Hydrological Reconstruction of Extinct, Thermal Spring Systems Using Hydrobiid Snail Paleoecology

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By

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CERTIFICATION OF APPROVAL

I certify that I have read *Hydrological Reconstruction of Extinct, Thermal Spring Systems Using Hydrobiid Snail Paleoecology* by Zita Maliga, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirements for the degree: Master of Science in Applied Geosciences at San Francisco State University.

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In the thermal spring deposit of the extinct Garabatal hydrologic system in Cuatro Cienegas (Mexico), gastropod shell distribution was found to be clustered and preserved substrate preference patterns observed in the living system. A facies map of depositional habitats was created and gastropod distribution was visualized using Geographic Information Systems maps. From this, a hydrological flow model of the living system was reconstructed. A novel method of multivariate statistical analysis was also created and used to assess faunal associations. This method allowed us to assess the significance of associations in gradational and overlapping microhabitats, as well as to account for natural variations in species abundance. The taphonomy of subfossil gastropod shells was assessed using X-Ray Diffraction and Scanning Electron Microscopy. The methods employed in this analysis make this system a good model, which can be used to understand other ancient and unknown systems.

I certify that the abstract is a correct representation of the content of this thesis.

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Chair, Thesis Committee Date

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1.0 INTRODUCTION

Desert thermal springs are isolated oases where species of freshwater gastropods live under stress from competition for food, predation, and fluctuating water conditions (Thorp and Covich, 1991, Dillon, 2000). Niche partitioning allows freshwater gastropods to survive in microhabitats within these systems, with habitats changing on a scale of just a few meters. Gastropod taxa in the thermal springs of Cuatro Cienegas, Mexico (Figure 1.1) are distributed by microhabitat preference according to three predominant substrate types: soft mud, vegetation, and hard rocky substrates or stromatolites.

In this study, I apply an actuopaleontological approach (Schafer, 1972) to evaluating the potential for reconstruction of microhabitats within desert spring deposits, in that living systems are analyzed and the initial stages of taphonomy are assessed. This type of study is possible in the valley of Cuatro Cienegas because historically active spring systems have been documented and previous observations of the system can be compared to the deposits seen today. Using contour maps and statistical analysis, my study shows that the distribution of subfossil shells from historically active pool deposits is correlated to the three major substrates. I make additional observations about the flow rate of water in the field site, by correlating the percentage of gastropods preferring soft substrate microhabitat with the amount of soft substrate buildup caused by various flow conditions. This allows me to distinguish between 1) seasonally active, low water-flow environments with high soft substrate buildup and 2) more permanent

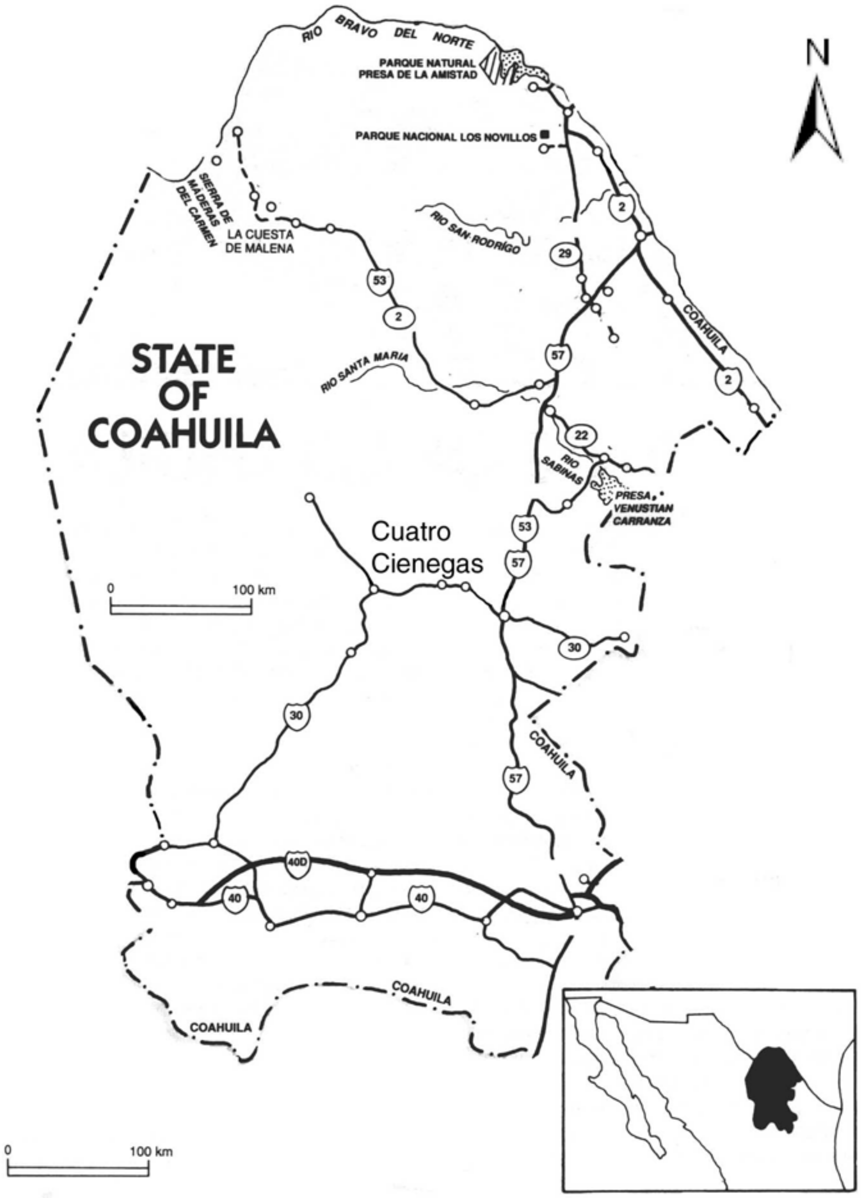

Figure 1.1. Location map showing Cuatro Cienegas in North-Central Mexico (Cummings, 1998).

water bodies containing high water flow conditions from actively flowing spring sources and subsequent low soft substrate buildup (Taylor, 1966, Minckley, 1969, Minckley, 1984).

The Garabatal is one of many spring systems located in the valley of Cuatro Cienegas. I mapped a portion of the extinct Garabatal spring system (Figure 1.2) using a handheld Global Positioning System (GPS) device and created a facies map using Geographic Information Systems (GIS) software. Pools, channels, and other facies within the field site were sampled along transects. These samples were sorted and counted, then superimposed onto the GIS map of the field site to visualize gastropod distribution patterns. Statistical analysis of gastropod associations further verified the presence of gastropod microhabitat preference preserved in spring deposits (Reyment, 1971, Harper, 1978, Davis, 1986).

Since microhabitats are preserved in the subfossil record, they have the potential to be preserved in the geological record. The results from my work at Cuatro Cienegas can be used as a model system, with sampling and analytical techniques applied to ancient and unknown paleoecological communities. This study has implications for astrobiological research in that it further substantiates the importance of microhabitat analysis in the exploration of relict life on other planets. The desert thermal springs at Cuatro Cienegas are similar to isolated, island ecosystems with respect to a high occurrence of speciation and endemism due to biogeographic isolation (Boss, 1978). However, they are applicable to our search for life on other planets, where potential

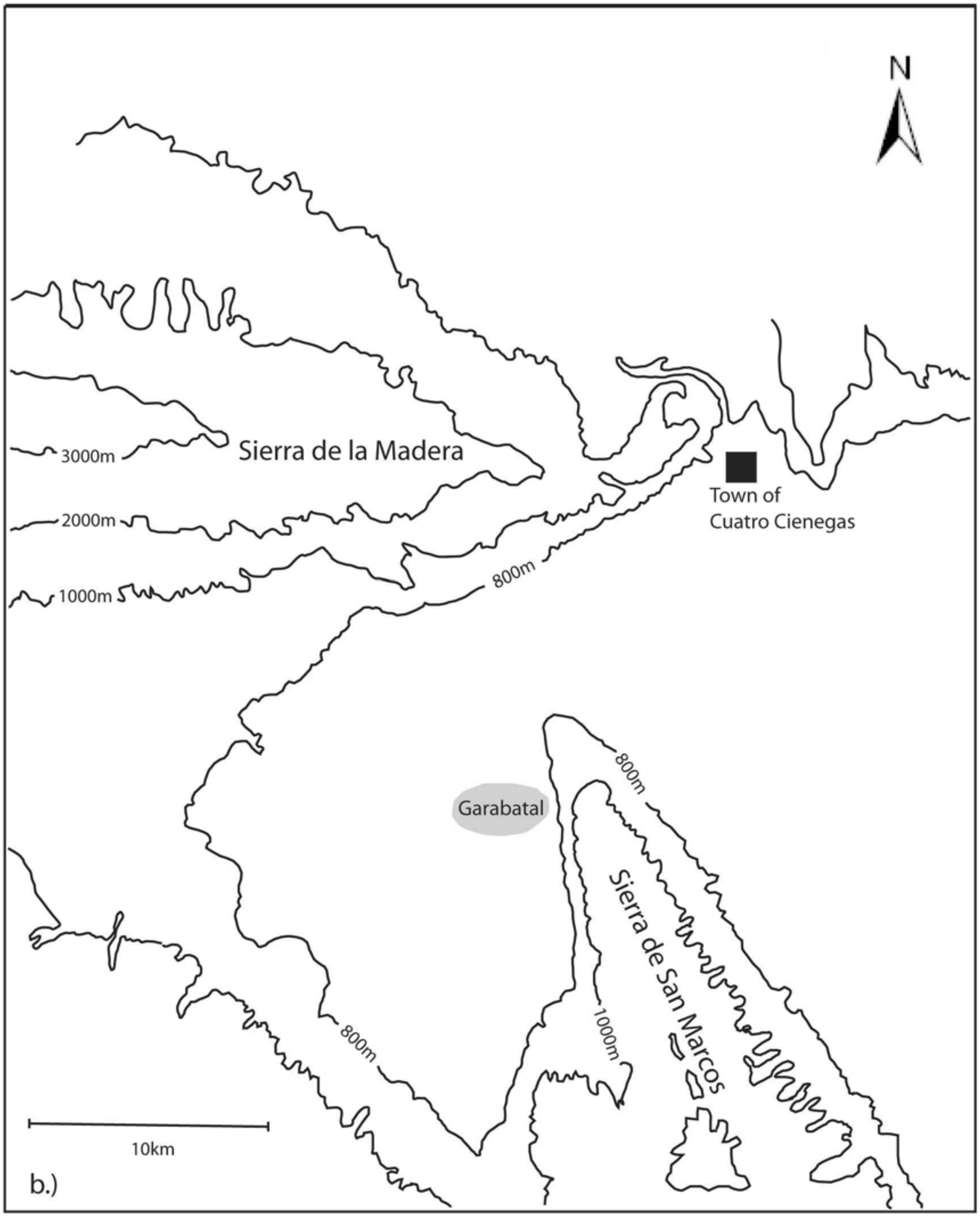

Figure 1.2 Topographic map showing the location of the Garabatal spring system indicated in gray (Meyer, 1973).

thermal spring ecosystems are being explored as a likely source for the origins and refuges of extraterrestrial life.

This work also has applications to conservation efforts in Cuatro Cienegas and other threatened desert springs systems. By using gastropods as biomarkers with which to delimit the extent and flow conditions of historically active spring system, this work can also define areas where restoration efforts should be concentrated and help to establish the effectiveness of current restoration efforts.

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2.0 CHARACTERISTICS OF CUATRO CIENEGAS

2.1 Geologic Setting

The study area encompasses a portion of the Garabatal spring system, located in the valley of Cuatro Cienegas de Carranza. The valley is situated in the Coahuila province of Northern Mexico (Figure 1.1), which is defined biogeographically as part of the Chihuahuan Desert in the southern portion of the Basin and Range province (Campa, 1985). The valley lies at an altitude of 740 m, is 30 by 40 km in extent, and is located in the Sierra Madre Oriental mountain range (Taylor, 1966). This range formed by contractual processes during the Mesozoic Laramide orogeny (Moran-Zenteno, 1994). It changed to an extensional regime in the Tertiary and is currently part of the Basin and Range province (Sedlock et al., 1993). Bisecting the valley is the Sierra de San Marcos (Figure 1.2), a breached, asymmetric anticline (McKee et al., 1990).

2.2 Spring Systems in Cuatro Cienegas

The springs at Cuatro Cienegas are thought to have been active for at least 30,000 years (Meyer, 1973). The stability of the system, along with its geographic isolation, are believed to be responsible for the high level of endemism present in the valley (Minckley, 1969). The springs at Cuatro Cienegas have been compared to Ash Meadows in Nye County, Nevada, and the Rift Lakes of Africa, which are also desert aquatic systems with high levels of endemism (Minckley, 1969).

The valley of Cuatro Cienegas is believed to have held large, pluvial lakes in the past, although the lakes were not sufficiently long lived to cut terraces or leave beach deposits (Minckley, 1969). A map from the 1860's shows two large lakes in the valley, named Lago de Agua Verde and Lago de Santa Tecla (Minckley, 1969). The history of the valley's hydrology has been one of increasing dryness. The area of Green Water Lake, in the southeastern portion of the valley, is now pitted with many small pools, locally called posas, which were formed by subsidence and collapse of underground solution channels. Minckley (1969) also indicated that the modern day lake in the southwestern portion of the valley, Laguna Grande, is located in the approximate position of the ancient Lago de Aqua Verde and may be a remnant of the old lake. Minckley

(1969) hypothesized that the individual drainage systems in the basin were previously linked, but became isolated as the water table dried up over time. Although the basin had only internal drainage at one time, a geologically recent surface water connection opened in the form of the Rio Salado de Nadadores drainage system, which brought freshwater into the basin from the east before it dried up due to water diversion for irrigation. In all, Minckley (1969) identified seven drainage systems in the valley: Posas de la Becerra, Rio Mesquites, Rio Puente Chiquito, Laguna Tio Candido, Santa Tecla, Rio Salado de Nadadores, and Rio Churince.

Today, most of the springs in Cuatro Cienegas originate near the base of the Sierra de San Marcos, with water traveling up pre-existing fault planes and other fractures (Minckley, 1969). Large, spring-fed lakes typify the sources of springs, while large evaporitic barrial lakes are often found in the peripheral portion of the spring and lie farther from the base of the mountain (Minckley, 1969).

2.3 Water Chemistry

Water chemistry analysis (Minckley and Cole, 1968) showed that waters in the springs of Cuatro Cienegas are well oxygenated, are 25-35^{o}C at the spring source, and are heavily mineralized. The water contains high levels of sulfate (SO_4^{2-}), carbonate (CO_3^{2-}), and calcium (Ca^{2+}) ions at the spring source, with all spring sources having similar water chemistry. Farther from the source, calcium (Ca^{2+}) and carbonate (CO_3^{2-}) become depleted, as calcium carbonate ($CaC0_3$) precipitates out of solution, and the water becomes enriched in magnesium (Mg^{+}). Low concentrations of sodium (Na^{+}), and potassium (K^+) are also present in the water. Gypsum ($CaSO_4 \cdot 2H_2O$) precipitates as the sulfate-laden water evaporates from evaporitic lakes. Over time, dune systems develop adjacent to these water bodies, reaching heights of up to 60.96 m (Pinkava, 1984) and composed of up to 95% gypsum grains (Minckley, 1969).

2.4 Stromatolites and Travertine

Calcium carbonate precipitation at Cuatro Cienegas is described by Minckley (1969) as resulting from two processes, evaporitic and biological. Plants growing near the water's edge promote evaporation through transpiration. Calcium carbonate is the least soluble salt to precipitate out of the water through this evaporative process, and it builds up to form a hard ledge at the edge of a water body. In this way, a travertine ridge is built through a mechanical, evaporitic process.

Travertine also builds up due to the activity of microbial communities to form stromatolite structures. Stromatolites are important microhabitats for gastropods in Cuatro Cienegas. Though rare on earth today, stromatolites are the most commonly found fossil from the first three billion years of Earth's history, from the Archaean (3500 Ma) to the end of the Proterozoic (520 Ma) (Cowen, 1995). The stromatolite communities create a slightly basic chemical microenvironment just above the algal mat surface, which promotes the precipitation of calcium carbonate onto the algal mat (Farmer, 1999, Farmer, 2000). Winsborough (1990) identified four different types of stromatolites in Cuatro Cienegas: two types of laminated stromatolites, a stony stromatolite, and an intricate stromatolite. The organisms involved in creating these various types of stromatolites are summarized in Table 2.1.

	Description	Created by
Type 1	Laminated stromatolite and oncoloids. They form microterraces	*Homoeothrix balearica*
	or small horizontal, lobate ledges.	*Schizothrix lacustris*
Type 2	Laminated stromatolites and oncoloids. They form	*Gongrosira calcifera*
	bulbous cushions at the ends of branched digitate elements.	Cyanobacteria
		Diatoms
Type 3	Non-laminated stromatolite. They form large, globose structures	*Dichothrix bonetiana*
	with sinuously- incised surfaces.	*Schizothrix lacustris*
		Cyanostylon sp.
		Diatoms
Type 4	Laminated stromatolites. They form domed structures.	*Scytonema mirabile*
		Schizothrix affinis
		Diatoms

Table 2.1 The four types of stromatolites described in Cuatro Cienegas (Winsborough, 1990).

2.5 The Garabatal Springs

The name Garabatal, or “scribbles” in Spanish, refers to the unique growth of travertine-lined stream channels in the area. Overhanging ledges form at the top of channels, restricting the opening to a sliver. Looking down on them, the channels define a convoluted path linking pools together in irregular patterns. The Garabatal springs are hydrologically connected to the Posas de la Becerra drainage system (Minckley, 1969). From the Posas de la Becerra springhead, water flows northward.

Before the Garabatal spring system dried up approximately 20 years ago due to water diversion, the living Garabatal system was undisturbed. The living system at Garabatal was reported to be seasonal and more highly variable than other spring systems in the valley (Winsborough, 1990). Winsborough (1990) identified four pools in the field site, Laguna Garabatal and three unnamed pools. It is these locations that are identified in my study and form the boundaries of my field site.

According to Winsborough (1990), Laguna Garabatal was the largest and topographically highest of the lakes. It was up to 30 meters wide and 2 m deep, with a largely unvegetated, sandy bottom composed of carbonate grains and gastropod shells. Laguna Garabatal's water chemistry from April 1979 to January 1988 is summarized in Table 2.2.

Spring water flowed from Laguna Garabatal to a second lake about 35 m away. The second lake was 40 x 80 m, filling to one meter in depth during the rainy season (Winsborough, 1990). Since abundant macroscopic algae called *Chara*, or muskgrass, grew in this lake (Winsborough, 1990), I herein refer to it as Laguna Chara.

Laguna Chara was also connected to a smaller, funnel-shaped pool that reverses itself and at times forms a whirlpool. The substrate in this pool is reported to be variable, at times covered with black mud and at other times scoured clean (Winsborough, 1990). I herein refer to this pool as Posa Regresando.

Temperature	21.7 - 31.9°C
pH	6.5 - 8.0
Conductivity	2720-2900 μmhos
DO	6.2 mg/l
Salinity	1.3-1.8 ppt
TDS	2498.2 mg/l
Mg^{2+}	124.0-133.7 mgl/l
Ca^{2+}	384.8-392.8 mgl/l
Na^{+}	186.2-209.2 mg/l
S^{2-}	16.1 mmol/l
SO_4^{2-}	1546.6 mg/l
Cl^{-}	120.5-131.2 mg/l
HCO_3^{-}	128.1 mg/l
K^{+}	10.4-11.0 mg/l
Sr^{2+}	15.5 mg/l
Si	15.9-19.9 mg/l
F^{-}	2.8-3.2 mg/l
NO_3^{-}	5.6 mg/l
PO_4^{-}	.013 mg/l
Cd	.02 ppb
Pb	5.6 ppb
Ni	2.3 ppb
Co	.03 ppb
Fe	2.9 ppb
Mn	.52 ppb
Cu	.4 ppb

Table 2.2 Summary of water chemistry data from Laguna Garabatal collected from April 1979 to January 1988 (Winsborough, 1990).

During the rainy season, water flowed out of Laguna Chara through a “shallow marsh surface laced with anastomosing travertine dams about 25 cm tall and several meters long” (Winsborough, 1990). It filled a small lake that was often dry but contained travertine ridges at various elevations from previous water conditions in the spring system. This lake is herein referred to as Posa Terminal.

3.0 PREVIOUS STUDIES OF GASTROPOD MICROHABITATS

The gastropods found within the pools of Cuatro Cienegas have been previously described and the microhabitats of these gastropods have been well documented in living springs systems (Taylor, 1966, Hershler, 1984, Hershler, 1985). In addition to describing the faunal community of Cuatro Cienegas, I explore other paleoecological studies of desert springs systems in order to establish the significance of this study in a broader context.

3.1 Gastropod Taxonomy

The most common family of freshwater gastropods in the valley of Cuatro Cienegas is the Hydrobiidae (Taylor, 1966). The Hydrobiidae belong to the prosobranch group of gastropods, which have heavy shells, gills, and an operculum (Thorp and Covich, 1991). They grow slowly and sexes are separate in most cases. The Hydrobiidae are a diverse family of freshwater gastropods, with over 1,000 recent species and over 400 recent and fossil genera described (Hershler and Ponder, 1998). They typically have a small shell size (1.5-6.0 mm in length) and have 4-6 convex, teleoconch whorls (Hershler and Ponder, 1998). The hydrobiid gastropods of Cuatro Cienegas were first described by Taylor (Taylor, 1966) with a subsequent revision of species by Hershler (1985) (Table 3.1).

Taylor (1959)	**Hershler (1985)**
Coahuilix hubbsi	*Coahuilix hubbsi*
	Coahuilix landyei
Cochliopina milleri	*Cochliopina milleri*
	Cochliopina riograndensis
Durangonella coahuilae	*Durangonella coahuilae*
Durangonella sp.	*Durangonella seemani*
Mexipyrgus carranzae	*Mexipyrgus carranzae*
Mexipyrgus churinceanus	
Mexipyrgus escobedae	
Mexipyrgus lugoi	
Mexipyrgus mojarralis	
Mexipyrgus multilineatus	
	Mexistiobia manantiali
Mexithauma quadripaludium	*Mexithauma quadripaludium*
Nymphophilus minckleyi	*Nymphophilus minckleyi*
	Nymphophilus acarinatus
	Orygoceras sp.
Paludiscala caramba	*Paludiscala caramba*
Drepanotrema sp.?	
Physa virgata	

Table 3.1 Comparative list of freshwater gastropods described by Taylor (1966) and Hershler (1985).

Phylogenetic analysis of hydrobiids based on morphological features continues to be challenging. According to Wilke et al. (2001), the principal problems with hydrobiid classification are their morphological simplicity, with the few robust anatomical features exhibiting a high degree of intraspecific variation and homoplasy (Wilke et al., 2001). This observation is supported by research on hydrobiid gastropods in Cuatro Cienegas, where landmark-based morphometric analysis of individuals of the genus *Mexipyrgus* revealed an unusually high variability of shell shape both between and within hydrologic systems (Tang and Roopnarine, 2003).

Bonner (1965) described the high variability in species morphology as a product of two factors: multiple choice variability and range variation. Multiple choice variability causes morphologic variation due to large scale changes in environmental conditions, while range variation defines a certain range of morphology for a given species based on the many variables of environmental processes interacting with the biochemical processes occurring during an individual's growth and development. In either case, morphologic variability of invertebrates may be more influenced by phenotypic than genotypic causes and species that are more generalized tend to be more morphologically variable (Dodd and Stanton, 1990).

Besides the Hydrobiidae, several other species of gastropods can be found in the valley of Cuatro Cienegas. These include *Gundlachia excentrica*, *Dreptanotrema* sp., *Heliosoma anceps*, *Assimineae* sp., *Physa virgata,* and *Fossaria obrussa* (Taylor, 1966, Hershler, 1985).

3.2 Gastropod Habitats and Microhabitats

Table 3.2 lists the common habitats of gastropods in Cuatro Cienegas. Taylor (1966) found that large pools were dominated by three gastropod taxa, all of which prefer different substrates. *Nymphophilus minckleyi* was found at the edges of pools on *Nymphaea*, water lily, leaves and rarely on lower surfaces of oncolites and stromatolites.

