring run 5 as it entered the river. This area is also notable for the abundance of Riccia, which is otherwise sparsely found in the upper spring run reach. A search of approximately 1-hour in water with depths ranging from 1.5-3.5 feet and looking on silt-free rocks resulted in zero *H. comalensis*. A total of 24 adult and 1 larval *M. pusillus* were found.

A search of favorable-looking habitat below Spring Island also yielded zero *H. comalensis*. This search involved turning rocks in 2-4 feet of water where bubbles were observed in relatively (though not completely) silt-free rocks for approximately 45 min. Twenty-six adult and 4 larval *M. pusillus* were found.

An additional hour was spent searching rocks above Spring Island in areas where springflow was clearly issuing from the bottom (Site 5; Figure 1). This area was approximately 2-3 ft deep and was immediately adjacent to the area that had been dredged at one point in time. Areas with the most beetles were sandy and had moderate springflow (more than observed in any other subsurface areas). Numerous *M. pusillus* adults were observed. Many were brought back to the shoreline to observe under the microscope, but they were so abundant that not all were collected. An estimate of the number of *M. pusillus* adults collected was ~50, with about half observed under the microscope to verify identification. Many of the rocks had multiple beetles (i.e. 4-6 or more) and one rock had 30 or more adult beetles on the underside. All larvae collected (~15) were *M. pusillus*. In addition to the abundant *M. pusillus*, nine *H. comalensis* adults were collected. Two of these were kept and later verified to the species level by Dr. David Bowles (TPWD).

3.3 Winter Sample

Day One (1/02/02)

Sampling was focused around the shoreline habitat where *H. comalensis* was documented to occur. One BIO-WEST employee conducted quantitative samples using the same methods described above, while another BIO-WEST employee conducted a thorough search of adjacent habitat. The quantitative samples where conducted virtually the exact same location as in the fall sample, and included the same number of samples (6). The results were similar to the earlier observations; a total of 3 *H. comalensis* were found in the 6 samples to yield an estimate of 2.0 individuals per m^2. Unlike the previous trip, however, one *M. pusillus* adult was sampled to yield an estimate of 0.67 individuals per m^2. In addition, 5 adult *H. comalensis* and 5 adult *M. pusillus* were found in habitat immediately adjacent to the sampled areas, but were not included in the calculations. The areas where these beetles were found were immediately adjacent to the shoreline and were not easily included in the square frame for sampling. This also occurred in the fall, when 3 additional *H. comalensis* were found in adjacent to the samples and it suggests that the population may be underestimated for the area during both sample events.

One note from the quantitative samples is that it was clear that *H. comalensis* was not found in habitats with silt-covered rocks. When a sample area was partially covered in silt, the only *H. comalensis* that were found in that site were in the clear rock/gravel areas. This was also observed in quantitative samples in spring run 3, and similarly evident when searching other habitats, including areas at the bottom of Landa Lake. Measurements of depth and flow were similar to that observed in the fall sample.

Extensive searches in habitats up- and downstream of the shoreline habitat where quantitative sampling occurred resulted in an additional 4 adult *H. comalensis*, 1 adult *M. pusillus*, 3 larval *H. comalensis*, 1 exuvia (exoskeleton) shed by a larval *H. comalensis*, and 1 larvae that was too small to correctly identify with the field microscope. Clearly, this area harbors a relatively abundant population of *H. comalensis*. Interestingly, *H. comalensis* is more abundant in this area than the much more common species in the Comal Spring system (*M. pusillus*).

Day Two (1/3/02)

Quantitative samples in spring run 3 were conducted on this day. Because only 4 samples were taken in the previous trip, a larger number of samples (8) were taken here. The first two samples were made in the traditional manner, with all individuals of both species of riffle beetles gathered and returned to the microscope for verification of species. However, the cold weather appeared to be having a negative effect on the beetles and it was decided to determine species for all remaining individuals using size/color comparisons with the naked eye. Two *M. pusillus* adults were retained and used to make the comparison with all sampled adults.

A total of 28 adult *M. pusillus*, 4 adult *H. comalensis*, and one larvae (not identified under the microscope) were found. In addition, one adult riffle beetle (suspected of being *H. comalensis*) accidentally fell back into the water before being identified. This yields an estimate of 14.0 *M. pusillus* adults and 2.0 *H. comalensis* (or possibly 2.5) per m^2. These numbers are probably more representative of the true populations than the samples in the fall, because of the problems with silt mentioned before. The samples taken on this date, were also taken in a wider range of habitat types and the beetles of both species were more evenly spaced between the different samples.