Mexithauma quadripaludium was found on hard substratum, stones or stromatolites, or on the firm, shelly bottom in areas of high water flow. *Mexipyrgus* was always present in soft, muddy substrate which was composed of gastropod copropel. Taylor also noted the presence of *Cochliopina milleri* in large pools, a less abundant species always associated with soft sediments like *Mexipyrgus*.

Hershler (1985) agreed with Taylor's (1966) interpretation of substrate preference for *Mexipyrgus carranzae*, *Mexithauma quadripaludium*, and *Nymphophilus minckleyi*. Hershler (1985) also noted that *Durangonella coahuilae* prefers soft sediment and *Coahuilix milleri* prefers aquatic vegetation (this description of microhabitat interpretation for *Coahuilix milleri* disagrees with Taylor (1966)). In pools where both *Nymphophilus* and *Mexithauma* coexisted with abundant travertine and vegetation, *Mexithauma* was found preferentially on travertine and *Nymphophilus* was found preferentially on aquatic vegetation, such as *Nymphaea*, *Chara*, and *Utricularia* (bladderwort). In areas of reduced microhabitat diversity, Hershler (1985) suggested that *Mexithauma* and *Nymphophilus* may compete with one another. Species of gastropods associated with springheads included *Coahuilix hubbsi*, *Coahuilix landyei*, *Paludiscala caramba*, *Durangonella coahuilae*, and *Stiobia*, with the first three species restricted to springheads.

Genus	**Species**	**Size (mm)**	**Frequency within Microhabitats**	**Habitat**	**Observed Microhabitat**
Coahuilix	*hubbsi*	1-1.5	Common	Spring-heads	organic-rich mud
Cochliopina	*milleri*	2	Uncommon	Spring outflows	vegetation
Durangonella	*coahuilae*	3-4	Uncommon	all areas	soft, organic sediments
Mexipyrgus	*carranzae*	7-8	Common	large springs	soft sediment
Mexithauma	*quadripaludium*	6-7	Common	large springs, outflows	aquatic vegetation, sand, travertine (stromatolites)
Nymphophilus	*minckleyi*	5-6	Common	Large springs	aquatic vegetation and travertine (stromatolites)
Physa	*virgata*	4	Uncommon	all areas	calm waters, low oxygen, areas prone to drying

Table 3.2 Common gastropod habitats (Taylor, 1966, Hershler, 1985).

3.3 Paleoecological Studies

My research lies within the realm of paleoecological studies, exploring the community ecology, biogeography, and taphonomy of desert thermal springs ecosystems with a focus on examining the preservation potential of microhabitats within the system. It looks at the biocoenosis, or the total living parts of a system that are preserved, and compares it to the thanatocoenosis, or death assemblage. Normally, the thanatocoenosis is composed of preserved hard parts such as shells, bones, and spores. Under exceptional preservation conditions, soft parts of organisms such as tissues and feathers may also be preserved. In this study, the thanatocoenosis consists of gastropod shells.

Taphonomy is the study of the postmortem alterations to an organism which lead to fossilization, and is characterized by various factors leading to differential necrolysis, biostratinomy, and fossil diagenesis. The primary taphonomical process is necrolysis, or the decomposition of an organism. This process is affected in large part by the biostratinomy, which is the sedimentologic process that incorporates potential fossils. In general, fossils are best preserved when there is a high sediment influx that buries the organism quickly, protecting it from necrolysis and transportation. Subsequent mineralogical alterations in the fossil occur through a set of processes called diagenesis.

Of relevance to this study is the diagenetic recrystallization of aragonite to calcite, a more stable form of calcium carbonate. The shells of gastropods are typically composed of aragonite or an aragonite and calcite mix (Evans, 1972). Aragonite recrystallizes to calcite early in the diagenetic process especially in wet environments (Bathurst, 1986), so its presence can be used as evidence that diagenesis has not yet occurred. The aragonite in subfossil gastropods can be dated using radiometric carbon dating or amino acid racemization techniques.

The degree of preservation of gastropod shells is dependent on the substrate the gastropods are deposited in. According to Evans (1971), gastropods are well preserved in calcic substrates such as Jurassic travertines and limestone colluvium. According to Stanton and Dodd (1990), aragonitic shells often occur as molds or have been replaced by calcite in well-cemented limestone and chalk facies, whereas aragonitic shells are often missing or absent in carbonate sand facies.

Community-based paleoecological studies seek to understand the ecology of a community by focusing on those parameters that are preserved in the fossil record (Dodd and Stanton, 1990). More commonly, they are autecology studies, which look at the distribution and variation of one species within an ecosystem. Among other things, these studies examine the size of organisms to determine survivorship curves and relate the mean size of an organism to water temperature and salinity in freshwater or marine ecosystems. Synecological studies, which interpret how a group of organisms interact and are interdependent, appear less frequently in the literature and are highly dependent upon multivariate statistical analyses (Dodd and Stanton, 1990). This is a synecological study because it looks at the assemblage of freshwater gastropods in depositional facies.

Biogeographic studies typically look at the spatial distribution of organisms on a large scale (Dodd and Stanton, 1990), searching for patterns of distribution that are typically defined as either random, uniform, or clumped. Random distributions of organisms have no patterns to their spatial distributions. The presence of a random distribution of a fossil taxon may be attributed to (1) an artifact of preservation, (2) a reflection of randomly distributed resources, or (3) no strong habitat preference of the organism such as with generalist taxa. It could also be a product of post depositional transport. A uniform distribution shows a pattern of uniform density of taxa throughout a given area. A uniform fossil distribution suggests that the organism had a certain habitat range in life and may have been competitive with other individuals of its species. A clumped pattern of distribution suggests that meaningful species associations are preserved in the fossil record and areas of preferential habitats for organisms existed in the ecosystem. The results of biogeographic analysis are dependent on the scale of the sampling method. At certain scales a pattern will not be visible. However, on a global scale, all organisms show clumping (Dodd and Stanton, 1990). The preservation of species patterns is dependent on several factors, including the types of species observed, time averaging of species, and post-depositional transport. Time averaging is the net effect of the period of deposition on the fossil assemblage retained within sedimentary units. Cummings (1986) suggested that the natural clumping of species is retained despite time averaging.

4.0 METHODS

This study employed both field and lab elements. Facies delineation and the majority of the sampling and sorting were completed in the field, at Cuatro Cienegas. Statistical analysis, Scanning Electron Microscope (SEM) work, X-Ray Diffraction (XRD) analysis, and Geographic Information System (GIS) mapping were completed at various locations in the San Francisco Bay Area.

4.1 Facies Delineation

In the spring and summer of 2003, I mapped a portion of the Garabatal hydrologic system using a handheld Garmin Geographic Positioning System (GPS) unit. A total of 213 GPS points were used to evaluate a 160 m^2 area. Based on previous publications and facies criteria outlined in section 3.2, I identified deposits that were habitats for freshwater gastropods, sampling larger deposits extensively as they were the most likely sources of microhabitat development (Hershler, 1985). Based on geomorphologic features I chose the following habitats to sample: large pools, small pools, marshy areas, travertine-lined channels, playas, and springheads.

4.2 Gastropod Taxonomy

Based on my observations of depositional facies types, I sampled deposits of what had originally been two large pools, one channel, several smaller pools, and one playa in the study area. One hundred and forty-six samples were collected along transects in my field area, and 17 samples were collected from 6 locations of active springheads or potential springhead deposits (Figure 4.1).

Sampling was conducted along transects, either every 5 m or every 10 m. Sampling along transects ensure objective, random samples for statistical analysis and the reliability of the contour maps, which are dependent on the density and uniformity of the sampling points (Davis, 1986). Transects were laid out using a measuring tape, with a flag placed at every sampling location. The large pools were sampled along several transects to account for spatial variability. Laguna Chara was originally sampled in March 2003 as a pilot study to determine whether gastropod abundance and variability would be preserved in pool deposits. Laguna Chara was sampled extensively, with a bulk sample collected every 5 m along transects that were spaced 10 m apart (Figure 4.2). Positive results from the March sampling effort led to the further characterization of the field site and more sampling in July, 2003. Laguna Garabatal was sampled with a sparser sampling scheme, with bulk samples taken every 10 m and transects that were spaced 10 m apart (Figure 4.3, Figure 4.4a). Smaller pools and the playa were sampled along one transect which spanned across the width of the pool or channel, every 5 m for small pools and every 10 m for the large playa area. Two to three samples were collected from the walls of possible springheads, but the marshy areas were not sampled. In addition, a sampling pit was dug in the center of Laguna Chara (Figure 4.4b) to determine whether gastropod shells were preserved in the sediment at depth. The pit was dug with a hand shovel, and gastropods were sampled every 10 cm using a hand trowel. The pit was dug to a total depth of 110 cm, where the water table was encountered.

During transect sampling, I collected bulk samples (Jaehnig, 1971) from the top 2.5 cm of the sediment using a hand trowel and sampling from an area that was 30 cm^2 (Figure 4.4c). I measured the sampling area using a transect square that was 30cm^2. The samples were collected in canvas bags (Figure 4.4d), then dried and weighed. The drying was done in the field, where sediments were dried for at least twenty-four hours. The samples were then sieved using a mesh sieve with a 1 mm size opening and washed with tap water. The sediment was too coarse to use a .05 mm sieve to sort and sift the samples, though this is the size generally recommended in gastropod sampling procedures (Jaehnig, 1971, Evans, 1972, Ashbaugh and Metcalf, 1986). After sifting and washing, the gastropods were carefully extracted with tweezers and sorted taxonomically. In general, the entire sample was sorted and adult individuals were counted.

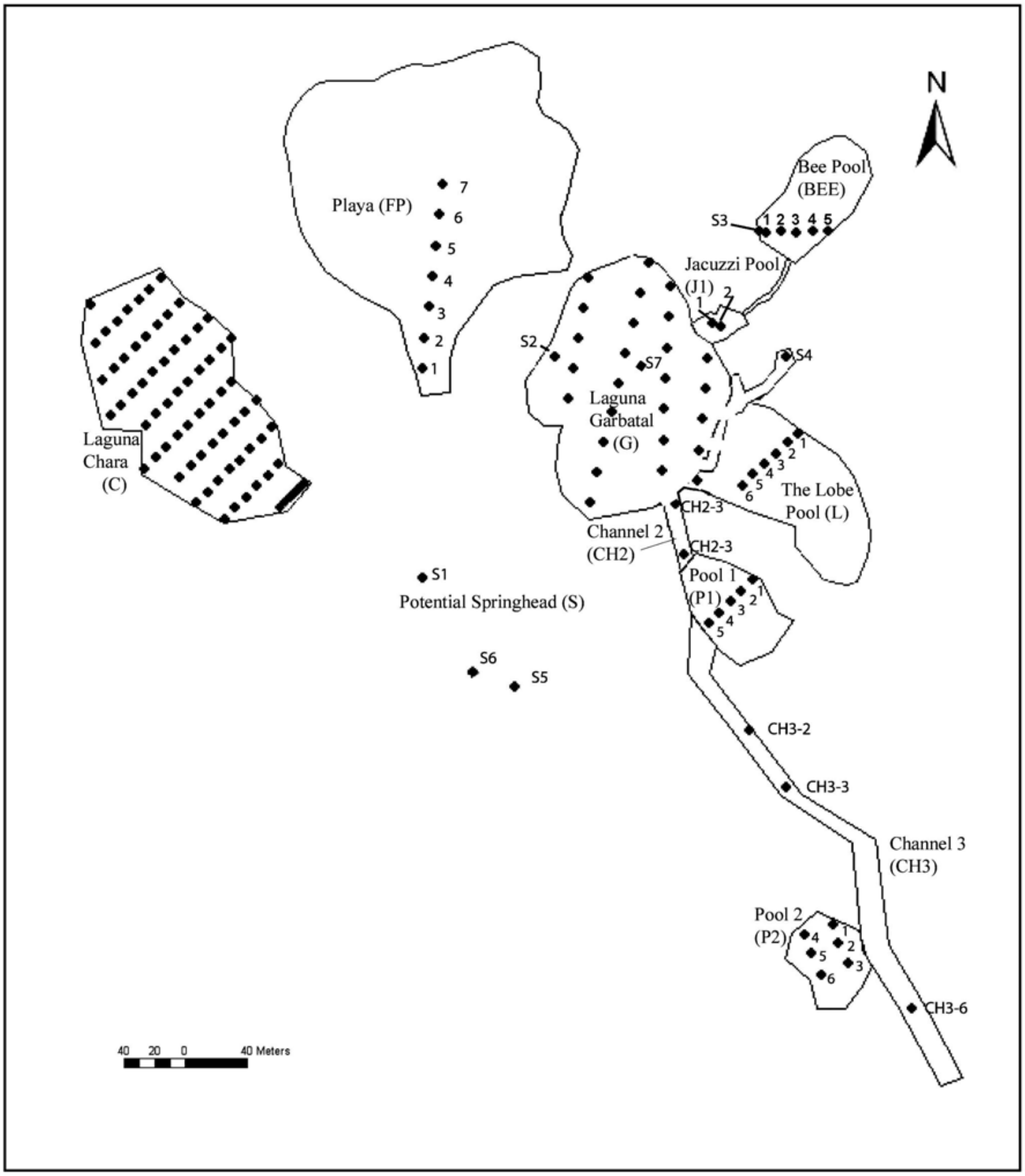

Figure 4.1 Sampling locations for the Garabatal spring system (Figure 1.2) with their identification numbers. Sampling points for Laguna Chara and Laguna Garabatal are in separate figures.

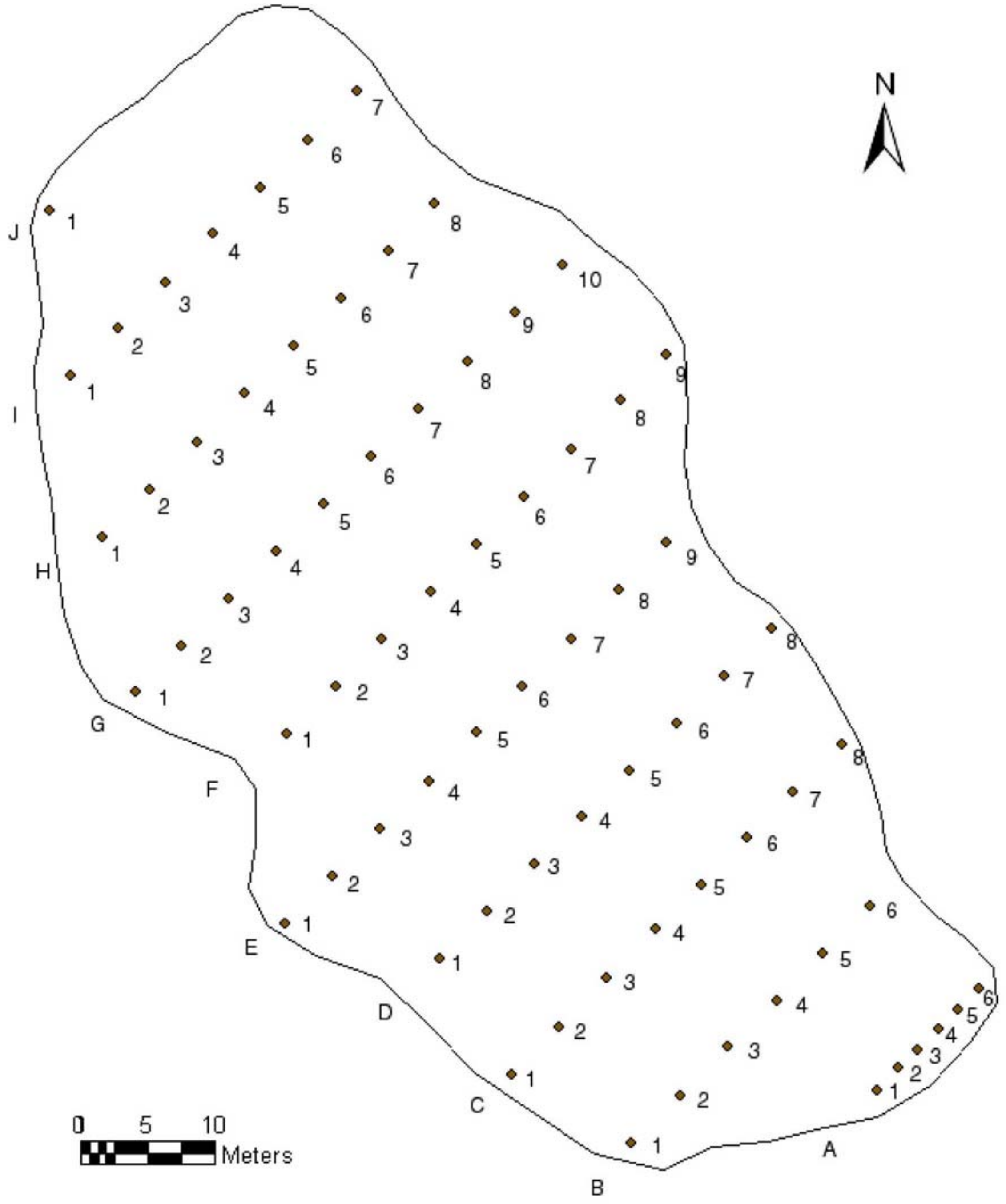

Figure 4.2 Sampling locations along transects A-J for Laguna Chara (Figure 4.1).

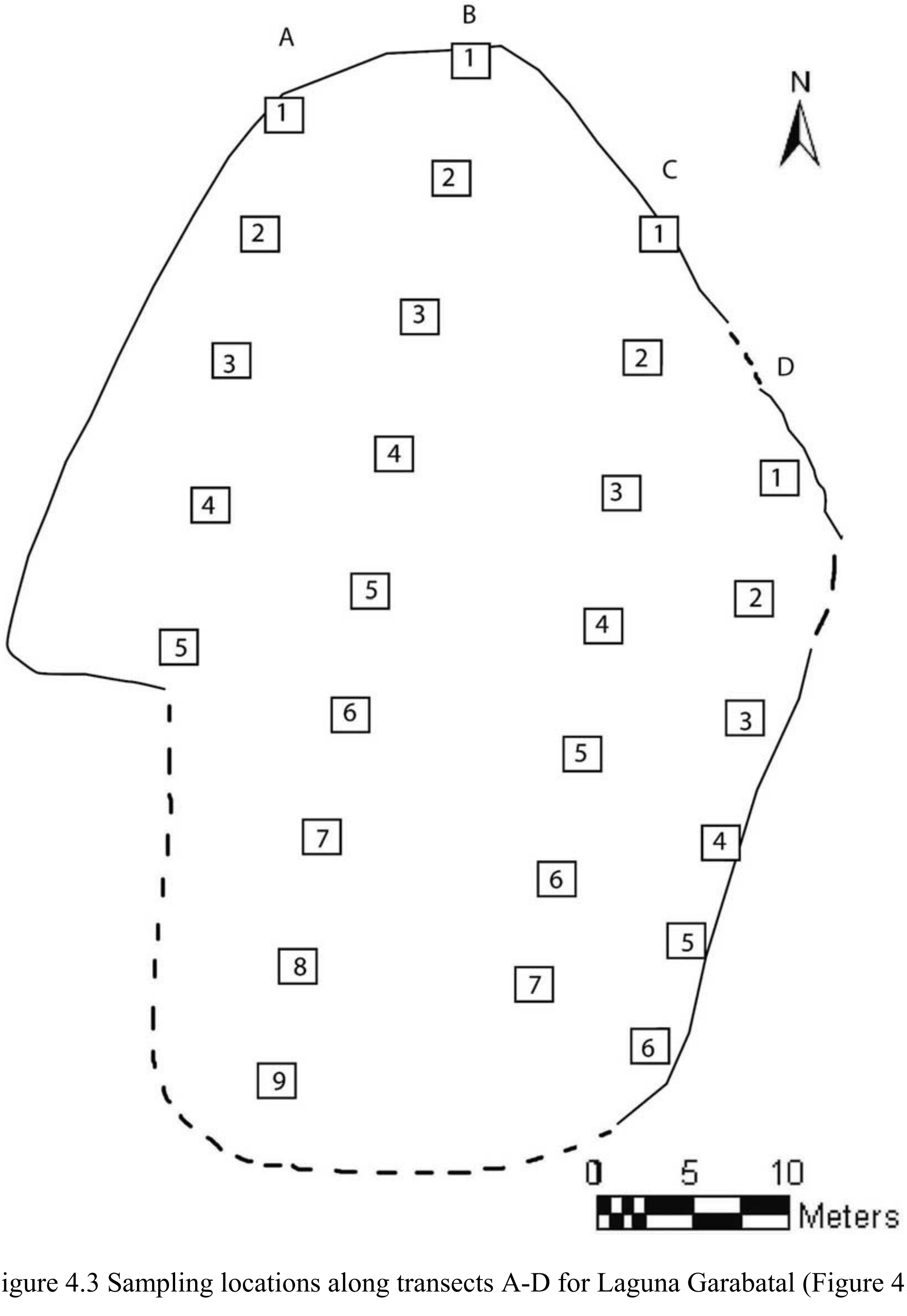

Figure 4.3 Sampling locations along transects A-D for Laguna Garabatal (Figure 4.1).

a) b)

c) d)

Figure 4.4 a) sampling along transect grid lines at the Laguna Garabatal deposit, b) a sample pit dug in the center of Laguna Chara deposit, c) an example of a sampling location, d) labeling bags of bulk samples.

Juveniles with only 1.5 to 3 whorls were not counted (Jaehnig, 1971). On the few occasions where gastropod density was very high, >1000 gastropods per sample, the sample was subdivided and the total amount of gastropods was calculated from the subsample. Gastropod identification was done to the genus level using (Hershler, 1985) categorization. A total of 23,360 gastropods were analyzed from the bulk samples, consisting of 6 six different gastropod taxa.

4.3 Geographic Information Systems Maps of Gastropod Frequency and Distribution

I took 213 Global Positioning System (GPS) points at the edges of various facies. I put the points into the ERDAS Imagine 8.0 GIS program. This gave me a rough estimate of the extent of pools. I adjusted the GPS points in order to correct for the +/-2-3 m uncertainty indicated in the GPS readings. The final dimensions of the facies were based on measurements made with a 91.44 m measuring tape in the field.

Using ERDAS Imagine and ArcView software, I created a GIS map of the field site based on the various facies I had determined. Using the universal kriging method with Arc View software, I also made contour maps of the gastropods. Universal kriging creates contour maps by estimating the surface at unsampled locations. This enabled me to visually and qualitatively assess whether taxa were distributed in a random, clustered, or uniform pattern.

4.4 Statistical Analysis

I performed statistical analyses to further evaluate the distribution pattern of gastropod taxa in my field area. In total, I evaluated the association probability of 6 genera of gastropods to determine whether their co-occurrences and distributions were significant or due solely to random chance. Both frequency of occurrence analysis and association analysis were performed. In total, I evaluated the association potential of six taxa of gastropods. Terrestrial gastropods were not included in my analysis. Springhead samples were also excluded from my analysis.

I used the sorting function in Microsoft Excel 2000, to perform a frequency of occurrence analysis on my sampled data. However, a more detailed approach to the study of organismal associations was created for this study, and is herein called association analysis. This multi-variate method accounts for gradational changes in species habitat, makes allowances for multiple habitat preferences of species, and allows for the possibility of overlapping habitats. This is accomplished by employing a statistical method that accounts not only for the number of species occurrences, but also accounts for the relative abundance of species within that locality. It looks at the specific combinations of organisms at each sampling locality and assigns each organism a weighted value based on the density and the total number of species within the sampled site. The occurrence of each faunal combination is compared to the same data set, randomized to remove the effects of natural variability of species abundance. This test can establish which associations occur in significantly higher proportions than the randomized data set. The null data set should have a probability of occurrence for each association that is proportional to the occurrence of individual taxa in the bulk samples, while the sample data set should only have a select number of meaningful combinations occurring in the data set. In this study, we expect to see that the null data set contains all sixty-four combinations of species associations.

For association analysis, I used Jump 4.0.4 statistical software to look at the various associations of taxa in my field samples. This type of analysis is best suited for species assemblages that are not affected by transport processes, such as the subfossil assemblage of gastropod taxa in Cuatro Cienegas.

4.5 X-Ray Diffraction Analysis

I used X-Ray Diffraction (XRD) analysis to determine the mineralogical content of the gastropods in order to assess the degree of diagenesis in the samples. Each sample consisted of only one gastropod genus, which included *Mexipyrgus*, *Nymphophilus*, and *Mexithauma* taxa (Appendix 6). In general, larger, individuals were selected. XRD analysis was performed at San Jose State University, using a diffractometer made by Philips Electronics. I was assisted by Professor Dave Anderson (San Jose State University) who ran the XRD machine and helped me interpret the sample results. I picked 10 shells from each sample to be tested. I washed the shells with dilute soapy water to remove sediment within and around the shell, patted the shells with a tissue, and allowed them to air-dry overnight. The shells were then ground using a marble mortar and pestle. I added a few drops of ethanol to the shell mixture and spread a thin film of finely ground shell solution evenly onto a glass slide. The ethanol was allowed to evaporate and the slide was placed into the XRD machine for analysis.

4.6 Scanning Electron Microscopy

I took pictures of the various taxa of gastropods using a Scanning Electron Microscope (SEM) to get detailed pictures showing the growth lines and other markings on gastropod taxa. SEM samples were prepared at the California Academy of Sciences. Gastropod shells were washed in a solution of dilute, soapy water. They were allowed to sit in the water for at least 15 minutes and were then brushed gently with a paintbrush to remove dirt clinging to the outside of the shell and to excavate sediment trapped within the shell. The shells were subsequently dried with a paper towel. Both damaged and undamaged shells were selected. The cleanest, best preserved shells were mounted on aluminum pins as models for Plate 1. Other damaged or altered shells were photographed as well (Plate 2).

Using a Denton Desk II Sputter Coater, the samples were coated with a mixture of gold and palladium in a chamber filled with argon gas. They were photographed using a LEO 1450VP model SEM.

5.0 RESULTS

The results of facies mapping are discussed below and the features of the various facies are explained. I also discuss the gastropod taxonomy that was determined from sorting the bulk samples. Then, contour maps created using GIS are explained to show the relative abundance and distribution of each taxa, followed by a explanation of results from statistical analysis, including frequency of occurrences analysis and association analysis. Finally, I present the results of the XRD analysis and SEM photographs.

5.1 Facies Delineation

I created a map of the field area (Figure 5.1) using my knowledge of the landform geomorphology of fluvial systems, observed sedimentologic changes, as well as the location of travertine mounds and ledges to help delineate the various facies. Within this area I identified four pools previously described by Winsborough (1990); (Laguna Chara, Laguna Garabatal, Posa Terminal, and Posa Regresando), five additional small pools (which I named Pool 1, Pool 2, the Lobe, the Jacuzzi, and the Bee pool), two marsh areas and one playa (Figure 5.2). I also located possible springheads (S1-S7) (Figure 4.1). The locations of the former pools (Winsborough, 1990) were verified by Dean Hendrickson (personal communication) during my June, 2003 fieldwork.

5.1.1 *Large Pools*

Large pools were identified as landforms with flat-bottomed areas greater than 50 m in width. They generally had travertine mounds or ledges at their edges, where they were formed by stromatolite activity in the living system. Where travertine mounds occurred, the pools had gently sloping sides that extended up past the travertine mounds and formed the boundary of the pools for my sampling. Ledge-type stromatolites formed nearly vertical walls and defined sharp boundaries for pools. The pool deposits were either soft bottomed with variable thickness of white, carbonate sand and mud or hard

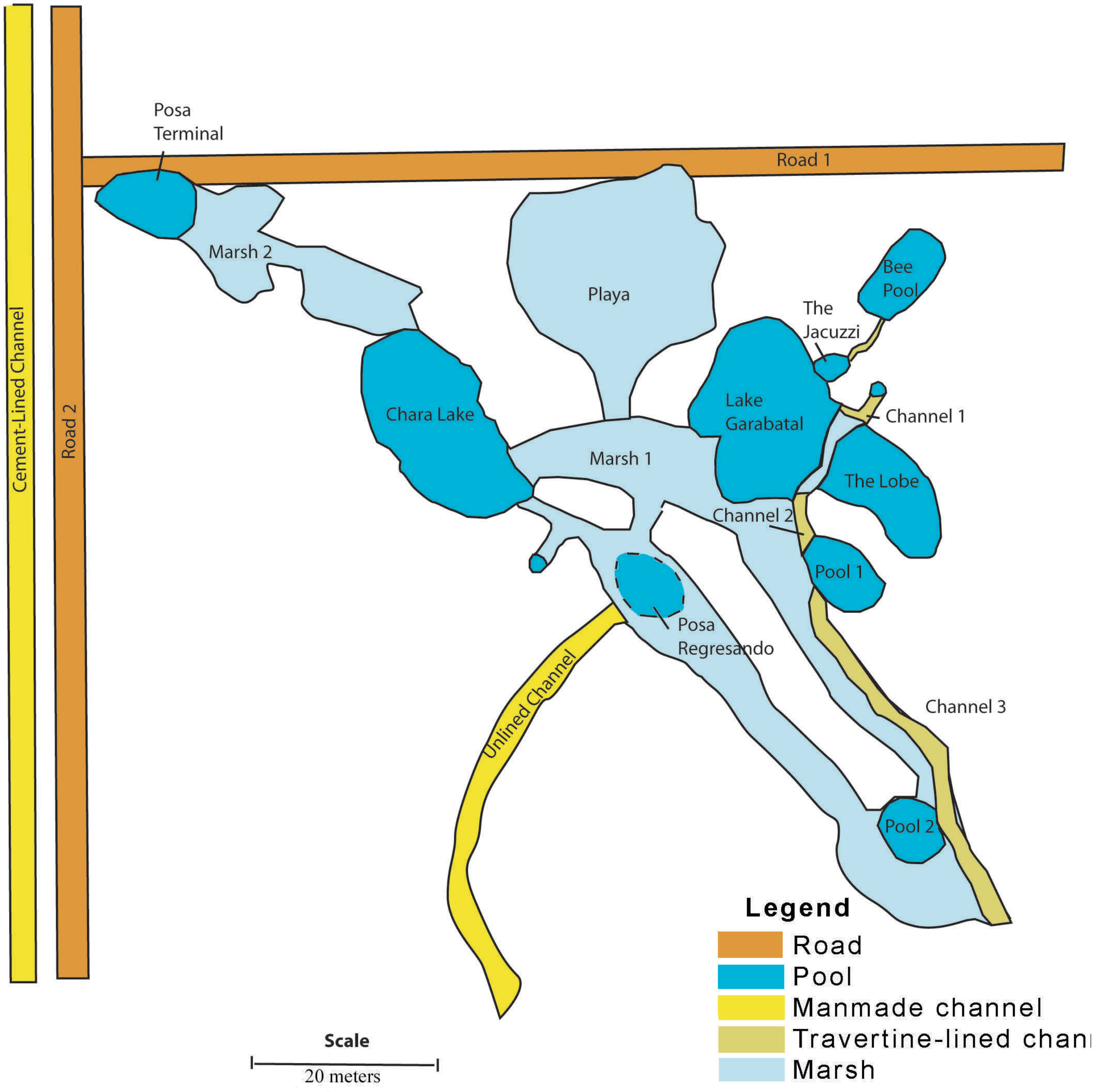

Figure 5.1 Map of habitat environments for the Garabatal field site (Figure 1.2).

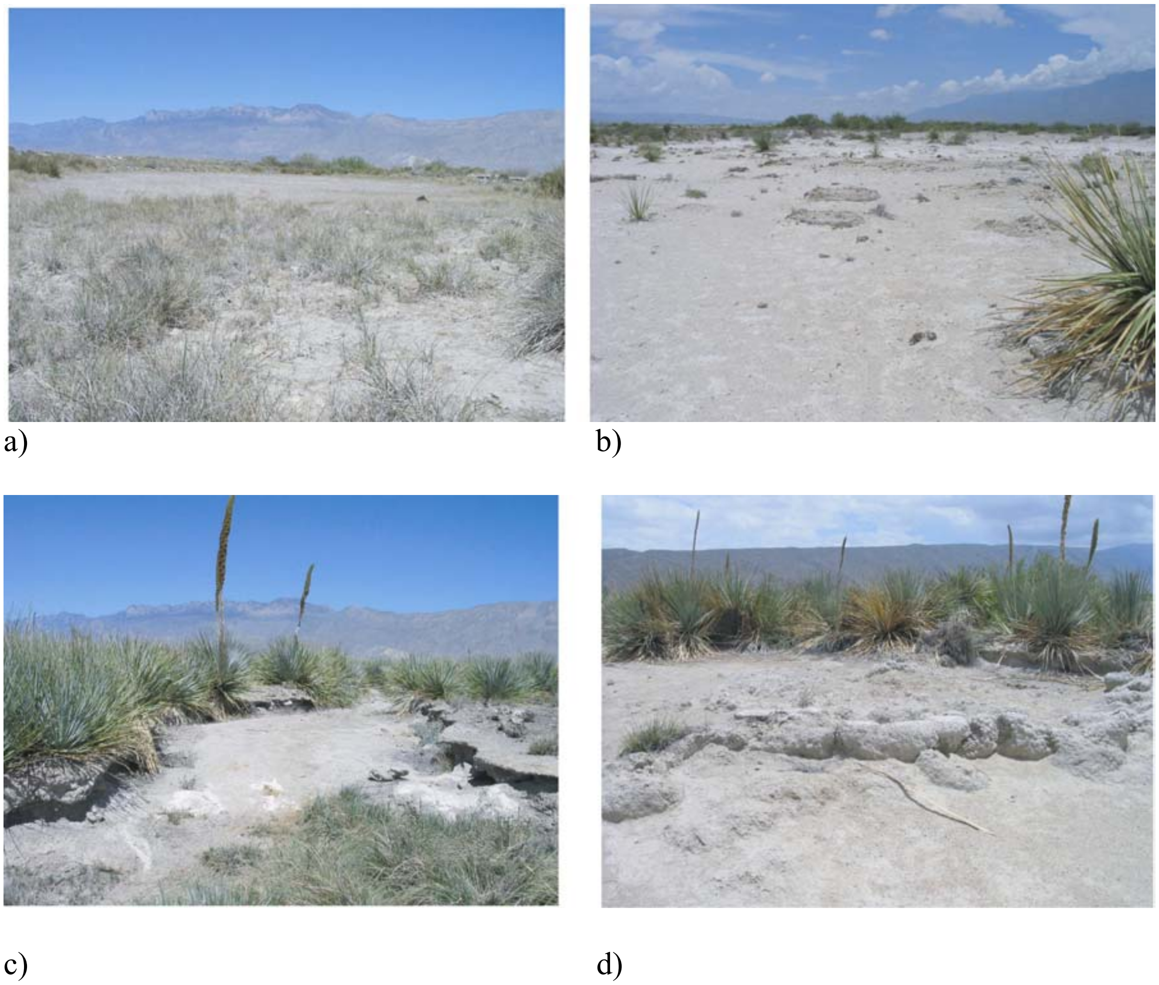

Figure 5.2 Sampled facies types a) large pool at Laguna Chara b) playa at Playa c) travertine-lined channel at Channel 3 and d) small pool at Jacuzzi pool.

travertine. Feral horses were observed to walk through the area throughout the course of the field study and hoof prints were abundant in the field site.

Laguna Chara pool (Figure 5.2a) was flat bottomed, with gently sloping sides in the western edge of the lake deposit and vertical travertine ledges approximately 1 m tall on the northeastern edge of the lake. The pool deposit was measured at 50 m in width and 85 m in length. The lake had three outlets: a small outlet in the eastern end of the lake deposit led to a narrow channel connecting it to the Posa Regresando, a larger outlet on the northeastern portion which led to Marsh 1 and connected Laguna Chara to Laguna Garabatal, and a third outlet in the northwestern portion of the pool deposit leading to Marsh 2 and connecting Laguna Chara to the Posa Terminal. The sediment at the bottom of Laguna Chara was moist, and a pit dug in the center of the lake showed that the water table was only 110 cm from the ground surface. Low-lying grass grew in the center of the pool deposit and a cluster of sedges grew in the northeastern portion, partially obscuring the opening to Marsh 1.

The pool deposit from Laguna Garabatal was 40 m by 90 m, and located in the northeastern portion of my field site. This pool exhibited variable substrate at the pool deposit's bottom. The northwestern portion of the pool consisted of travertine covered with a thin layer, 1-3 cm, of gastropod shells and carbonate sand. The stromatolite ledge, approximately 30 cm wide and had well-developed tooth-like form. This transitioned into low-lying mound stromatolites in the northern edges of the pool, with continued facies of travertine lined bottom and thin carbonate sand and shell layer covering it. Within this area, a well-developed outlet existed, which led to a concave inner pool area containing another outlet, the springhead, by way of a travertine-lined inner channel.

The remainder of the Laguna Garabatal pool had thicker layers of carbonate sand and gastropod shells with some soil development and vegetation. Vegetation included yucca, sedges, and grass. The southern portion of the pool sloped gradually upward in elevation to connect with Marsh 1 to the south and southeast. In the northwest, Laguna Garabatal connected to a small pool ringed by well-developed stromatolite mounds, named Jacuzzi (Figure 5.2d) for its proximity to the larger pool. To the northeast, Laguna Garabatal connects with Channel 1 and to the southeast it connects with Channel 2. Between Channel 1 and 2, the channel is poorly developed and this area looks as if it may have had a hydrologic connection to the Lobe during times of high water levels.

5.1.2 *Small Pools*

Small pools were defined as <50 m wide, flat-bottomed landforms. These deposits generally had carbonate sand bottoms with variable amounts of soil development and grass growing in the pool deposit's center. The edges of the two smaller pools identified had gently sloping sides and tufa mounds at their edges. The tufa mounds, <20 cm, were much smaller than those seen in the large pools. Small pools identified included Posa Terminal, the Posa Regresando, Pool 1, Pool 2, the Bee pool, the Jacuzzi, and the Lobe.

The Posa Terminal pool deposit contained stromatolite mounds at its edges and connected to the Marsh 2 area to the south. The center of the pool deposit was heavily overgrown with trees and other vegetation, making sampling along transects impossible. The pool was at least a meter deep and approximately 20 m by 13 m in extent.

The extent of the Posa Regresando pool deposit is difficult to ascertain because of subsidence in the area around it. The steep walls at the source of the spring are as much as 3 m in depth. The original funnel shape of the pool is barely maintained, and the sediment in the area was soaking wet and treacherous to sample. The area was also heavily overgrown by patchy, but thick clumps of sedges and some grass. A small seep flowed out the ground at no particular location, and flowed into a small pool that looked like it was the outflow for the pool, when the pool reversed itself. Dozens of fish were in this pool.

5.1.3 *Marsh*

Marsh deposits contained a hummocky terrain approximately 0.5 m in depth, which gave no clear indication of the direction in which water traveled. These areas were delimited, but no name was given as they were not sampled.

5.1.4 *Channels*

Travertine-lined channels (Figure 5.2c) were about 10 m wide and up to 1m high with a thin layer, <10 cm thick, of dried, carbonate mud at the bottom of the channel. At the top of the channel, the travertine had overhanging ledges. These channels connected to larger pools. Channels identified were Channel 1, Channel 2, and Channel 3.

5.1.5 *Playa*

An area of dense gastropod shells, with low-lying concentrically placed travertine mounds was found in the northern portion of the field site (Figure 5.2b). The travertine ridges formed at the water's edge, and the deposits created from varying water levels in the playa area had caused the concentric rings of travertine to form. This region was topographically higher than the pool deposits. It contained thin, <5 cm thick, unconsolidated sediment, which rested on flat limestone. In defining the playa area, I recorded the extent of the high density of gastropod shells in this elevated plain, called Playa.

5.1.6 *Springheads*

I tried to identify possible sources for springs in the area. I sampled at the source of one small, active seep (sampling site S1) (Figure 4.1), which ran into a small pool. This living pool looked like it was the point of collapse for a subterranean channel. This included locating and sampling the walls of inflows from which water may have entered or left the pools from an underground source when the system was still active.

5.2 Gastropod Taxonomy

All but two species of gastropods recovered in samples from this study are hydrobiids. Of the remainder, one is a pulmonate, *Physa virgata*, and the other is a terrestrial gastropod, *Gastrocopta pentodon.* The identifying features of shells (Taylor, 1966, Hershler, 1985) for the collected gastropods are described below. Anatomical features of gastropods are not discussed, except for the presence of ovoviviparity in so far as it relates to sexual dimorphism of the shell within species. Because necrolysis destroys the body of the gastropod soon after death, gastropod anatomy is not a useful tool for analyzing subfossil shells.

5.2.1 *Coahuilix*

Coahuilix hubbsi (Plate 1a) has a colorless, thin, translucent, planispiral shell, which is 1.5 mm long. The shell is dextrally coiled, with 2.5 whorls in a shell, separated by pronounced sutures. The aperture is inclined 30 degrees to the coiling axis and the growth lines are more pronounced near the aperture of the shell (Hershler, 1985).

C. hubbsi is oviparous, an egg layer, and the species is sexually dimorphic, with the width of the female shells being wider than the male shells (Hershler, 1985). This species is endemic to Cuatro Cienegas (Taylor, 1966). *Coahuilix landyei*, though reported as sympatric with *Coahuilix hubbsi* in springhead microhabitats (Hershler, 1985), was not seen in the one sample that produced specimens of this genus. However, due to the fragile nature of the *Coahuilix* shell, it is acknowledged that some *Coahuilix landyei* may have been present but not preserved in the sample. It is possible that the shell of *Coahuilix hubbsi* is more robust.

5.2.2 *Cochliopina*

The shell of *Cochliopina milleri* (Plate 1b) is white, planispiral to broadly conical, and 1-2 mm in length. It has rounded whorls with deep sutures, a circular aperture, pronounced lirae, and straight axial growth lines. This species is highly variable in the closeness and direction of its coil (Hershler, 1985).

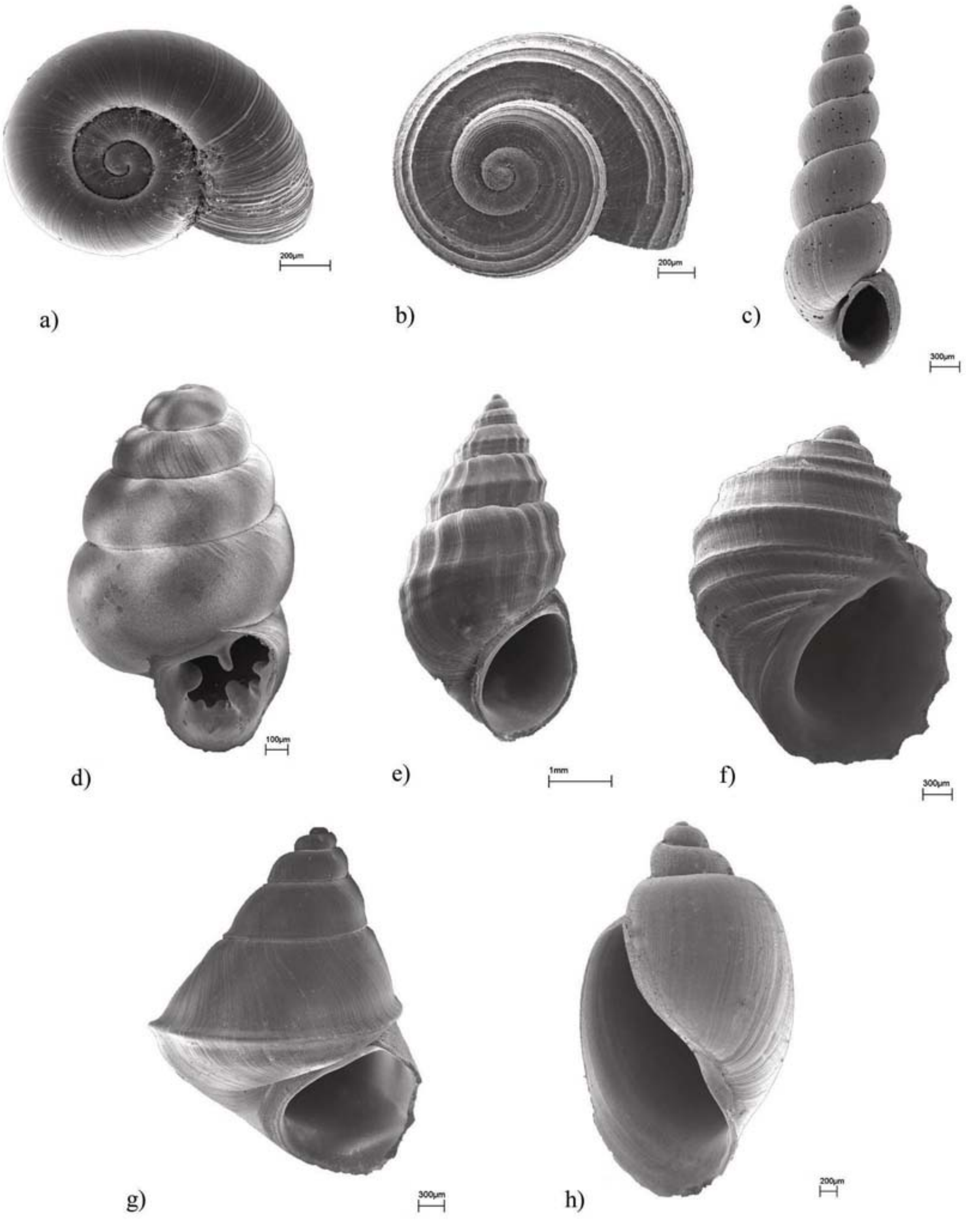

Plate 1 Gastropods collected in field site a) *Coahuilix hubbsi*, b) *Cochliopina milleri*, c) *Durangonella coahuilae*, e) *Mexithauma quadripaludium*, f) *Nymphophilus minckleyi*, g) *Physa virgata*, and h) *Gastrocopta pentodon*.

Sexual dimorphism has been reported in this species, with females having wider, longer shells (Hershler, 1985). *Cochliopina milleri* is also endemic to Cuatro Cienegas (Taylor, 1966). The other species of *Cochliopina* found in Cuatro Cienegas, *C. riograndensis* was not found and is not believed to have been in my field area since its occurrence was known to be restricted to the southeastern portion of the basin during the 1980's (Hershler, 1985).

Cochliopina was originally assigned to the Hydrobiidae family, most closely related to *Cochliopina francesae* (Guatemala) (Taylor, 1966). However, recent molecular studies have suggested that the Cochliopidae belong in their own, separate family (Wilke et al., 2001).

5.2.3 *Durangonella*

Durangonella coahuilae (Plate 1c) has a colorless, thin, translucent shell, which is turriform in shape and 3-4 mm in length. It is dextrally coiled, with 5-8 round whorls, the shell is smooth, and the aperture is crescent-shaped with no apertural lip (Hershler, 1985).

D. coahuilae is ovoviviparous and sexually dimorphic, with female shells having fewer whorls and smaller, wider shell than males (Hershler, 1985). *D. coahuilae* is endemic to Cuatro Cienegas (Taylor, 1966). Several species of *Durangonella* were postulated to exist by Taylor (1966), and two species of *Durangonella* have been described, *D. coahuilae* and *D. seemani* (Hershler, 1985). In addition, four other species of *Durangonella* are known from the shell only (Hershler, 1985).

5.2.4 *Gastrocopta*

The shell of *Gastrocopta pentodon* (Plate 1d) is colorless, translucent, beehive-shaped, and is approximately 2 mm in length. It is dextrally coiled with five, rounded whorls and deep sutures. The shell is smooth and growth lines are curved. The aperture is flared at the end and ovate-lunate in shape. An apertural lip is present. Large, well-developed apertural teeth include one large parietal tooth, one large columellar tooth, and one large palatal. On either side of the large palatal tooth, there are two smaller apertural teeth of identical size.

This species is a terrestrial gastropod found living at high elevations in the southwestern United States, namely New Mexico (Ashbaugh and Metcalf, 1986). Its high morphologic variability is believed to be part of an ecophenotypic continuum with *Gastrocopta pentodon* on one end, phenotypically expressed in dry open areas, and the *Gastrocopta tappaniana* phenotype expressed in moister areas (Ashbaugh and Metcalf, 1986). In samples collected from the field site, the *Gastrocopta pentodon* phenotype was observed.

5.2.5 *Mexipyrgus*

Mexipyrgus carranzae (Plate 1e) has a thick, conical shell, which varies in size from 6-7 mm. The shell is white with dark brown color banding. Sculpture begins at the third whorl, where spiral chords predominate (Hershler, 1985). Axial ribs dominate in the fourth whorl and later noded ribs may be prominent (Hershler, 1985). The shell is elongate and conical with up to seven dextrally coiling whorls.