An additional survey of the habitat where a single *H. comalensis* larvae was found in the summer (Site 2; Figure 1) yielded zero beetles of either species after ~ 45 min.

An interesting observation made while sampling spring run 3 during this trip was the apparent mating of a pair of *M. pusillus*. The pair were observed on the underside of a smallish rock (~50 mm) in very shallow water (~0.2 ft) with a significant influence of lateral springflow.

Day Three (1/08/02)

Sampling this day was focused on deeper areas where SCUBA and snorkel gear were required. The two primary areas sampled were the deepest portion of Landa Lake (the same area sampled in the fall) and just upstream of Spring Island, where 9 *H. comalensis* were found in the fall.

Sampling the deepest portion of Landa Lake for approximately 1.5 hours resulted in numerous *M. pusillus* adults (~50) and 6-8 larvae, but zero *H. comalensis* were found. upstream of Spring Island resulted in numerous *M. pus*illus adults (40-50+ gathered, more viewed underwater and returned), 4 *M. pusillus* larvae, and 2 *H. comalensis* adults. This indicates that the species is likely not abundant at the substrate surface in either location (populations occurring in hyporheic habitat were not sampled). Although more were found during the fall trip in these areas, the proportion of the two species is heavily dominated by M. pusillus. More surveys of the bottom of Landa Lake would be necessary to assess the extent of *H. comalensis* in those areas.

4.0 SUMMARY AND RECOMMENDATIONS

The Comal Springs riffle beetle (*H. comalensis*) was found in several habitats that are outside of the currently defined range for the species. It was previously believed that the species was restricted to spring runs 1, 2, and 3; however, we found them to be relatively abundant in one location along the shoreline of Landa Lake, far removed from the influence of spring run 3. We also found *H. comalensis* to be abundant in areas of upwelling springflow just upstream of Spring Island, and even found two individuals in the deepest portion of Landa Lake where springflow was evident.

Our estimates of the population density in the shoreline habitat were similar to those estimated from spring run 3 using the same sampling methods (2.0 individuals per m^2 in both instances). This suggests that the population in that area is experiencing similar habitat quality as in spring run 3 (the overall population size is likely smaller though, due to a smaller area of suitable habitat). These estimates are lower than the highest observed density in spring run 3 by Bowles (draft report 2000), but the methods used in that study were more thorough (and involved preserving all specimens) and likely resulted in more beetles recovered from gravel substrates. Sampling visually with our methodology limited the impact to the population, but probably also reduced our effectiveness at truly estimating the population, particularly individuals found in smaller substrates.

Finding populations in areas that were previously believed to be outside of the tolerance range of the species calls into question the argument that this species has a very limited range of physico-chemical requirements (as found in the spring run habitats) to survive. Our standard parameter measurements at the individual sample areas revealed limited variation due to the high flow conditions that were present throughout the study; however, the persistence of *H. comalensis* in areas outside of the spring runs would expose these individuals to a wider range of physico-chemical variation annually. We did observe that *H. comalensis* does appear to require rocks and gravel that are free of silt buildup; even in areas where beetles were found, they were restricted to portions of the habitat that were largely silt-free. Individuals were also found exclusively in areas where springflow was evident during the higher than normal conditions in which all sampling occurred. However, we still do not know if they are present in those areas when springflow is reduced or ceased entirely, or whether the species responds to decreasing flow by retreating to more subterranean habitat. In addition, while all of the areas in which the beetles were found did have some springflow evident, it was not necessarily a significant velocity. The shoreline habitat had only minimal springflow evident from small openings in the shoreline edge (measured at 0.20 m/sec or less), and not all beetles were observed to be directly adjacent to the flow.

More research is clearly needed regarding the habitat requirements of the Comal Springs riffle beetle, and hopefully the laboratory study currently being conducted by BIO-WEST will yield insight into the extent to which this species uses the subsurface habitat around spring openings. This will be particularly critical as it relates to low-flow conditions which could not be sampled during this study, but which may be approximated in the laboratory. That study will potentially provide answers to questions about how the species survived the drought of record, and many other periods of extended drought, including several in recent years.

5.0 REFERENCES

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