The tip of the shell of a living female *Mexipyrgus* is pink because the pink reproductive organs of the female shows through the translucent shell. This coloration, along with the body, disappears after death. *Mexipyrgus* is also ovoviviparous and sexually dimorphic, with females shells having larger, wider shells and more prominent sculpture (Hershler, 1985). *Mexipyrgus carranzae* is restricted to the valley of Cuatro Cienegas (Taylor, 1966).

The revision of nominal *Mexipyrgus* species is employed in my taxonomical analysis. Eight different species of *Mexipyrgus* were originally described in Cuatro Cienegas (Taylor, 1966) based on color banding of the shell. This classification was later revised to one species, *Mexipyrgus carranzae*, on the basis of anatomical similarities (Hershler, 1985). Although *Mexipyrgus* taxonomy is still in flux, I have used Hershler's (1985) revision as the basis for my study.

5.2.6 *Mexithauma*

Mexithauma quadripaludium (Plate 1f) has a thick, globose shell, and is 6-7 mm in length. The shell has an elliptical aperture and it is dextrally coiled with prominent spinal cords (Hershler, 1985). The inner lip of the shell is thickened, while the outer lip is thin.

Mexithauma is ovoviviparous and sexually dimorphic, with females having a wider aperture (Hershler, 1985). In life, the shell may be covered with a thick layer of diatoms. This taxon is endemic to Cuatro Cienegas (Taylor, 1966).

5.2.7 *Nymphophilus*

The shell of *Nymphophilus minckleyi* (Plate 1g) is white, thick, trochoid, and 5-6 mm in length. It is dextrally coiled with six flattened to slightly rounded whorls and possesses a strong spinal keel near the sutures past the fourth whorl. The aperture is roundly lunate, the post-embryonic growth lines are coarse and wavy, and the sutures are strongly indented (Hershler, 1985).

Nymphophilus minckleyi is an egg layer, and sexual dimorphism is not pronounced (Hershler, 1985). *Nymphophilus minckleyi* is endemic to the valley of Cuatro Cienegas (Taylor, 1966).

The other described species of *Nymphophilus*, *Nymphophilus acarinatus* was not present in my samples. Its distribution was restricted to the southeastern portion of the basin in the 1980's, and it did not share habitat with *Nymphophilus minckleyi* (Hershler, 1985).

5.2.8 *Physa*

Physa virgata (Plate 1h) has a very thin, white shell, succiniform shape, and is 4 mm in length. The shell has four rounded whorls with prominent sutures. The aperture is narrowly ovate-lunate with an apertural lip.

Physa is a pulmonate with the ability to self-fertilize (Dillon, in press). *Physa virgata* is not endemic to Cuatro Cienegas, and it is common in North America (Taylor, 1966).

5.3 Gastropod Abundance Distribution and Contour Maps

Spatial distribution analysis using GIS software showed that gastropod shell abundance was clustered and non-random. This is in agreement with the observations of strong habitat preferences exhibited by living populations of these gastropods described in section 3.2. Contouring freshwater gastropod taxa within the study area gave a good overview of their spatial distribution. The overall distribution of each freshwater taxon is discussed below. In addition, a reconstructed hydrological map of the area is made using soft sediment distribution as a proxy for historic water flow rates.

5.3.1 *Total Gastropod Density*

A contour map of the total number of gastropods per kg (Figure 5.3) shows that the highest gastropod density, 700-800 gastropods/kg, was found in the southeastern portion of Laguna Chara, near the lake's connection to an unlined channel that leads to Posa Regresando. Gastropod density is also high in the southern portion of Laguna Garabatal, where it connects to Channel 2. These areas of high gastropod abundance are both in areas within large pools that meet a channel outlet. This could represent a trend in gastropod distribution, but the evidence is inconclusive.

5.3.2 *Coahuilix*

No contour maps of *Coahuilix* were made because this taxon was only found in one sample. However, an explanation of the physical properties of the sampling location are discussed to give further background into the type of habitat where *Coahuilix* may be found in.

Coahuilix was found in the black mud of the currently active springhead (S1) (Figure 4.1), which consisted of a small seep that flowed into the opening of an underground channel. Gastropods were dense in the black mud immediately around the source flow and the first sample yielded 58 *Coahuilix* shells. However, subsequent samples taken from the area around the seep yielded no more *Coahuilix* shells, suggesting that *Coahuilix* was restricted to the very small area within 15 cm of the outflow. The black mud was fine-grained and was very different from the white, carbonate and copropel sediments present at the bottom of the sampled pools and channels.

5.3.3 *Cochliopina*

Cochliopina appears to be most abundant at the edges of pools, based on its distribution on the contour maps (Figure 5.4, 5.5). The occurrence of *Cochliopina* was rare compared to the abundance of other gastropod taxa. The highest total density was only 20 gastropods/kg sample with the highest occurrence of *Cochliopina* near the edges of Pool 2 and the edges of the larger pools such as Laguna Garabatal and Laguna Chara (Figure 5.1). The total relative density of *Cochliopina* was never above 20% and it is interesting to note the similar distribution pattern seen in both total and relative density of *Cochliopina*. This distribution of *Cochliopina* disagrees with Taylor's (1966) observation of *Cochliopina* microhabitat in soft sediment of large pools, but is in keeping with Hershler's (1985) observation of *Cochliopina* on vegetation, which is more prevalent at the edges of pools.

5.3.4 *Durangonella*

The distribution of *Durangonella* (Figure 5.6, 5.7) suggests that it is found in both small and large pools, tending to be more abundant near the edges of pools. The distribution of *Durangonella* density and relative density is similar (Figure 5.6, 5.7). The highest density of *Durangonella*, 150 gastropods/kg, is found in the southwest portion of Laguna Garabatal where it connects with Channel 2. This was also an area of high total gastropod density in all taxa. The highest relative abundance of *Durangonella* was 80% in a sample from Pool 2, though the density of *Durangonella* mostly ranged from 10-20% in areas where it was common. The distribution maps of *Durangonella* suggest that it is an uncommon gastropod and this is in agreement with previously reported work, though *Durangonella*'s documented preference for soft substrate (Hershler, 1985; Taylor, 1966) is not supported by the contour data.

5.3.5 *Mexipyrgus*

Contour maps of *Mexipyrgus* distribution (Figures 5.8, 5.9) indicate that 1) there was a low density of *Mexipyrgus* in Laguna Garabatal, 2) that the smaller pools and the channel contained an intermediate number of *Mexipyrgus* and 3) that the playa area and Laguna Chara contained the highest percentages of *Mexipyrgus*. *Mexipyrgus* distribution correlates with the expected abundance of soft sediment, given that high water flow rates scour away soft sediment and low water flow rates allow soft sediment to accumulate. Relative abundance of *Mexipyrgus* is low in the center of Laguna Garabatal, which is also the location of a previously active springhead and an outflow channel. Laguna Garabatal may have had a low amount of soft substrate buildup. This can still be observed in areas of the lake during my field study, where the hard travertine bottom was covered only by a thin layer of soft substrate. Laguna Chara and the playa area have the highest relative abundance of *Mexipyrgus* and are also the areas where water flow was most likely to be low. The strong correlation of *Mexipyrgus* with soft substrate as well as its high abundance in pools of Cuatro Cienegas is in agreement with previous observations of *Mexipyrgus* ecology (Taylor, 1966, Hershler, 1985).

It is interesting to note that the northwest corner of Laguna Garabatal, which contained a very high density of *Mexipyrgus*, looked similar to and was nearly at the same elevation as the playa. This region may have been connected to the playa during times of higher water level. Even though both areas had only a thin layer of soft sediment, their higher topography would have shielded these areas from strong water currents. A ring of low-lying stromatolites delimited the northern edge of Laguna Garabatal. These were the same type of concentrically grown, low-lying stromatolites that occurred within the playa area.

5.3.6 *Mexithauma*

Mexithauma is moderately abundant in all sampling areas, with the conspicuous exception of Laguna Chara (Figure 5.10, 5.11). *Mexithauma* exhibits the highest total abundance in the Lobe pool and in the southern portion of the Playa. *Mexithauma* reaches a density of approximately 160 shells/kg, although its average density ranges from 20-40 shells/kg.

The contour map of relative abundance also shows the same pattern. Again, *Mexithauma* is conspicuously rare in Laguna Chara, but continues to show a strong presence throughout the rest of the field site. In general, *Mexithauma* does not show a strong distributional trend towards being at the edges of pools, where it has been documented with hard, travertine substrate (Taylor, 1966, Hershler, 1985). However, the presence of a high number of *Mexithauma* in Laguna Garabatal suggests that *Mexithauma* may be sharing a microhabitat with *Nymphophilus*, which is also documented to prefer hard substrate (Taylor, 1966, Hershler, 1985).

5.3.7 *Nymphophilus*

Contour maps of *Nymphophilus* distribution (Figures 5.12, 5.13) are opposite to the distribution of *Mexipyrgus*. The highest relative abundance of *Nymphophilus*, 80-100%, occurs in the center of Laguna Garabatal, which is also the location of the active springhead. *Nymphophilus* percentage is also high in the southwest corner of Laguna Garabatal, in samples from the Lobe and the Bee pool, as well at the edges of Laguna Chara. *Mexipyrgus* and *Nymphophilus* were the two most common gastropods in the field site. The highest density of *Mexipyrgus*/kg was in the range of 250-400, while the highest density of *Nymphophilus* was almost twice as high at 600-700 gastropods/kg. However, the high density of *Mexipyrgus* occurred in a broad area of Laguna Chara and the playa, while the high density of *Nymphophilus* only occurred in one small corner of Laguna Chara. Because this high density was determined from only one sample, the range 600-700 gastropod/kg of *Nymphophilus* density may be an anomaly. 400-500 gastropods/kg may be a better estimate of high *Nymphophilus* density, similar to that of *Mexipyrgus*. The observation of *Nymphophilus* as a common gastropod observed on travertine and aquatic vegetation (Taylor, 1966, Hershler, 1985) is consistent with the contour map distribution.

5.3.8 *Physa*

The highest density of *Physa* in my samples occurred in the southern portion of Laguna Garabatal, where it was present in the range of 20-25 shells per kg of sample (Figure 5.14). The highest percentage of *Physa* was found just to the east of Laguna Garabatal, though this was only in the range of 11-15% (Figure 5.15). *Physa* distribution shows a slight preference towards being distributed at the edges of pools, rather than at their center. However, it is not possible to make any strong correlations between *Physa* and a preferential microhabitat based on the contour map data and no microhabitat preference is documented for *Physa* in Cuatro Cienegas. It is possible that *Physa* does not have strong habitat preferences or that their low numbers prevent a clear preserved signal.

5.3.9. *Hydrologic flow evaluation*

A contour map showing the relative abundance of *Mexipyrgus* to the total abundance of *Mexipyrgus* and *Nymphophilus* was created (Figure 5.16). These two gastropods were chosen because they were the two most common taxa in the field areas and because their shells had similar physical characteristics. *Mexipyrgus* made up 60.0% of the composition of the bulk samples, while Nymphophilus made up 34.2%. Together, they accounted for 94% of the individuals in my sample data set. Both taxa had thick shells and were approximately the same size. Therefore, they were likely to be similarly affected by taphonomic processes. The two taxa also had opposing microhabitat preferences, with *Mexipyrgus* preferring soft substrate sediment and *Nymphophilus* preferring hard substrate or vegetation. Arrows indicating the direction of flow from an area of high relative *Mexipyrgus* abundance to areas of low relative *Mexipyrgus* abundance correlate well with Winsborough's (1990) description of water flow in the area. Because the two pools have such differing contour profiles, it is unlikely that post-depositional transport or erosion is responsible for *Mexipyrgus* distribution. The results of *Mexipyrgus* distribution contouring suggest that microhabitats are responsive to subtle hydrologic differences. Therefore, microhabitat analysis of gastropods can be used to detect hydrologic differences in pool deposits that appear geomorphically similar.

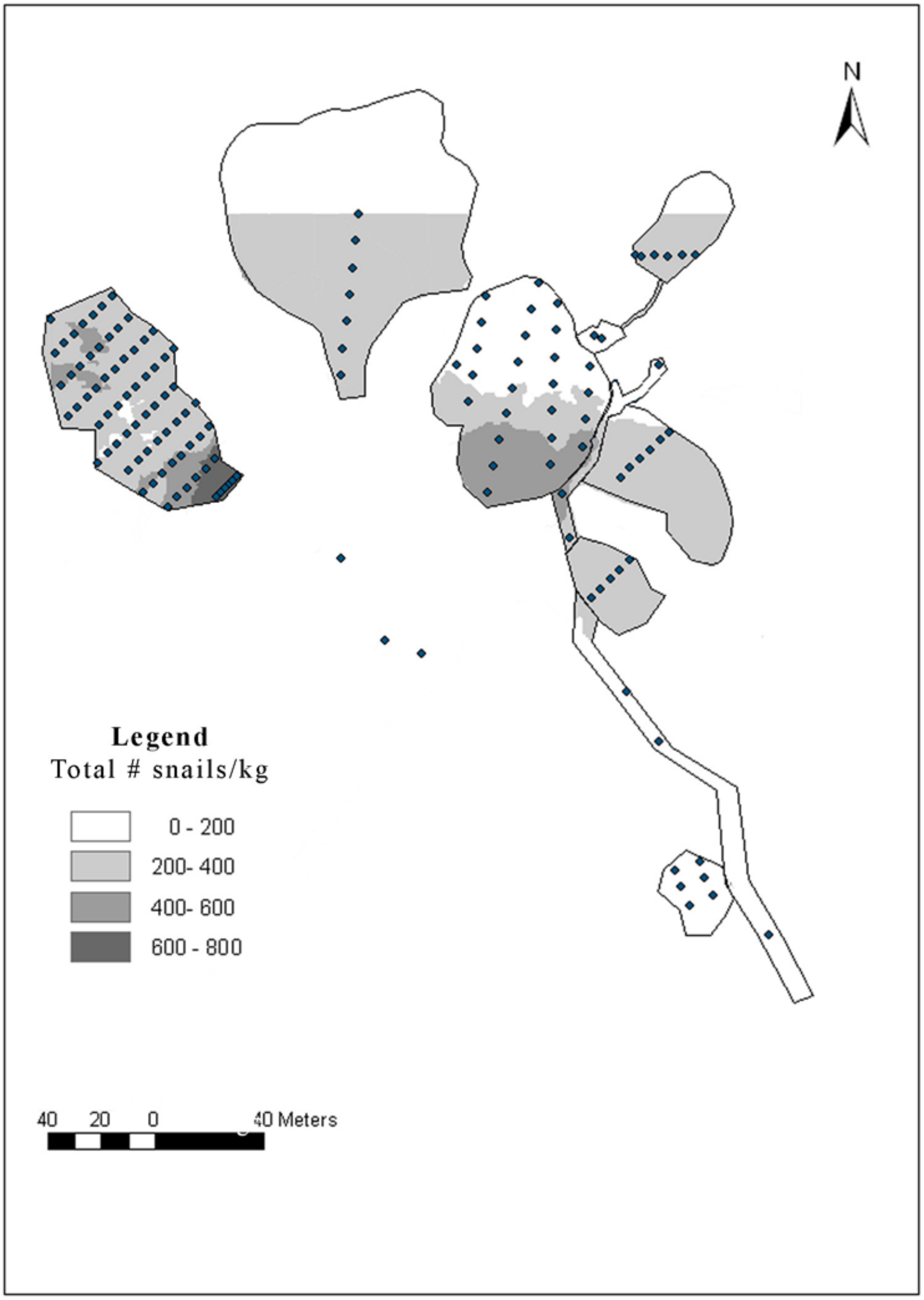

Figure 5.3 Contour map showing the distribution of the total number of snails in the field site. Diamonds represent sampling points.

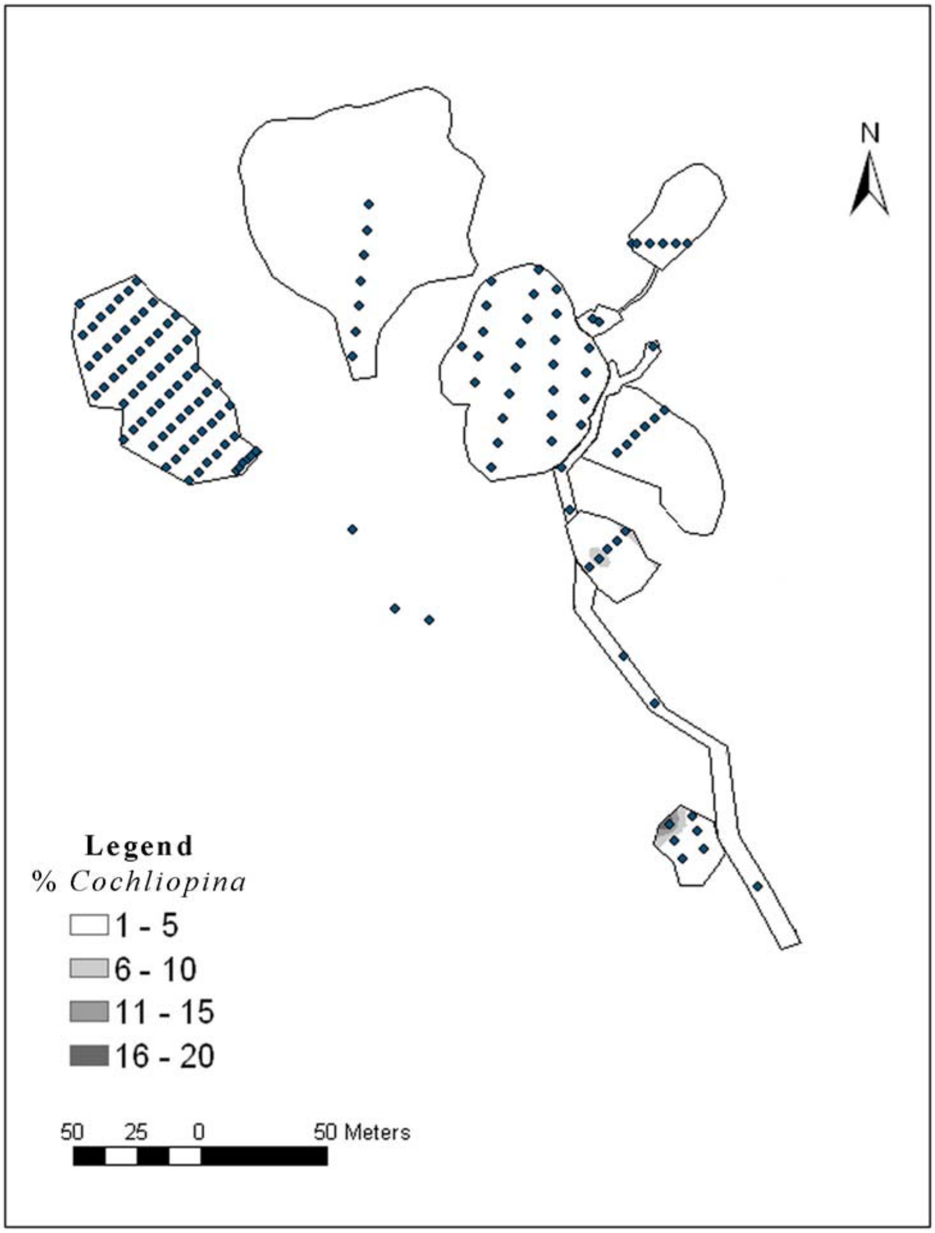

Figure 5.4 Contour map showing the distribution of *Cochliopina* in the field site. Diamonds represent sampling points.

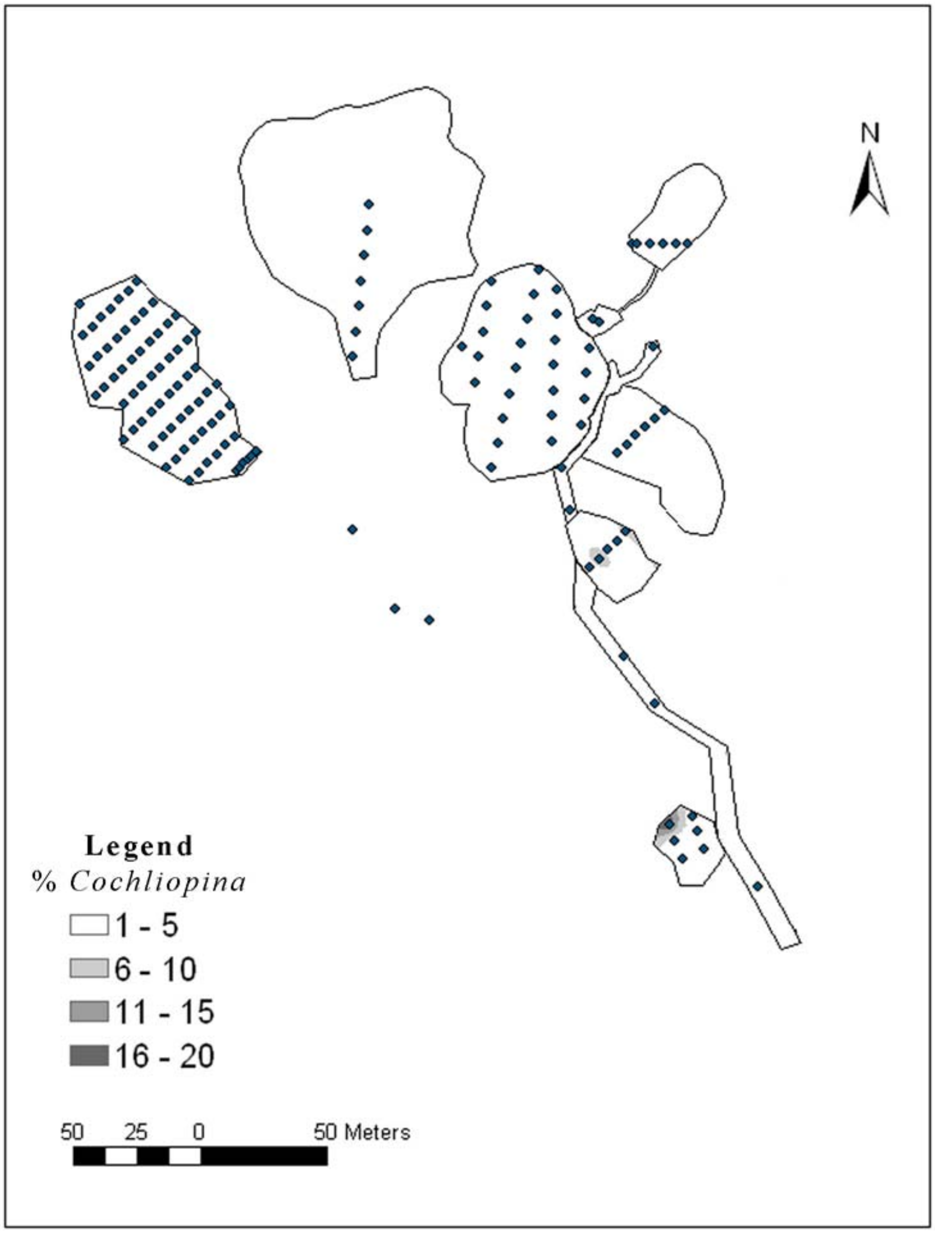

Figure 5.5 Contour map showing relative distribution of *Cochliopina* in the field site. Diamonds represent sampling points.

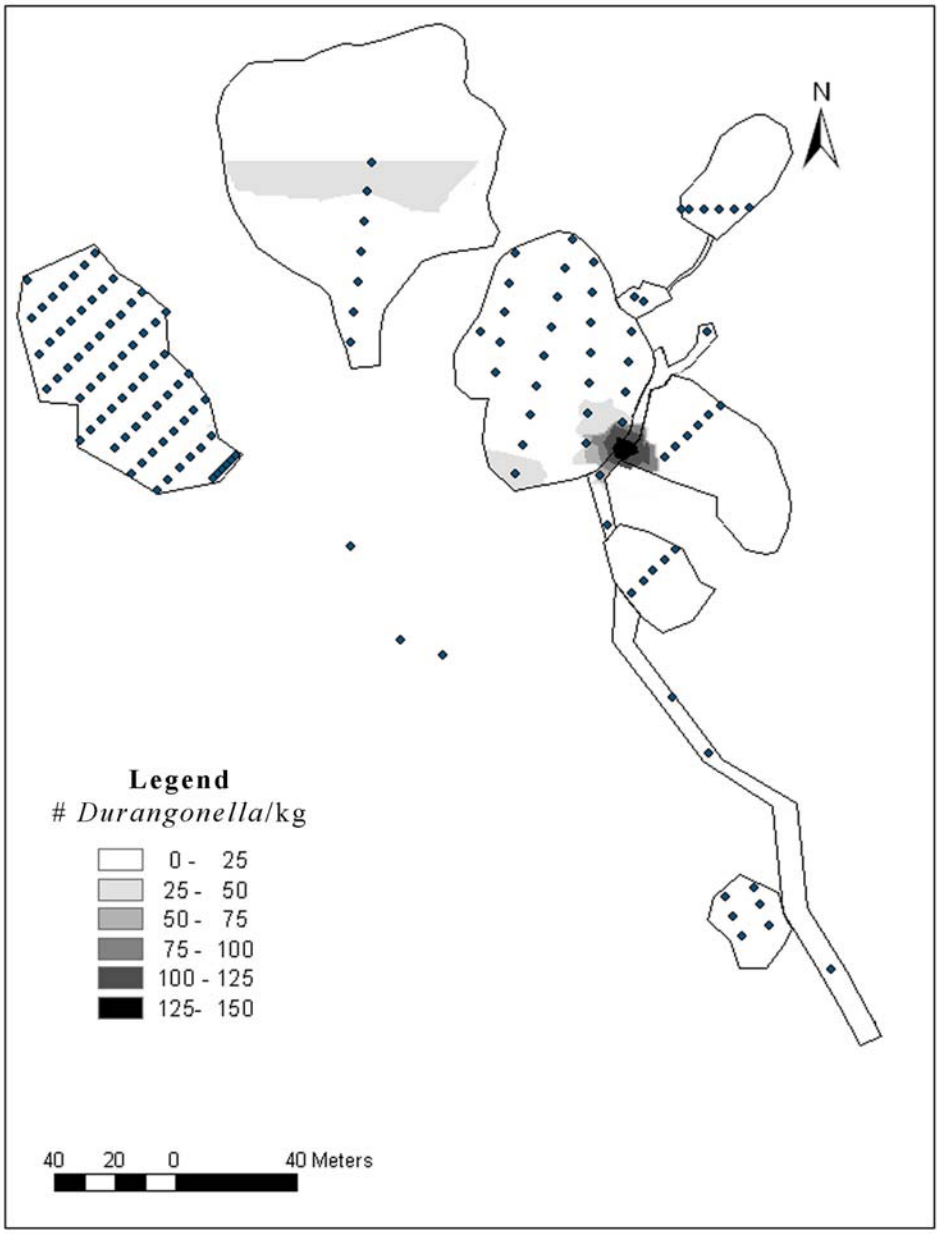

Figure 5.6 Contour map showing the distribution of *Durangonella* in the field site. Diamonds represent sampling points.

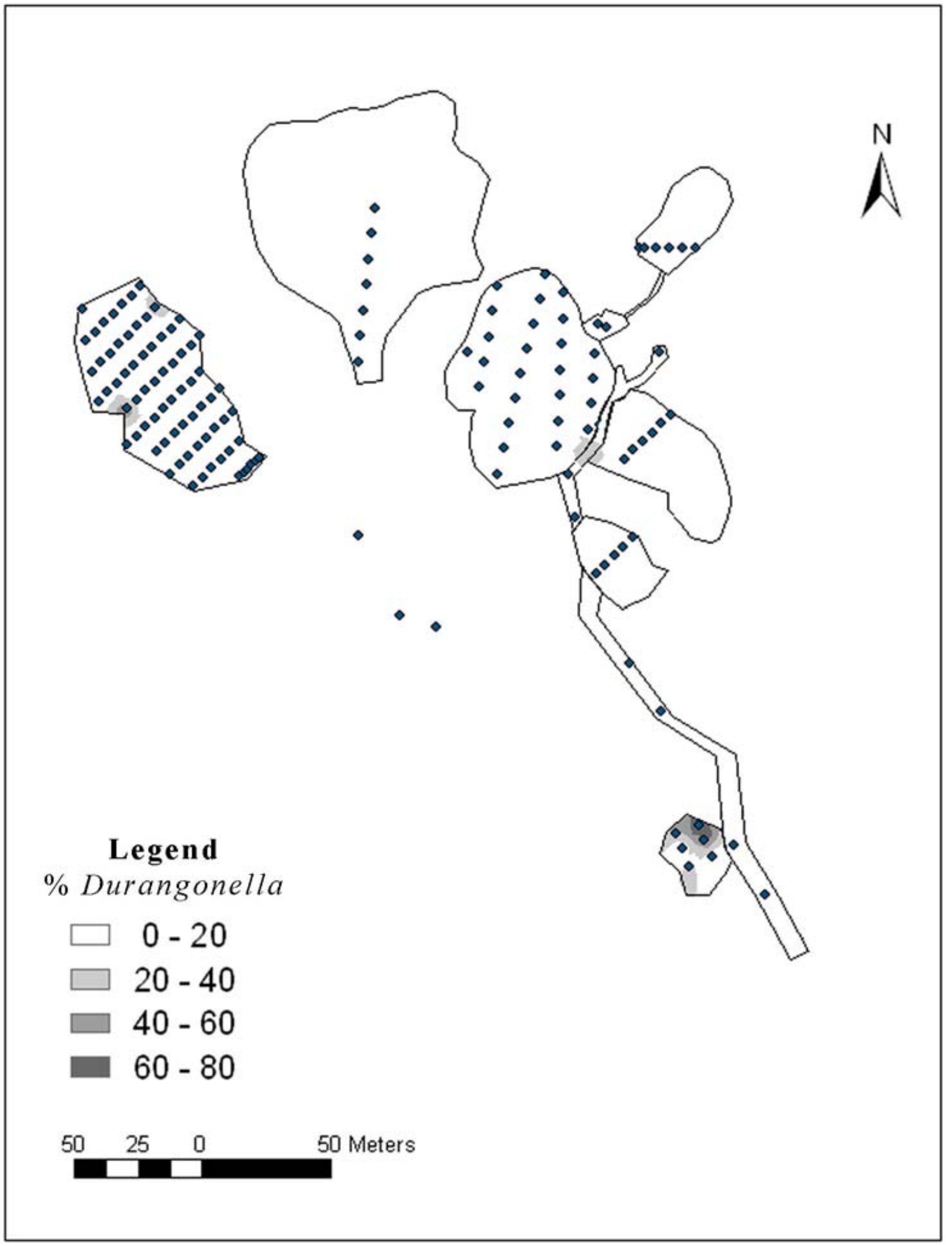

Figure 5.7 Contour map showing the relative distribution of *Durangonella* in the field site. Diamonds represent sampling points.

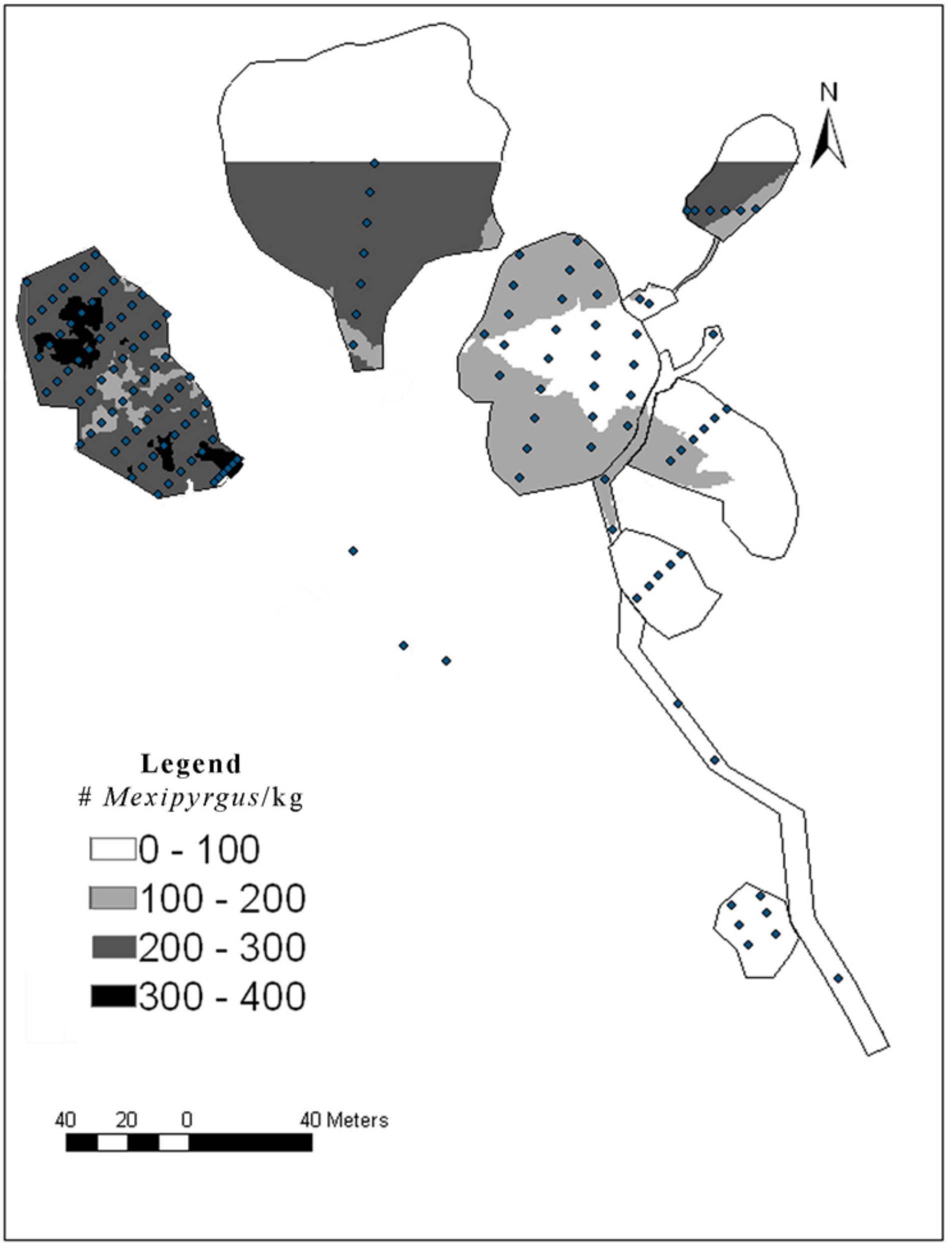

Figure 5.8 Contour map showing the distribution of *Mexipyrgus* in the field site. Diamonds represent sampling points.

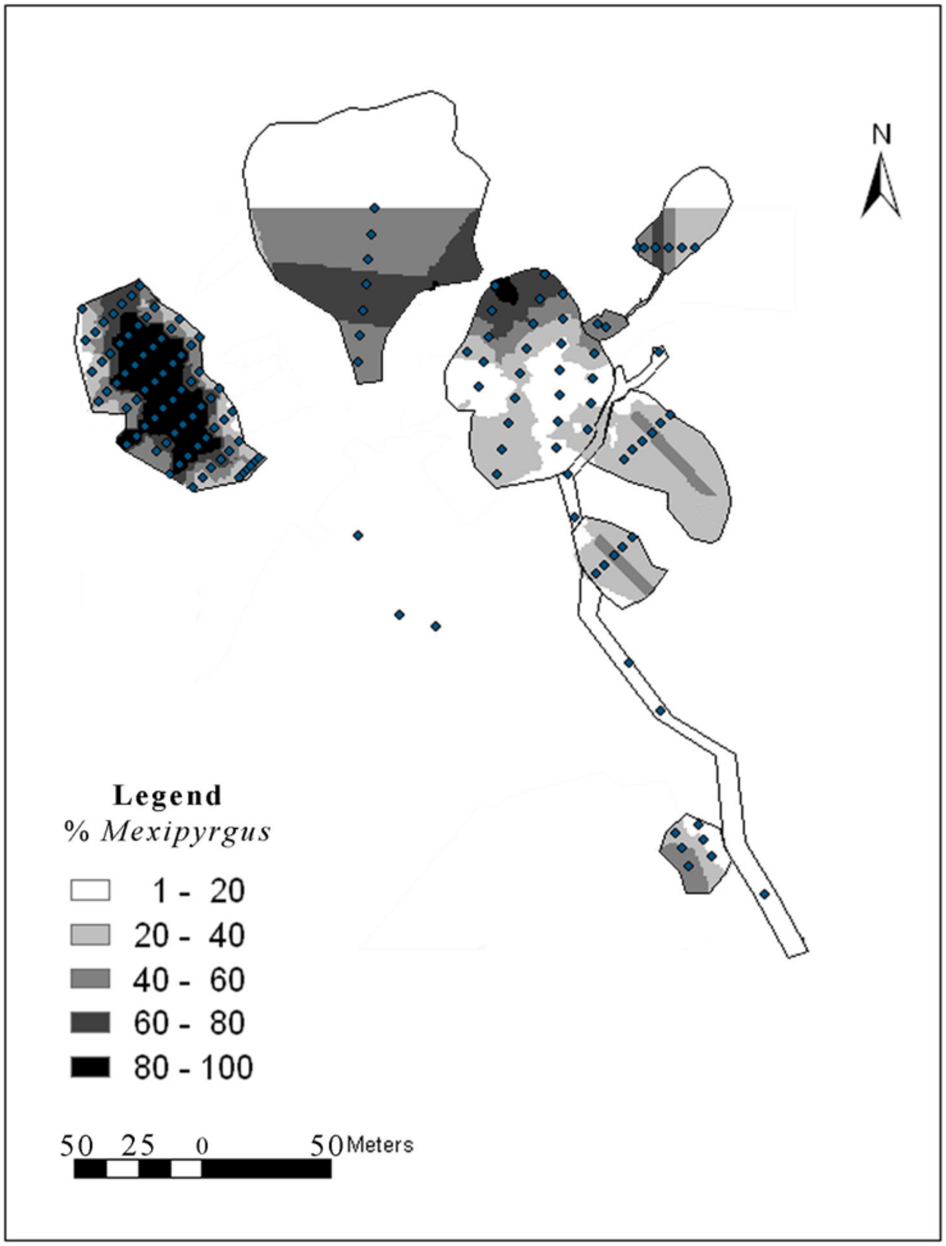

Figure 5.9 Contour map showing the relative distribution of *Mexipyrgus* in the field site. Diamonds represent sampling points.

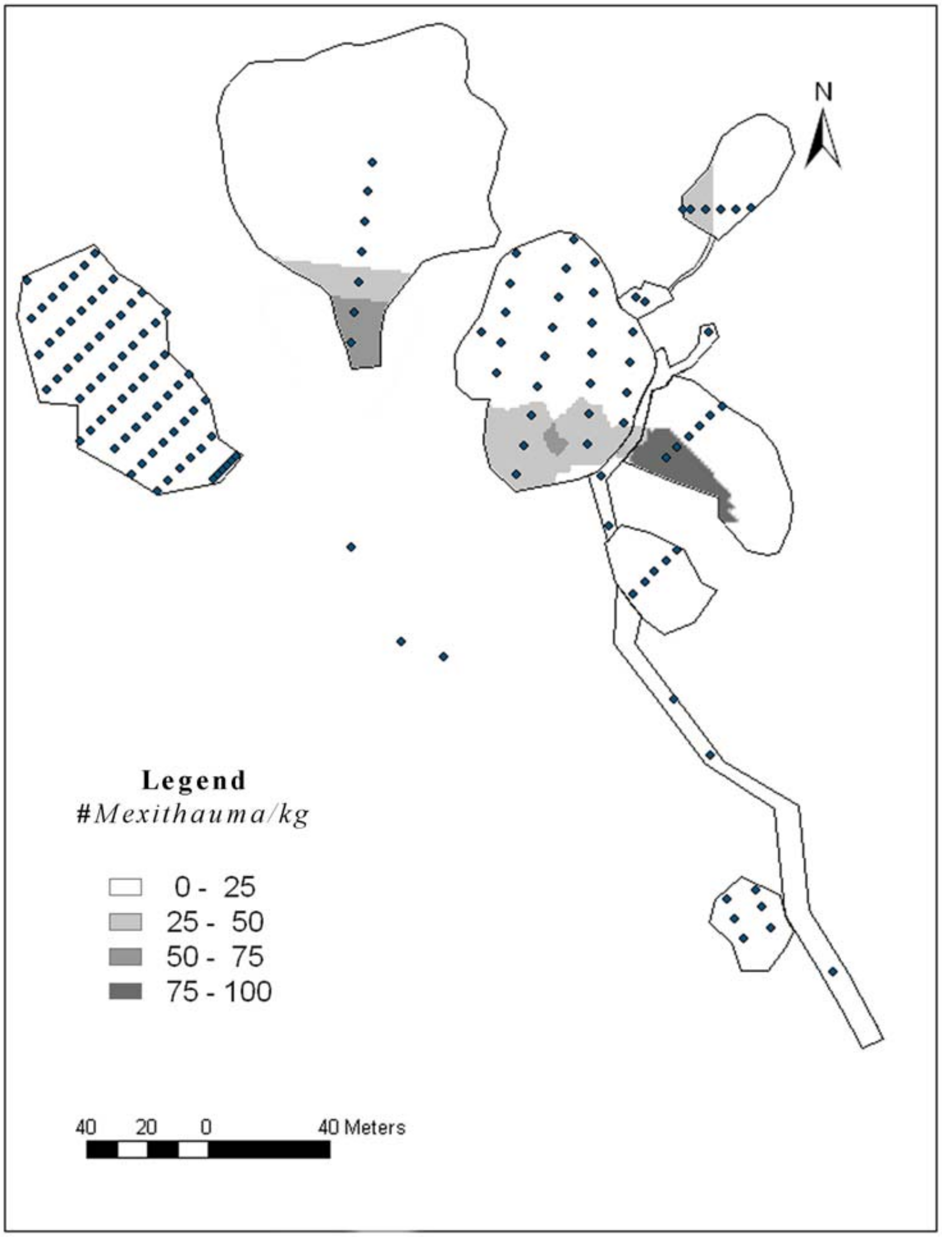

Figure 5.10 Contour map showing the distribution of *Mexithauma* in the field site. Diamonds represent sampling points.

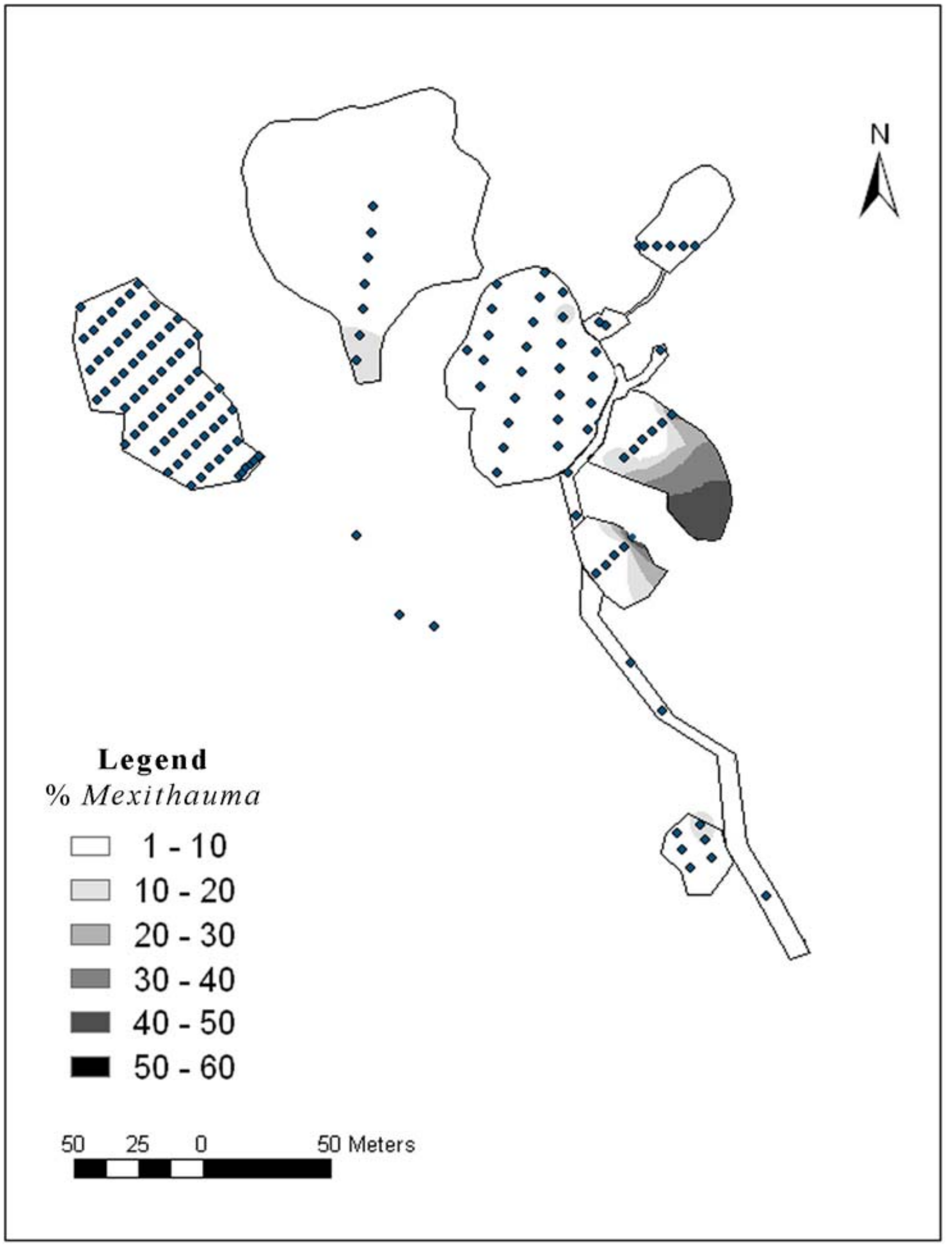

Figure 5.11 Contour map showing the relative distribution of *Mexithauma* in the field site. Diamonds represent sampling points.

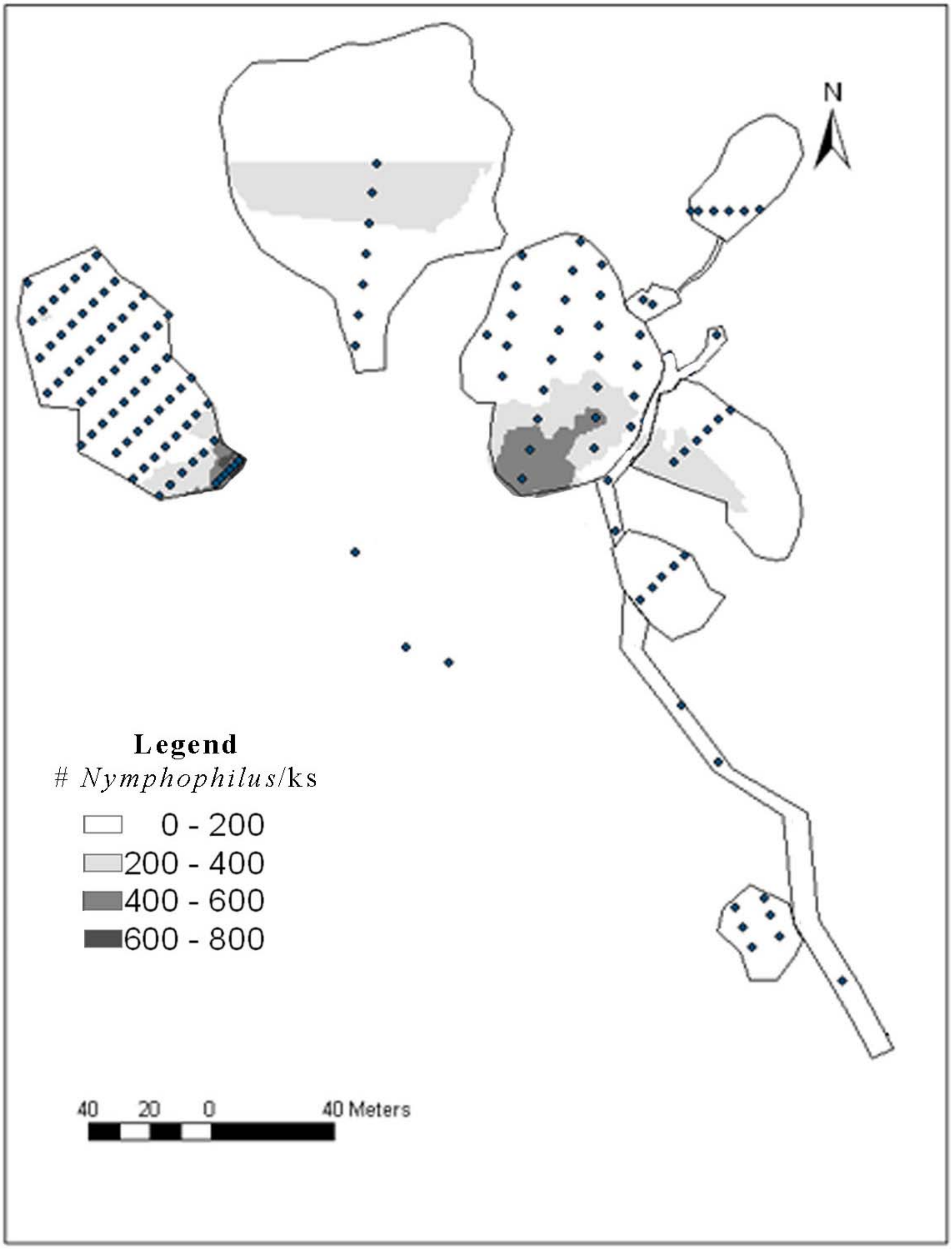

Figure 5.12 Contour map showing the distribution of *Nymphophilus* in the field site.

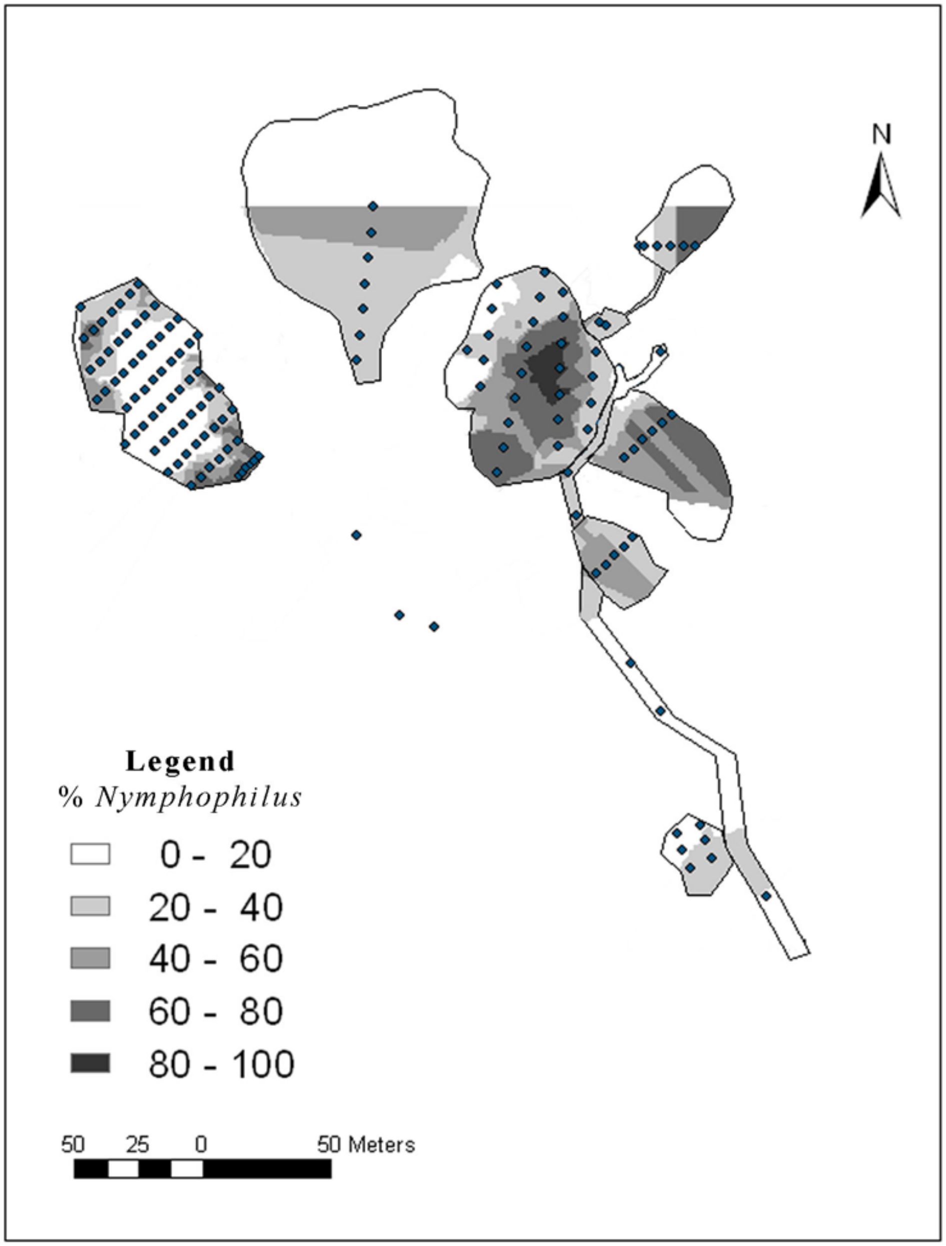

Figure 5.13 Contour map showing the relative distribution of *Nymphophilus* in the field site. Diamonds represent sampling points.

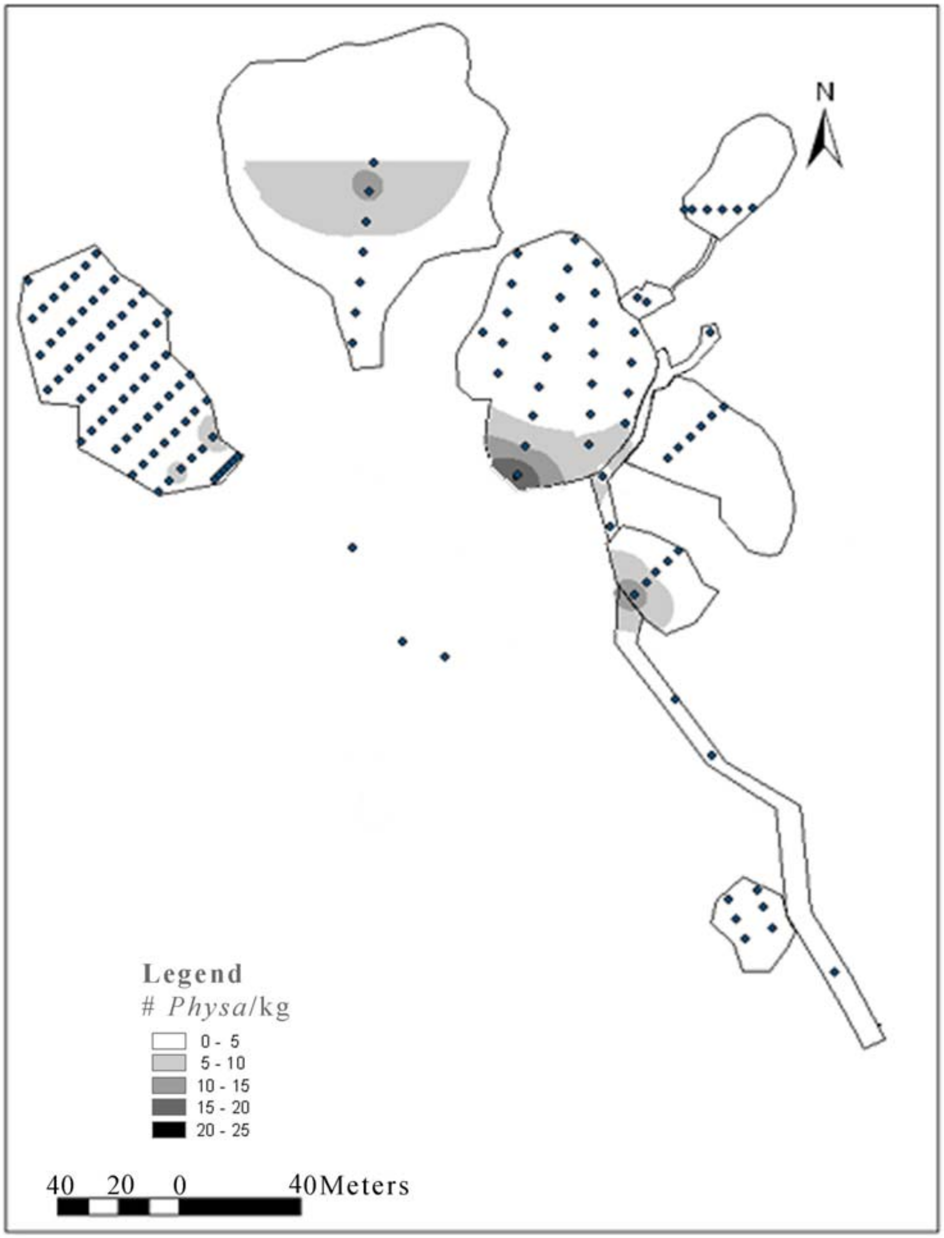

Figure 5.14 Contour map showing the distribution of *Physa* in the field site. Diamonds represent sampling points.

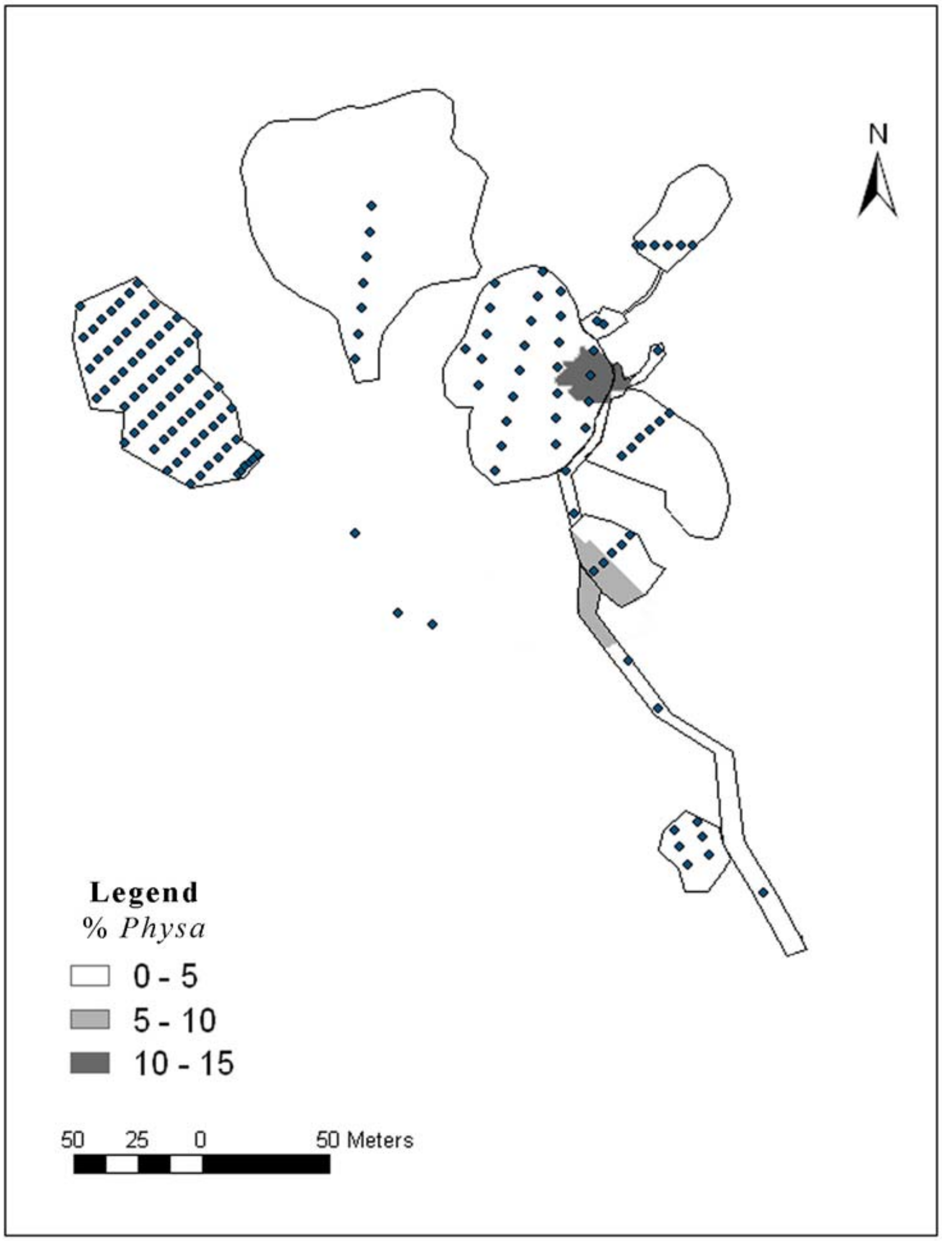

Figure 5.15 Contour map showing the relative distribution of *Physa* in the field site. Diamonds represent sampling points.

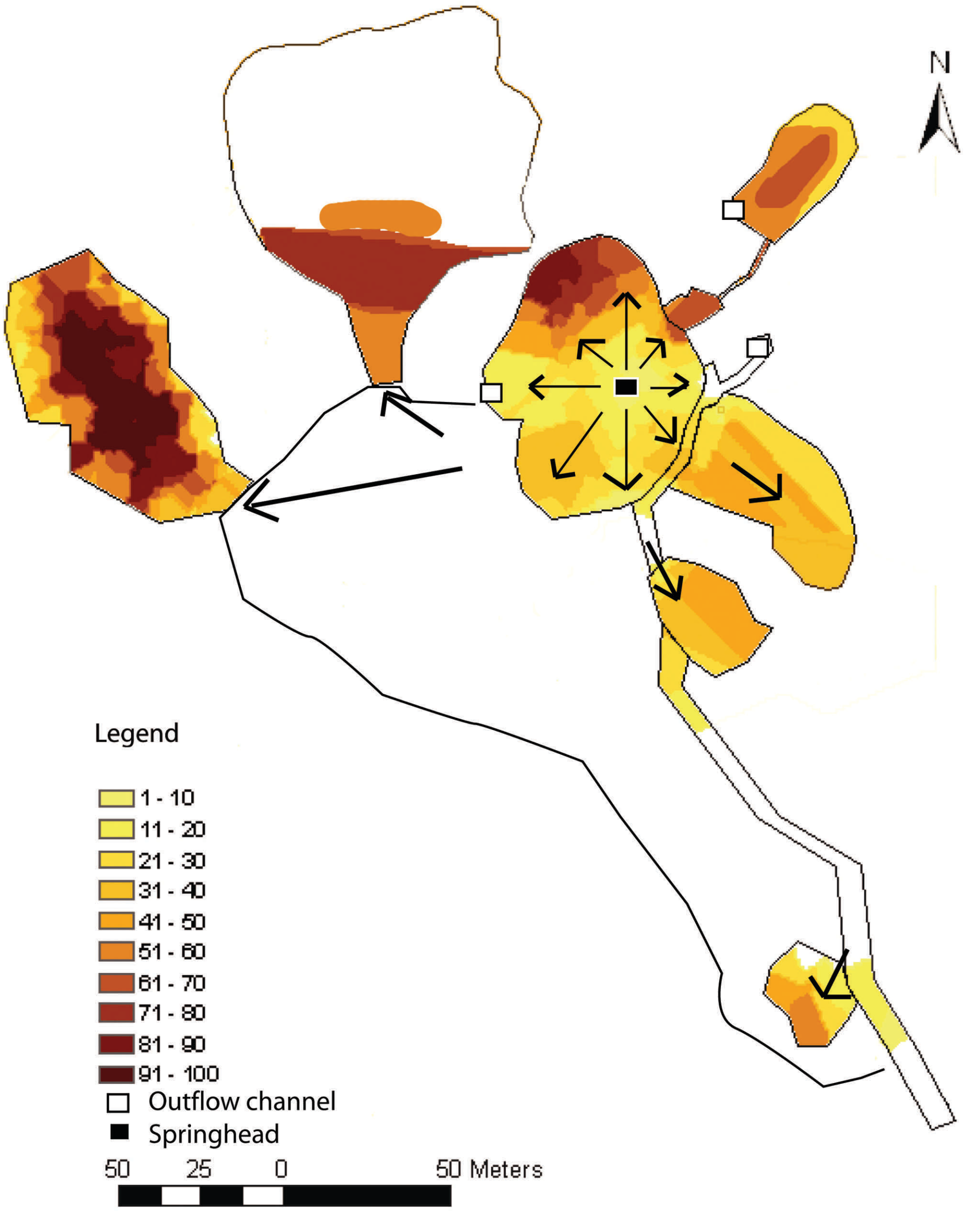

Figure 5.16 Contour map showing the water flow patterns relative to *Mexipyrgus* distribution. Diamonds represent sampling points.

5.4. Statistical Analysis

5.4.1 *Number of Co-occurrences*

Cluster analysis is a common statistical analysis test used by paleontologists to look at associations preserved in death assemblages. It examines the frequency of associations and it determines a common habitat for species based on the frequency of occurrence. Frequency of occurrences analysis is the first step in cluster analysis and was performed on the data set from my field study (Table 5.1) to determine the relevance of this statistical technique to the microhabitat identification of gastropod taxa in the Garabatal field site.

Results from frequency of occurrences analysis on my data set suggest that *Mexipyrgus* and *Nymphophilus* are found in close association with each other because they have the highest incidence of co-occurrence, 131 occurrences or 89.7% of the total samples. It also suggests that *Mexithauma* shows no strong correlation with *Mexipyrgus* or *Nymphophilus*, and is least likely to be found with *Cochliopina*. *Durangonella* shows no strong association with any of the other species, although it is also least likely to be associated with *Cochliopina* and somewhat less likely to be found with *Physa*. *Physa* is more likely to be associated with both *Mexipyrgus* and *Nymphophilus* than the other three taxa. *Cochliopina*, however, shows no preference for any of the other taxa.

	Mexipyrgus	*Nymphophilus*	*Mexithauma*	*Durangonella*	*Cochliopina*	*Physa*
Mexipyrgus	X	131	54	49	8	41
Nymphophilus	131	X	55	53	10	44
Mexithauma	54	55	X	36	5	21
Durangonella	49	53	36	X	7	25
Cochliopina	8	10	5	7	X	9
Physa	41	44	2	25	9	X

X-No Data

Table 5.1 Frequency of occurrences analysis.

The results of the frequency of occurrences analysis are not in keeping with the observed microhabitat preferences previously observed (Taylor, 1966, Hershler, 1985), nor do they match the trends seen in the contoured maps of gastropod distributions. Paleontologists interpret associations based on habitats and indeed *Mexipyrgus* and *Nymphophilus* share the same overall habitat, but they have opposing microhabitats within the system. In addition, frequency of occurrences analysis assumes that all species within a system are equally abundant, and therefore the occurrence of all species is equally likely. This is not the case for any living system and cannot be assumed for a death assemblage. Even in subfossil samples, the correlation of uncommon species is related to their microhabitat preference, although a large sample size is often needed before a trend can be established. Because frequency of occurrences analysis does not reflect the true complexity inherent within one system, it is not a good indicator of habitat changes between systems and is even less useful as a tool for predicting microhabitat associations in a single system.

5.4.2 *Association Analysis*

Out of 64 possible associations (Appendix 9.8), I found that only 21 combinations were present in my sample dataset (Appendix 9.9a). When resampling from my original data, to randomize the associations between the gastropod taxa, sixty-three of the sixty-four associations were found in the resampled, or null (H_0), data set (Appendix 9.9b). Since the null data were resampled 1000 times, I divided the number of occurrences in the null data set H_0 by 1000 (Appendix 9.10).

Only three associations (3, 15, and 47) were significant after I accounted for the random chance of association in the sample set (Appendix 9.11-14). The results of association analysis immediately reveal the gradational nature of species associations in the pool deposits. Although gastropods have microhabitat preferences, the presence of any gastropod is not exclusive to a certain microhabitat. Rather, certain habitats are dominated by different species of gastropods. This is illustrated in Appendix 9.15h, which shows the percent compositions of the gastropods in the various associations where they were found. The three most significant associations are described below.

Association #	#Ha-Ho (n=1)	Ha-Ho (p)(n=1)
0	3.853	0.282
1	0.400	0.029
2	-0.165	-0.012
3	14.298	1.045
7	-4.948	-0.362
10	-0.821	-0.060
11	-9.312	-0.681
14	-0.141	-0.010
15	6.360	0.465
19	-1.388	-0.101
23	-0.492	-0.036
35	-0.042	-0.003
39	-4.774	-0.349
42	0.168	0.012
43	-4.018	-0.294
47	7.771	0.568
50	0.906	0.066
51	-0.079	-0.006
58	0.996	0.073
59	1.450	0.106
60	1.000	0.073
63	2.658	0.194

n-number of sample sets

Ha-sampled data set

Ho-null data set

Table 5.2 Number of occurrences associations for sampled data compared to the null data set.

Association #3 consists of samples composed solely of *Mexipyrgus* and *Nymphophilus* shells, although this assemblage is clearly dominated by *Mexipyrgus*. Eighty-one percent of the mean (weighted percentage) and 93% of the mean weighted number of shells belong to *Mexipyrgus* (Table 5.3, 5.4). This correlates well with a soft substrate microhabitat, which was also evident in the contour maps of the field site.

Association #15 consists of *Mexipyrgus, Nymphophilus, Mexithauma, and Durangonella*. However, *Nymphophilus* is the most significant contributor to this association by its percent composition in the samples. The *Nymphophilus* population reflects a split in its microhabitat preferences. Two distinct peaks for abundances are seen in *Nymphophilus*, corresponding to its dual preference for both aquatic vegetation, which overlaps the soft substrate microhabitat, and travertine, which is incompatible with the soft substrate microhabitat. The large number of *Nymphophilus* correlates well with vegetative microhabitats.

Association #47 is a diverse array of many different types of gastropods including *Mexipyrgus*, *Nymphophilus*, *Mexithauma*, *Durangonella*, and *Physa*. *Nymphophilus* and *Mexithauma* make up the bulk composition of these samples (Table 5.3, 5.4). This is consistent with observations of *Nymphophilus* and *Mexithauma* existing within hard travertine substrate and tufa. The presence of *Durangonella* is contrary to previous observations of *Durangonella* in soft sediment (Hershler, 1985). However, it does correlate with my observations of numerous *Durangonella* within living stromatolite samples and with contour mapping in the field site.

Since *Durangonella* is also found in soft substrate within the center of dried pools, a fourth habitat is suggested for *Durangonella* based on the idea of either a fourth unknown variable that has not been accounted for or a fourth variable that creates a class of generalists. *Durangonella* may in fact be preferentially found in living stromatolites due to predation pressures of cichlids in large pools, but it is not restricted to soft substrate.

The diverse assemblage represented by #47 also suggests that stromatolites are a good substrate for gastropods. Gastropods have plenty of algae and bacteria to graze on and are relatively protected from predation by fish species. However, stromatolites may also be a good place for the preservation of thinner and weaker shells, which may be preferentially crushed in softer sediments, which undergo consolidation.

Association #	**Mw**	**Nw**	**Tw**	**Dw**	**Cw**	**Pw**
3	81.2	1.0				
15		22.5	0.6			
47	9.6	32.6	43.5	23.1		7.5

Mw- weighted *Mexipyrgus*
Nw- weighted *Nymphophilus*
Tw- weighted *Mexithauma*
Dw- weighted *Durangonella*
Cw- weighted *Cochliopina*
Pw- weighted *Physa*

Table 5.3 Weighted mean of each species.

Association#	Mw	Nw	Tw	Dw	Cw	Pw
3	93.1	45.9				
15		19.1	32.2	17.0		
47	6.4	18.8	59.5	56.9		33.7

Mw- weighted *Mexipyrgus*
Nw- weighted *Nymphophilus*
Tw- weighted *Mexithauma*
Dw- weighted *Durangonella*
Cw- weighted *Cochliopina*
Pw- weighted *Physa*

Table 5.4 Weighted relative abundance mean of each species.

5.4.3 *X-Ray Diffraction*

Results of the XRD analysis show that *Mexipyrgus*, *Nymphophilus*, and *Mexithauma* shells are made exclusively of aragonite, with no other minerals present in samples taken from the sediment surface and at 10 cm depth. This is not unusual for gastropod shells, which tend to be made up of aragonite or a combination of calcite and aragonite (Prothero, 1998). A small amount of calcite was found in samples recovered from a depth of 110 cm, suggesting that some of the aragonite had recrystallized to calcite. Though samples collected between 10 and 110 cm were not analyzed by XRD analysis, it is likely that the amount of calcite incorporated into gastropod shells increased gradually with increasing depth. In the field area, the water table was detected at this depth. With further tests, we may be able to see trace amounts of other minerals, and discover why some of the subfossil gastropod shells, *Mexithauma* in particular, are discolored and pink, suggesting incorporation of iron into their shells.

6.0. DISCUSSION

In this section I will describe how the new statistical method I developed can analyze the complex variability of a thermal springs system. I will give an overview of shell preservation within the Garabatal system.Finally, I will discuss some applications of my work in the areas of astrobiology and conservation.

6.1 Variability and Organization of the Cuatro Cienegas System

The desert thermal springs of Cuatro Cienegas are highly variable environments on many different levels of organization. Variability is seen between spring systems, with the Garabatal spring system being one of the most variable and seasonal within Cuatro Cienegas (Winsborough, 1990). Variation also exists within the different facies of a spring system because changes in flow rates and alteration of water chemistry occur as water moves away from the springhead. Organisms such as cyanobacteria and macrophytes affect substrate formation in pools, and gastropod taxa are able to distribute themselves according to preferred substrate and microhabitats. There is also variability within the gastropod species themselves. *Mexipyrgus carranzae* also displays a wide range of morphotypes which differ between and within systems (Tang and Roopnarine, 2003), eight of which were originally described as unique species (Taylor, 1966, Hershler, 1985, Tang and Roopnarine, 2003). In my own samples, I found that the spiral keel of *Nymphophilus minckleyi* was variably expressed and represented a gradation from smoother keel to a strongly pronounced keel.

Yet, within this variability we see organization on many different levels. This organization is not only evident in living systems, but my study shows that it can be preserved in extinct systems at both large and small scales. By looking at the faunal community in a systematic way, and using transects to sample within pool deposits, I was able to detect the distributional signal within the freshwater gastropod taxa in the Garabatal spring deposits. Using a subfossil system to analyze community ecology has advantages over analysis in the living system in that it allowed me to look at a larger number of individuals and have a larger sample size on which to base my observations. Twenty-three thousand gastropod shells were counted over the course of this study. In comparison, biological studies of gastropods in Cuatro Cienegas have used sample sizes of a few hundred or fewer gastropods in the interest of preserving the population numbers of the endemic and endangered gastropods that are being studied.

Having a large sample size to work with also allowed me to use association analysis to analyze my data and detect strong statistical patterns. Because the signal from microhabitat partitioning was strong and because post-depositional transport within the system was minimal, a smearing effect from erosion, transport by seasonal rain events, or animal disturbance did not destroy the signal of relevant gastropod associations in the system.

6.2 Shell Preservation over Time

My study shows that the dried thermal spring system of the Garabatal retains a high abundance of subfossil gastropods. Likely factors that have affected gastropod preservation in pools include mechanical destruction by the trampling of feral horses and other animals, the amount of organic acid produced by rotting vegetation in standing water, and gastropod shell destruction through predation by molluscivorous cichlids and other predators. All of these factors could lead to the preferential destruction of thin-shelled gastropods over thick-shelled gastropods, as well as uneven preservation of gastropod shells in the area. Though most shells were found intact, shells tended to break or chip at the aperture (Plate 2a); although the apex was also broken in some specimens. Open shell forms, such as the corkscrew-shaped *Cochliopina milleri* (Hershler, 1985) were also more likely to break than shell shapes with closed, compact whorls. Damage from borings (Plate 2b) in gastropod shells as well as pockmarks (Plate 2c) or tunneling (Plate 2d) on various gastropod taxa can also undermine shell integrity.

Using subfossil shells to identify gastropod species is harder than distinguishing between live specimens since one cannot use the operculum shape or anatomical features to distinguish between species. No opercula or remnant body parts were recovered from any of the bulk samples. Information from shell color is also lost in subfossil samples, as the shells are bleached white from the sun even in 20 year old specimens.

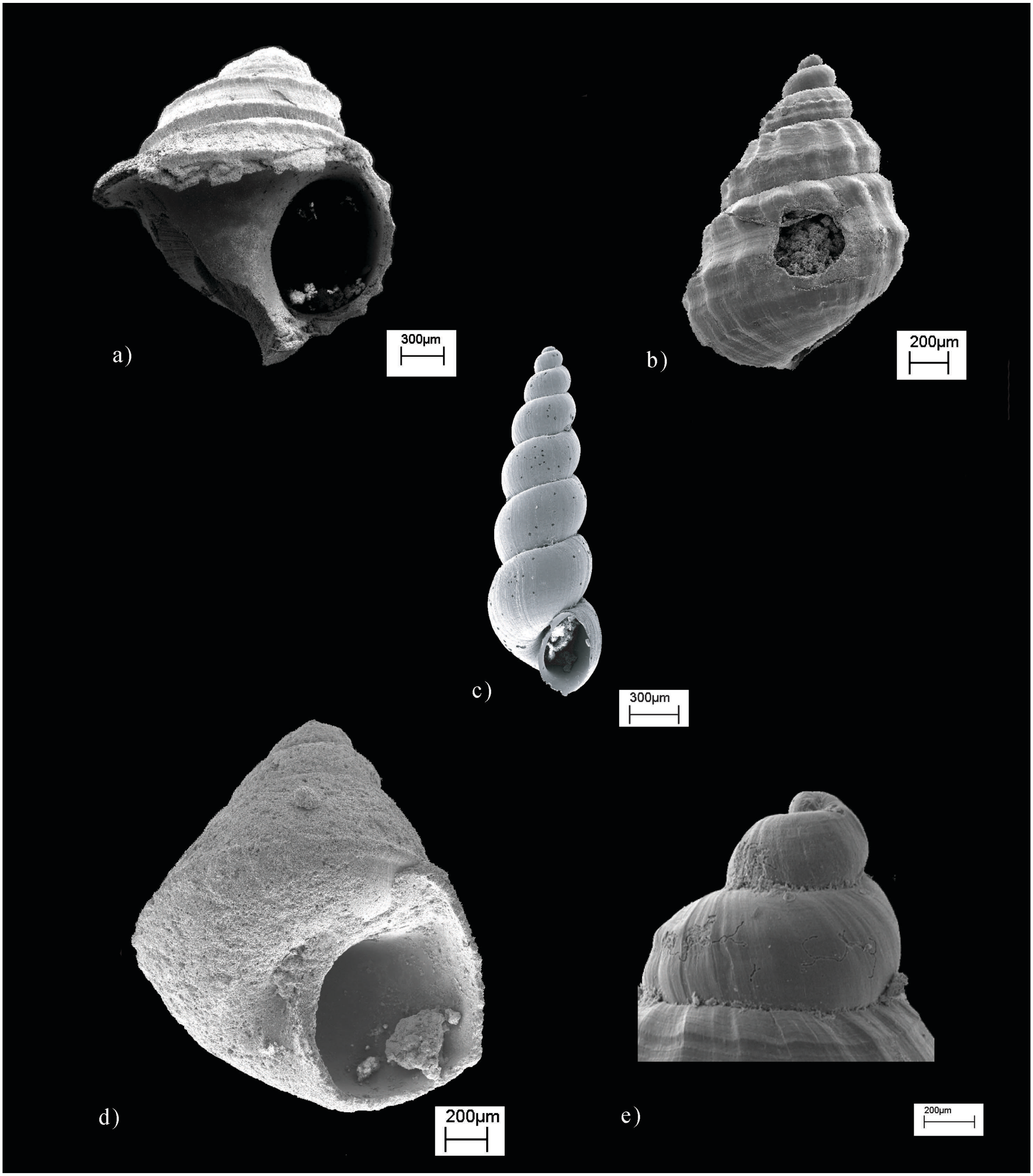

Plate 2 a) Broken *Mexithauma* shell, b) borehole in *Mexipyrgus* shell, c) pockmarks on *Durangonella,* d) dissolution of *Nymphophilus* shell, e) tunneling on outer *Mexipyrgus* shell.

Overall, I found that the gastropod shells were very well preserved in the field site samples; even the thin-shelled gastropods were found wholly intact. Their presence in soft sediment may help cushion any impact from trampling by humans and animals. In addition, many gastropod shells were found within stromatolite samples, and may have become trapped in the interstitial spaces as the stromatolite calcified over them. Modern oncoloid samples taken from Rio Mesquites spring system were broken to extract gastropods during a collaborative research experiment with the Jim Elser lab from Arizona State University. Within the interstitial spaces of the oncoloids and in my later analysis of dried stromatolite material, gastropods were found in grooves and holes within the samples. It appeared as though they had become trapped within the stromatolite, and had continued to live within the cavity for some time.

Gastropod shells in stromatolite samples have the best chance of preservation in the fossil record because the stromatolite is less likely to become consolidated than soft sediments in pools. In this case, the gastropods from the ring of stromatolites surrounding an ancient pool have the potential to record the extent of an ancient pool, even when the rock itself consists solely of travertine. In consolidated travertine rock, the original stromatolite forms may be obscured by compaction.

One of the difficulties with paleoecological reconstruction in thermal springs, as is the case in Cuatro Cienegas, is that the land becomes altered by subsidence and dissolution. This is very common in karst areas, where sinkholes are prone to forming and deformation occurs in response to changes in the level of the water table (Bathurst, 1975). The travertine that precipitates in this area, due to the activity of stromatolite building bacteria and diatoms (Winsborough, 1990), provides some measure of reinforcement to the structure of more permanent bodies of water such as pools and channels. This may allow Cuatro Cienegas to be an area of good preservation, and a good analog for preservation in an early Earth environment (Cowen, 1995). It also means that preferential microhabitat preservation is possible in thermal springs systems.

6.3 Astrobiology

Typically paleontologists undertaking biogeographic studies of organisms are looking for community changes that are regional or global in extent (Dodd and Stanton, 1990). Community relationships are difficult to determine because the original conditions can never be known, only inferred, often based on analogies to modern systems seen on Earth today (Schafer, 1972). Microhabitats are even more difficult to detect, due to transport by erosional processes and tectonic movements (Scott and West, 1976, Dodd and Stanton, 1990). On the other end of the spectrum, biologists looking at living systems can only make predictions about how and what portion of their communities will be preserved in the fossil record. It is rare that you can have both a well-studied system and also see the footprint that such a system leaves behind. This, however, is the unique case in Cuatro Cienegas, where water diversion has turned well-studied spring systems into depositional relicts over historic time.

When looking for life on other planets, I believe that the role of microhabitat partitioning takes on a greater significance than here on Earth. Broad generalizations about communities on Earth can be made because life is so abundant and the fossil record is accessible. As we have seen, life is not teeming on the other planets in the solar system (Bennet et al., 2004). Our efforts to detect life have narrowed to looking for signs of past life and looking for signs of habitats amenable to the origination of life, such as the presence of liquid water (Clifford et al., 2000, Varnes et al., 2003). Subsequently, a portion of astrobiological research focuses on understanding environments on early Earth, such as extreme environments (Rothschild and Mancinelli, 2001). The lack of plate tectonics on some other planets, like Mars, (Bennet et al., 2004) may help preserve the potential fossil record in extreme environments because it limits post-depositional transport of fossils.

The goal of my research was to provide evidence for the fact that microhabitat partitioning has the potential to be preserved in the fossil record in a meaningful way, and to provide tools for assessing the significance of observed associations between organisms. I accomplished both by showing that sampling along transects enables one to see the gradient of species change over a small spatial scale, within meters, and by showing that these species changes are meaningful and relate to microhabitat preferences of the organism in the previously living system.

6.4 Conservation

There are many organizations interested in protecting the springs of Cuatro Cienegas. Proteccion de la Fauna Mexicana A.C. (PROFAUNA), the federal agency Secretaria del Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP), the federal department of ecology Instituto Nacional de Ecologia (INE), The Nature Conservancy (TNC), the World Wildlife Fund (WWF), and the U.S. Fish and Wildlife Service (USFWS) have all been involved in conservation efforts in the valley (Calegari, 1997). Popular articles on the subject have increased global awareness of the region (Taylor, 1966, Grall, 1995, Jolly, 2002) and scientists have been active in facilitating the protection of the endemic species within Cuatro Cienegas.

The Garabatal springs system dried up as a direct result of water diversion through the cement-lined channel leading from the Posa de la Becerra springhead 20 years ago (Henderson et. al., in press). In June, 2003, the water table was measured at 110 cm below the ground surface at Laguna Chara. Theoretically, the water table would not have to be raised substantially to restore the springs in the Garabatal, a portion of the valley that is not utilized for economic or residential means.

Gastropod distribution can also be used as a biomarker to help define the extent of spring systems in other impacted areas of the valley, helping to distinguish the remnants of much older fluvial environments from historic changes to that system. In this way, gastropod taxonomy can help evaluate the habitat loss in an area as well as assess the effectiveness of conservation efforts to a system.

7.0 CONCLUSIONS

Microhabitat partitioning was found to be preserved in the subfossil assemblage of gastropods located in the dried deposits of the extinct Garabatal thermal spring system in the valley of Cuatro Cienegas. Depositional facies were distinguishable and correlated well with previous depositional environments documented in the field site (Winsborough, 1990). A GIS map of the depositional facies delimited the extent of pools, channels, marshes, and playas in the area.

Gastropod taxa found within the field site included individuals from the genera *Coahuilix*, *Cochliopina*, *Durangonella*, *Gastrocopta*, *Mexipyrgus*, *Nymphophilus*, *Mexithauma*, and *Physa*. Contour maps showing the distribution of freshwater gastropod taxa revealed that gastropod distribution was clumped and suggested that the clumping was related to microhabitat preference in the historically active spring system. A contour map based on the distribution of *Mexipyrgus*, a soft substrate dwelling taxa, correlated with low flow areas and was the most useful gastropod taxa for interpreting flow patterns in the field site.

I created a novel statistical method called association analysis for the purpose of analyzing the strength of taxa associations within the field site. Association analysis suggested that three gastropod associations were statistically significant in the field site, and these three associations correlated well with previous observations of microhabitat preference for travertine, vegetation, and carbonate sand substrate. Association analysis makes allowances for gradational changes in microhabitats, overlapping microhabitats, and variable taxon abundance within a system. This gives a better measure of the system because it accounts for more of the complexity inherent within ecosystems.

Supplemented with contour mapping of species distributions along transects, the methods employed in this analysis make this system a model which can be used to understand other ancient and unknown, complex ecological systems. The study of microhabitat analysis may be useful in evaluating death assemblages in paleoecological research. It can also used to assess changes within modern systems that have lost habitat due to human activity.

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9.0 APPENDIX

9.1 Sampling location descriptions.

Location	Sample	Sampling Date	Substrate Type
Laguna Garabatal	G-A1	6/27/2003	bare, next to stromatolite
Laguna Garabatal	G-A2	6/27/2003	bare
Laguna Garabatal	G-A3	6/27/2003	bare, very hard, v. little loose soil
Laguna Garabatal	G-A4	6/27/2003	some grass, mostly bare
Laguna Garabatal	G-A5	6/27/2003	next to stromatolite, bare with dry twigs
Laguna Garabatal	G-B1	6/27/2003	bare, next to stromatolite mounds
Laguna Garabatal	G-B2	6/27/2003	bare
Laguna Garabatal	G-B3	6/27/2003	grassy
Laguna Garabatal	G-B4	6/27/2003	grassy
Laguna Garabatal	G-B5	6/27/2003	sparse grass
Laguna Garabatal	G-B6	6/27/2003	sparse grass
Laguna Garabatal	G-B7	6/27/2003	sparse grass
Laguna Garabatal	G-B8	6/27/2003	patchy grass
Laguna Garabatal	G-B9	6/27/2003	next to stromatolite
Laguna Garabatal	G-C1	6/27/2003	bare, next to stromatolite
Laguna Garabatal	G-C2	6/27/2003	sparse grass
Laguna Garabatal	G-C3	6/27/2003	grassy
Laguna Garabatal	G-C4	6/27/2003	grassy
Laguna Garabatal	G-C5	6/27/2003	sparse grass
Laguna Garabatal	G-C6	6/27/2003	grassy
Laguna Garabatal	G-C7	6/27/2003	bare, next to stromatolite
Laguna Garabatal	G-D1	6/27/2003	next to stromatolite, patchy grass
Laguna Garabatal	G-D2	6/27/2003	lots of vegetation
Laguna Garabatal	G-D3	6/27/2003	patchy grass
Laguna Garabatal	G-D4	6/27/2003	patchy grass
Laguna Garabatal	G-D5	6/27/2003	patchy grass
Laguna Garabatal	G-D6	6/27/2003	next to stromatolite and channel
Lobe	L1	7/10/2003	edge of pool, next to ridge, not obvious stromatolite
Lobe	L2	7/10/2003	sample in bare ground, patchy grass
Lobe	L3	7/10/2003	patchy grass
Lobe	L4	7/10/2003	patchy grass
Lobe	L5	7/10/2003	patchy grass
Lobe	L6	7/10/2003	edge of pool, next to ridge, not obvious stromatolite
Pool1	P1-1	7/10/2003	edge of pool, grassy
Pool1	P1-2	7/10/2003	grassy
Pool1	P1-3	7/10/2003	grassy
Pool1	P1-4	7/10/2003	grassy

Pool1	P1-5	7/10/2003	grassy, at edge
Pool2	P2-1	7/11/2003	grass
Pool2	P2-2	7/11/2003	grass
Pool2	P2-3	7/11/2003	grass
Pool2	P2-4	7/11/2003	grass
Pool2	P2-5	7/11/2003	grass
Pool2	P2-6	7/11/2003	grass
Laguna Chara	C-A1	3/17/2003	next to pampas
Laguna Chara	C-A2	3/17/2003	bare
Laguna Chara	C-A3	3/17/2003	bare
Laguna Chara	C-A4	3/17/2003	bare
Laguna Chara	C-A5	3/17/2003	bare
Laguna Chara	C-A6	3/17/2003	next to desert sacatone
Laguna Chara	C-B1	3/17/2003	bare
Laguna Chara	C-B2	3/17/2003	bare, a little vegetation
Laguna Chara	C-B3	3/17/2003	bermuda grass
Laguna Chara	C-B4	3/17/2003	bermuda grass
Laguna Chara	C-B5	3/17/2003	bermuda grass
Laguna Chara	C-B6	3/17/2003	stromatolite
Laguna Chara	C-C1	3/17/2003	next to pampas
Laguna Chara	C-C2	3/17/2003	bermuda grass
Laguna Chara	C-C3	3/17/2003	bermuda grass
Laguna Chara	C-C4	3/17/2003	bermuda grass
Laguna Chara	C-C5	3/17/2003	bermuda grass
Laguna Chara	C-C6	3/17/2003	bare
Laguna Chara	C-C7	3/17/2003	stromatolite
Laguna Chara	C-D1	3/18/2003	next to sedge and channel opening
Laguna Chara	C-D2	3/18/2003	bermuda grass
Laguna Chara	C-D3	3/18/2003	bermuda grass
Laguna Chara	C-D4	3/18/2003	bermuda grass
Laguna Chara	C-D5	3/18/2003	bermuda grass
Laguna Chara	C-D6	3/18/2003	bermuda grass
Laguna Chara	C-D7	3/18/2003	bermuda grass
Laguna Chara	C-D8	3/18/2003	stromatolite
Laguna Chara	C-E1	3/18/2003	between stromatolites, next to sedge
Laguna Chara	C-E2	3/18/2003	1/2 bermuda grass 1/2 bare
Laguna Chara	C-E3	3/18/2003	bermuda grass
Laguna Chara	C-E4	3/18/2003	bermuda grass
Laguna Chara	C-E5	3/18/2003	bermuda grass
Laguna Chara	C-E6	3/18/2003	bermuda grass
Laguna Chara	C-E7	3/18/2003	bermuda grass
Laguna Chara	C-E8	3/18/2003	bermuda grass
Laguna Chara	C-E9	3/18/2003	stromatolite
Laguna Chara	C-F1	3/18/2003	stromatolite

Laguna Chara	C-F2	3/18/2003	bermuda grass
Laguna Chara	C-F3	3/18/2003	bermuda grass
Laguna Chara	C-F4	3/18/2003	bare
Laguna Chara	C-F5	3/18/2003	mostly bare, a little bermuda grass
Laguna Chara	C-F6	3/18/2003	bermuda grass
Laguna Chara	C-F7	3/18/2003	bermuda grass
Laguna Chara	C-F8	3/18/2003	bermuda grass
Laguna Chara	C-F9	3/18/2003	stromatolite
Laguna Chara	C-G1	3/20/2003	stromatolite
Laguna Chara	C-G2	3/20/2003	bare
Laguna Chara	C-G3	3/20/2003	bermuda grass
Laguna Chara	C-G4	3/20/2003	bermuda grass
Laguna Chara	C-G5	3/20/2003	1/2 bare1/2 bermuda grass
Laguna Chara	C-G6	3/20/2003	bermuda grass
Laguna Chara	C-G7	3/20/2003	bermuda grass
Laguna Chara	C-G8	3/20/2003	bermuda grass
Laguna Chara	C-G9	3/20/2003	bermuda grass
Laguna Chara	C-G10	3/20/2003	stromatolite
Laguna Chara	C-H1	3/20/2003	stromatolite
Laguna Chara	C-H2	3/20/2003	bare, next to pampas
Laguna Chara	C-H3	3/20/2003	bermuda grass
Laguna Chara	C-H4	3/20/2003	bare, a little bermuda grass
Laguna Chara	C-H5	3/20/2003	bermuda grass
Laguna Chara	C-H6	3/20/2003	bermuda grass
Laguna Chara	C-H7	3/20/2003	1/2 bermuda grass1/2 bare
Laguna Chara	C-H8	3/20/2003	stromatolite
Laguna Chara	C-I1	3/20/2003	bare
Laguna Chara	C-I2	3/20/2003	bermuda grass
Laguna Chara	C-I3	3/20/2003	bare
Laguna Chara	C-I4	3/20/2003	bermuda grass
Laguna Chara	C-I5	3/20/2003	bermuda grass
Laguna Chara	C-I6	3/20/2003	bermuda grass
Laguna Chara	C-I7	3/20/2003	stromatolite
Laguna Chara	C-J	3/20/2003	stromatolite
Channel A	CHA-1	7/4/2003	Live channel, soft sediment
Channel A	CHA-2	7/4/2003	Live channel, soft sediment
Channel A	CHA-3	7/4/2003	Live channel, soft sediment
Channel A	CHA-4	7/4/2003	Live channel, soft sediment
Channel A	CHA-5	7/4/2003	Live channel, soft sediment
Channel A	CHA-6	7/4/2003	Live channel, soft sediment
Channel A	CHA-7	7/4/2003	Live channel, soft sediment
Channel A	CHA-8	7/4/2003	Live channel, soft sediment
Channel A	CHA-9	7/4/2003	Live channel, soft sediment
Channel A	CHA-10	7/4/2003	Live channel, soft sediment

Channel 2	CH2-2M	7/4/2003	bare, travertine
Channel 3	CH3-2M	7/4/2003	bare, travertine
Channel 3	CH3-3M	7/4/2003	bare, travertine
Channel 3	CH3-6M	7/4/2003	bare, travertine
Channel 2	CH2-2S	7/4/2003	bare, travertine
Channel 3	CH3-2S	7/4/2003	bare, travertine
Channel 3	CH3-3S	7/4/2003	bare, travertine
Channel 3	CH3-6S	7/4/2003	bare, travertine
Bee	BEE1	7/11/2003	next to swallow hole, and bee hive
Bee	BEE2	7/11/2003	bare, soft sediment
Bee	BEE3	7/11/2003	bare, soft sediment
Bee	BEE4	7/11/2003	bare, soft sediment
Bee	BEE5	7/11/2003	bare, soft sediment
Jacuzzi	J1	7/11/2003	bare, soft sediment
Jacuzzi	J2	7/11/2003	bare, soft sediment
Playa	FP1	7/8/2003	bare, soft sediment
Playa	FP2	7/8/2003	bare, soft sediment
Playa	FP3	7/8/2003	bare, soft sediment
Playa	FP4	7/8/2003	bare, soft sediment
Playa	FP5	7/8/2003	bare, soft sediment
Playa	FP6	7/8/2003	bare, soft sediment
Playa	FP7	7/8/2003	bare, soft sediment

9.2 Raw data from sampling.

Location	**Sample #**	**Weight**	***Mexipyrgus***	***Nymphophilus***	***Coahuilix***	***Cochliopina***	***Mexithauma***	***Paludiscala***	***Durangonella***	***Physa***	***Gastrocopta***
Laguna Garabatal	G-A1	370	111	27	0	0	0	0	3	0	0
Laguna Garabatal	G-A2	315	31	8	0	0	1	0	0	1	0
Laguna Garabatal	G-A3	55	13	2	0	0	1	0	1	1	0
Laguna Garabatal	G-A4	600	30	39	0	0	5	0	0	5	0
Laguna Garabatal	G-A5	485	105	107	0	0	22	0	14	22	0
Laguna Garabatal	G-B1	540	128	85	0	0	3	0	0	3	0
Laguna Garabatal	G-B2	495	225	15	0	0	2	0	0	2	0
Laguna Garabatal	G-B3	570	49	35	0	0	3	0	0	3	0
Laguna Garabatal	G-B4	725	10	23	0	0	0	0	1	0	0
Laguna Garabatal	G-B5	460	8	33	0	0	0	0	1	0	0
Laguna Garabatal	G-B6	555	12	48	0	0	1	0	0	1	0
Laguna Garabatal	G-B7	390	40	79	0	0	7	0	0	7	0
Laguna Garabatal	G-B8	685	494	373	0	0	69	0	5	69	0
Laguna	G-B9	250	6	210	0	0	0	0	14	0	0

Garabatal											
Laguna Garabatal	G-C1	460	12	10	0	0	2	0	1	2	0
Laguna Garabatal	G-C2	370	3	8	0	0	2	0	0	2	0
Laguna Garabatal	G-C3	275	2	14	0	0	0	0	0	0	0
Laguna Garabatal	G-C4	250	0	5	0	0	0	0	0	0	0
Laguna Garabatal	G-C5	310	24	171	0	0	9	0	4	9	0
Laguna Garabatal	G-C6	475	38	274	0	0	18	0	22	18	0
Laguna Garabatal	G-C7	640	54	226	0	0	29	0	2	29	0
Laguna Garabatal	G-D1	350	15	10	0	0	0	0	0	0	0
Laguna Garabatal	G-D2	385	0	4	0	0	0	0	0	0	0
Laguna Garabatal	G-D3	480	5	10	0	0	1	0	0	1	0
Laguna Garabatal	G-D4	645	142	160	0	0	11	0	44	11	0
Laguna Garabatal	G-D5	455	73	72	0	0	27	0	109	27	0
Laguna Garabatal	G-D6	575	3	165	0	0	1	0	9	1	0
Lobe	L1	555	1	26	0	0	15	0	0	0	0
Lobe	L2	685	48	48	0	0	0	0	0	0	0
Lobe	L3	695	12	28	0	0	0	0	0	0	0

Lobe	L4	735	38	32	0	0	0	0	0	1	0
Lobe	L5	700	24	96	0	0	10	0	2	0	0
Lobe	L6	630	386	386	0	0	147	0	25	0	0
Pool1	P1-1	695	2	5	0	5	0	0	0	1	0
Pool1	P1-2	625	54	17	0	0	0	0	0	1	0
Pool1	P1-3	490	23	52	0	2	2	0	3	3	3
Pool1	P1-4	415	26	55	0	3	1	0	10	10	2
Pool1	P1-5	385	11	10	0	1	1	0	6	0	0
Pool2	P2-1	560	0	2	0	0	0	0	0	0	0
Pool2	P2-2	675	304	22	0	1	1	0	7	0	0
Pool2	P2-3	650	36	77	0	0	2	0	17	2	8
Pool2	P2-4	360	0	0	0	7	0	1	0	0	2
Pool2	P2-5	395	194	29	0	0	2	0	15	1	3
Pool2	P2-6	475	28	26	0	0	0	0	28	3	2
Laguna Chara	C-A1	475	37	160	0	0	1	0	0	0	0
Laguna Chara	C-A2	810	165	459	0	0	0	0	0	0	0
Laguna Chara	C-A3	580	187	222	0	0	0	0	1	1	0
Laguna Chara	C-A4	580	189	275	0	0	0	0	3	2	0
Laguna Chara	C-A5	420	349	482	0	0	9	0	1	0	0
Laguna Chara	C-A6	425	61	184	0	0	2	0	1	1	0
Laguna Chara	C-B1	295	75	117	0	0	1	0	1	0	0
Laguna Chara	C-B2	415	67	248	0	0	0	0	0	3	0
Laguna Chara	C-B3	305	114	125	0	0	1	0	0	4	0
Laguna Chara	C-B4	180	37	8	0	0	0	0	0	0	0
Laguna Chara	C-B5	175	89	26	0	0	0	0	0	0	0
Laguna Chara	C-B6	150	0	46	0	0	0	0	4	3	0
Laguna Chara	C-C1	305	166	27	0	0	0	0	0	0	0
Laguna Chara	C-C2	220	91	15	0	0	0	0	0	1	0
Laguna Chara	C-C3	347	169	16	0	0	0	0	0	0	0

Laguna Chara	C-C4	315	12	2	0	0	0	0	0	1	0
Laguna Chara	C-C5	370	32	5	0	0	0	0	1	0	0
Laguna Chara	C-C6	375	285	64	0	0	0	0	0	0	0
Laguna Chara	C-C7	285	1	134	0	0	0	0	12	1	1
Laguna Chara	C-D1	295	.	.	0	0	.	0	.	.	0
Laguna Chara	C-D2	560	104	8	0	0	0	0	0	0	0
Laguna Chara	C-D3	610	137	8	0	0	0	0	0	0	0
Laguna Chara	C-D4	575	177	33	0	0	0	0	0	1	0
Laguna Chara	C-D5	720	218	10	0	0	1	0	0	0	0
Laguna Chara	C-D6	645	225	9	0	0	0	0	0	0	0
Laguna Chara	C-D7	470	93	13	0	0	0	0	0	0	0
Laguna Chara	C-D8	415	0	39	0	0	0	0	15	0	0
Laguna Chara	C-E1	560	8	4	0	0	0	0	0	0	0
Laguna Chara	C-E2	535	363	64	0	0	1	0	0	0	0
Laguna Chara	C-E3	685	164	17	0	0	0	0	0	1	0
Laguna Chara	C-E4	460	21	0	0	0	0	0	0	0	0
Laguna Chara	C-E5	530	66	4	0	0	0	0	0	0	0
Laguna Chara	C-E6	740	66	6	0	0	0	0	0	0	0
Laguna Chara	C-E7	755	66	6	0	0	0	0	0	0	0
Laguna Chara	C-E8	615	286	28	0	0	0	0	0	0	0
Laguna Chara	C-E9	540	0	6	0	0	0	0	0	0	0
Laguna Chara	C-F1	450	0	2	0	2	0	0	6	1	0
Laguna Chara	C-F2	530	151	24	0	0	0	0	0	0	0
Laguna Chara	C-F3	610	91	8	0	0	0	0	0	0	0
Laguna Chara	C-F4	445	115	8	0	0	0	0	0	0	0
Laguna Chara	C-F5	760	66	10	0	0	0	0	0	0	0
Laguna Chara	C-F6	540	172	19	0	0	0	0	1	0	0
Laguna Chara	C-F7	530	99	11	0	0	0	0	0	0	0
Laguna Chara	C-F8	590	358	58	0	0	3	0	1	1	0

Laguna Chara	C-F9	1120	.	.	.	.	.	.	.	.	.
Laguna Chara	C-G1	480	0	1	0	0	0	0	0	0	0
Laguna Chara	C-G2	495	400	185	0	0	0	0	0	1	0
Laguna Chara	C-G3	395	197	37	0	0	0	0	0	0	0
Laguna Chara	C-G4	490	94	9	0	0	0	0	0	1	0
Laguna Chara	C-G5	605	145	7	0	0	0	0	0	0	0
Laguna Chara	C-G6	635	219	16	0	0	0	0	0	0	0
Laguna Chara	C-G7	620	111	14	0	0	0	0	0	0	0
Laguna Chara	C-G8	545	98	6	0	0	0	0	0	0	0
Laguna Chara	C-G9	385	264	60	0	0	0	0	0	0	0
Laguna Chara	C-G10	400	0	0	0	0	0	0	0	0	0
Laguna Chara	C-H1	665	0	0	0	0	0	0	0	0	0
Laguna Chara	C-H2	380	10	56	0	0	0	0	0	1	0
Laguna Chara	C-H3	385	279	47	0	0	0	0	0	1	0
Laguna Chara	C-H4	560	359	16	0	0	0	0	0	0	0
Laguna Chara	C-H5	590	133	15	0	0	0	0	0	0	0
Laguna Chara	C-H6	620	112	16	0	0	0	0	1	0	0
Laguna Chara	C-H7	560	145	19	0	0	0	0	0	0	0
Laguna Chara	C-H8	355	1	20	0	0	0	0	18	1	0
Laguna Chara	C-I1	410	11	35	0	0	0	0	0	0	0
Laguna Chara	C-I2	455	65	86	0	0	0	0	0	2	0
Laguna Chara	C-I3	395	154	163	0	0	0	0	0	1	0
Laguna Chara	C-I4	415	155	19	0	0	0	0	0	1	0
Laguna Chara	C-I5	475	247	35	0	0	0	0	1	0	0
Laguna Chara	C-I6	520	27	125	0	0	0	0	0	0	0
Laguna Chara	C-I7	240	1	0	0	0	0	0	0	0	.
Laguna Chara	C-J	335	0	0	0	0	0	0	0	0	0
Channel A	CHA-1	120	599	172	0	1	37	0	0	2	0
Channel A	CHA-2	108	545	105	0	2	24	0	3	1	0

Channel A	CHA-3	51.3	299	78	0	0	15	0	0	0	0
Channel A	CHA-4	73.5	580	158	0	0	33	0	1	1	0
Channel A	CHA-5	55	170	37	0	0	4	0	0	0	0
Channel A	CHA-6	60	11	29	0	0	1	0	1	0	0
Channel A	CHA-7	55	4	35	1	0	0	0	5	5	0
Channel A	CHA-8	55	4	15	1	0	0	0	2	2	0
Channel A	CHA-9	60	5	24	0	0	0	0	7	1	0
Channel A	CHA-10	75	1	42	0	0	0	0	7	1	0
Channel 2	CH2-2M	92.67	47	44	0	0	0	0	1	0	0
Channel 3	CH3-2M	47.92	12	8	0	0	1	0	5	0	0
Channel 3	CH3-3M	182.67	53	39	0	0	2	0	14	0	0
Channel 3	CH3-6M	75.8	25	30	0	0	2	0	0	0	0
Channel 2	CH2-2S	112.47	8	5	0	0	1	0	0	0	0
Channel 3	CH3-2S	269	10	9	0	0	1	0	3	0	0
Channel 3	CH3-3S	121.57	16	14	0	0	0	0	4	0	0
Channel 3	CH3-6S	97.14	43	40	0	0	4	0	0	0	0
Bee	BEE1	525	269	61	0	0	16	0	2	2	0
Bee	BEE2	450	495	62	0	0	21	0	0	0	0
Bee	BEE3	450	9	16	0	0	2	0	1	0	0
Bee	BEE4	475	11	23	0	0	1	0	12	0	0
Bee	BEE5	535	17	82	0	0	5	0	0	0	0
Jacuzzi	J1	317	49	31	0	0	10	1	6	0	0
Jacuzzi	J2	292	64	38	0	0	7	0	1	0	0
Playa	FP1	138	30	67	0	0	29	0	5	3	5
Playa	FP2	942	509	281	0	0	121	0	24	7	0
Playa	FP3	338	276	58	0	0	3	0	1	0	0
Playa	FP4	485	409	68	0	0	5	0	2	0	0
Playa	FP5	641	347	267	0	0	11	0	8	8	0
Playa	FP6	431	141	251	0	0	7	0	19	14	0

Playa	FP7	880	381	431	0	3	0	0	56	9	0

9.3 Gastropods per kilogram of sample.

Sample	Total Gastropods (1kg)	*Mexipyrgus* (1kg)	*Nymphophilus* (1kg)	*Coahuilix* (1kg)	*Cochliopina* (1kg)	*Mexithauma* (1kg)	*Paludiscala* (1kg)	*Durangonella* (1kg)	*Physa* (1kg)	*Gastrocopta* (1kg)
G-A1	381	300	73	0	0	0	0	8	0	0
G-A2	126	98	25	0	0	3	0	0	0	0
G-A3	308	236	36	0	0	18	0	18	0	0
G-A4	125	50	65	0	0	8	0	0	2	0
G-A5	515	216	221	0	0	45	0	29	4	0
G-B1	400	237	157	0	0	6	0	0	0	0
G-B2	489	455	30	0	0	4	0	0	0	0
G-B3	152	86	61	0	0	5	0	0	0	0
G-B4	47	14	32	0	0	0	0	1	0	0
G-B5	91	17	72	0	0	0	0	2	0	0
G-B6	110	22	86	0	0	2	0	0	0	0
G-B7	327	103	203	0	0	18	0	0	3	0
G-B8	1383	721	545	0	0	101	0	7	6	3
G-B9	952	24	840	0	4	0	0	56	28	0
G-C1	54	26	22	0	0	4	0	2	0	0
G-C2	35	8	22	0	0	5	0	0	0	0
G-C3	58	7	51	0	0	0	0	0	0	0
G-C4	20	0	20	0	0	0	0	0	0	0
G-C5	671	77	552	0	0	29	0	13	0	0
G-C6	743	80	577	0	0	38	0	46	0	2
G-C7	496	84	353	0	2	45	0	3	9	0
G-D1	72	43	29	0	0	0	0	0	0	0

G-D2	26	0	10	0	3	0	0	0	8	5
G-D3	35	10	21	0	0	2	0	0	2	0
G-D4	598	220	248	0	0	17	0	68	9	36
G-D5	626	160	158	0	0	59	0	240	7	2
G-D6	322	5	287	0	0	2	0	16	10	2
L1	76	2	47	0	0	27	0	0	0	0
L2	140	70	70	0	0	0	0	0	0	0
L3	57	17	40	0	0	0	0	0	0	0
L4	97	52	44	0	0	0	0	0	1	0
L5	188	34	137	0	0	14	0	3	0	0
L6	1499	613	613	0	0	233	0	40	0	0
P1-1	44	3	7	0	7	27	0	0	0	0
P1-2	114	86	27	0	0	0	0	0	1	0
P1-3	159	47	106	0	4	0	0	0	2	0
P1-4	225	63	133	0	7	4	0	6	6	6
P1-5	113	29	26	0	3	2	0	24	24	5
P2-1	23	0	4	0	0	3	0	16	0	0
P2-2	484	450	33	0	1	0	0	0	0	0
P2-3	184	55	118	0	0	1	0	10	0	0
P2-4	63	0	0	0	19	3	0	26	3	12
P2-5	573	491	73	0	0	0	3	0	0	6
P2-6	168	59	55	0	0	5	0	38	3	8
C-A1	417	78	337	0	0	2	0	0	0	0
C-A2	771	204	567	0	0	0	0	0	0	0
C-A3	709	322	383	0	0	0	0	2	2	0
C-A4	806	326	472	0	0	0	0	5	3	0
C-A5	2002	831	1148	0	0	21	0	2	0	0
C-A6	586	144	433	0	0	5	0	2	2	0
C-B1	657	254	397	0	0	3	0	3	0	0

C-B2	765	161	597	0	0	0	0	0	7	0
C-B3	800	374	410	0	0	3	0	0	13	0
C-B4	250	206	44	0	0	0	0	0	0	0
C-B5	658	509	149	0	0	0	0	0	0	0
C-B6	354	0	307	0	0	0	0	27	20	0
C-C1	633	544	89	0	0	0	0	0	0	0
C-C2	487	414	68	0	0	0	0	0	5	0
C-C3	533	487	46	0	0	0	0	0	0	0
C-C4	47	38	6	0	0	0	0	0	3	0
C-C5	103	86	14	0	0	0	0	3	0	0
C-C6	931	760	171	0	0	0	0	0	0	0
C-C7	524	4	470	0	0	0	0	42	4	4
C-D1	0	0	0	0	0	0	0	0	0	0
C-D2	200	186	14	0	0	0	0	0	0	0
C-D3	238	225	13	0	0	0	0	0	0	0
C-D4	367	308	57	0	0	0	0	0	2	0
C-D5	318	303	14	0	0	1	0	0	0	0
C-D6	363	349	14	0	0	0	0	0	0	0
C-D7	226	198	28	0	0	0	0	0	0	0
C-D8	130	0	94	0	0	0	0	36	0	0
C-E1	21	14	7	0	0	0	0	0	0	0
C-E2	801	679	120	0	0	2	0	0	0	0
C-E3	265	239	25	0	0	0	0	0	1	0
C-E4	46	46	0	0	0	0	0	0	0	0
C-E5	133	125	8	0	0	0	0	0	0	0
C-E6	97	89	8	0	0	0	0	0	0	0
C-E7	95	87	8	0	0	0	0	0	0	0
C-E8	511	465	46	0	0	0	0	0	0	0
C-E9	11	0	11	0	0	0	0	0	0	0

C-F1	24	0	4	0	4	0	0	14	2	0
C-F2	330	285	45	0	0	0	0	0	0	0
C-F3	162	149	13	0	0	0	0	0	0	0
C-F4	276	258	18	0	0	0	0	0	0	0
C-F5	100	87	13	0	0	0	0	0	0	0
C-F6	356	319	35	0	0	0	0	2	0	0
C-F7	208	187	21	0	0	0	0	0	0	0
C-F8	714	607	98	0	0	5	0	2	2	0
C-F9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C-G1	2	0	2	0	0	0	0	0	0	0
C-G2	1184	808	374	0	0	0	0	0	2	0
C-G3	593	499	94	0	0	0	0	0	0	0
C-G4	212	192	18	0	0	0	0	0	2	0
C-G5	252	240	12	0	0	0	0	0	0	0
C-G6	370	345	25	0	0	0	0	0	0	0
C-G7	202	179	23	0	0	0	0	0	0	0
C-G8	191	180	11	0	0	0	0	0	0	0
C-G9	842	686	156	0	0	0	0	0	0	0
C-G10	0	0	0	0	0	0	0	0	0	0
C-H1	0	0	0	0	0	0	0	0	0	0
C-H2	176	26	147	0	0	0	0	0	3	0
C-H3	850	725	122	0	0	0	0	0	3	0
C-H4	670	641	29	0	0	0	0	0	0	0
C-H5	250	225	25	0	0	0	0	0	0	0
C-H6	209	181	26	0	0	0	0	2	0	0
C-H7	293	259	34	0	0	0	0	0	0	0
C-H8	113	3	56	0	0	0	0	51	3	0
C-I1	112	27	85	0	0	0	0	0	0	0
C-I2	336	143	189	0	0	0	0	0	4	0

C-I3	806	390	413	0	0	0	0	0	3	0
C-I4	421	373	46	0	0	0	0	0	2	0
C-I5	596	520	74	0	0	0	0	2	0	0
C-I6	292	52	240	0	0	0	0	0	0	0
C-I7	4	4	0	0	0	0	0	0	0	0
C-J	0	0	0	0	0	0	0	0	0	0
CHA-1	6425	4992	1433	0	0	0	0	0	0	0
CHA-2	6009	5046	963	0	0	0	0	0	0	0
CHA-3	7348	5828	1520	0	0	0	0	0	0	0
CHA-4	10041	7891	2150	0	0	0	0	0	0	0
CHA-5	3746	3091	655	0	0	0	0	0	0	0
CHA-6	666	183	483	0	0	0	0	0	0	0
CHA-7	709	73	636	0	0	0	0	0	0	0
CHA-8	346	73	273	0	0	0	0	0	0	0
CHA-9	483	83	400	0	0	0	0	0	0	0
CHA-10	573	13	560	0	0	0	0	0	0	0
CH2-2M	993	507	475	0	0	0	0	11	0	0
CH3-2M	542	250	167	0	0	21	0	104	0	0
CH3-3M	591	290	213	0	0	11	0	77	0	0
CH3-6M	751	330	395	0	0	26	0	0	0	0
CH2-2S	124	71	44	0	0	9	0	0	0	0
CH3-2S	85	37	33	0	0	4	0	11	0	0
CH3-3S	280	132	115	0	0	0	0	33	0	0
CH3-6S	896	443	412	0	0	41	0	0	0	0
BEE1	666	512	116	0	0	30	0	4	4	0

BEE2	1285	1100	138	0	0	47	0	0	0	0
BEE3	62	20	36	0	0	4	0	2	0	0
BEE4	98	23	48	0	0	2	0	25	0	0
BEE5	194	32	153	0	0	9	0	0	0	0
J1	270	155	98	0	0	10	1	6	0	0
J2	357	219	130	0	0	7	0	1	0	0
FP1	139	30	67	0	0	29	0	5	3	5
FP2	942	509	281	0	0	121	0	24	7	0
FP3	338	276	58	0	0	3	0	1	0	0
FP4	484	409	68	0	0	5	0	2	0	0
FP5	641	347	267	0	0	11	0	8	8	0
FP6	432	141	251	0	0	7	0	19	14	0
FP7	880	381	431	0	3	0	0	56	9	0

9.4 Gastropods by relative abundance.

Location	Sample	*Mexipyrgus (%)*	*Nymphophilus (%)*	*Coahuilix (%)*	*Cochliopina (%)*	*Mexithauma (%)*	*Paludiscala (%)*	*Durangonella (%)*	*Physa (%)*	*Gastrocopta (%)*
Laguna Garabatal	G-A1	79	19	0	0	0	0	2	0	0
Laguna Garabatal	G-A2	78	20	0	0	2	0	0	0	0
Laguna Garabatal	G-A3	77	12	0	0	6	0	6	0	0
Laguna Garabatal	G-A4	40	52	0	0	6	0	0	2	0
Laguna Garabatal	G-A5	42	43	0	0	9	0	6	1	0
Laguna Garabatal	G-B1	59	39	0	0	2	0	0	0	0
Laguna Garabatal	G-B2	93	6	0	0	1	0	0	0	0
Laguna Garabatal	G-B3	57	40	0	0	3	0	0	0	0
Laguna Garabatal	G-B4	30	68	0	0	0	0	2	0	0
Laguna Garabatal	G-B5	19	79	0	0	0	0	2	0	0
Laguna Garabatal	G-B6	20	78	0	0	2	0	0	0	0
Laguna Garabatal	G-B7	31	62	0	0	6	0	0	1	0
Laguna Garabatal	G-B8	52	39	0	0	7	0	1	0	0
Laguna	G-B9	3	88	0	0	0	0	6	3	0

Garabatal										
Laguna Garabatal	G-C1	48	41	0	0	7	0	4	0	0
Laguna Garabatal	G-C2	23	63	0	0	14	0	0	0	0
Laguna Garabatal	G-C3	12	88	0	0	0	0	0	0	0
Laguna Garabatal	G-C4	0	100	0	0	0	0	0	0	0
Laguna Garabatal	G-C5	11	82	0	0	4	0	2	0	0
Laguna Garabatal	G-C6	11	78	0	0	5	0	6	0	0
Laguna Garabatal	G-C7	17	71	0	0	9	0	1	2	0
Laguna Garabatal	G-D1	60	40	0	0	0	0	0	0	0
Laguna Garabatal	G-D2	0	38	0	12	0	0	0	31	19
Laguna Garabatal	G-D3	29	60	0	0	6	0	0	6	0
Laguna Garabatal	G-D4	37	41	0	0	3	0	11	2	6
Laguna Garabatal	G-D5	26	25	0	0	9	0	38	1	0
Laguna Garabatal	G-D6	2	89	0	0	1	0	5	3	1
Lobe	L1	3	62	0	0	36	0	0	0	0
Lobe	L2	50	50	0	0	0	0	0	0	0
Lobe	L3	30	70	0	0	0	0	0	0	0

Lobe	L4	54	45	0	0	0	0	0	1	0
Lobe	L5	18	73	0	0	7	0	2	0	0
Lobe	L6	41	41	0	0	16	0	3	0	0
pool1	P1-1	7	16	0	16	61	0	0	0	0
pool1	P1-2	75	24	0	0	0	0	0	1	0
pool1	P1-3	30	67	0	3	0	0	0	1	0
pool1	P1-4	28	59	0	3	2	0	3	3	3
pool1	P1-5	26	23	0	3	2	0	21	21	4
pool2	P2-1	0	17	0	0	13	0	70	0	0
pool2	P2-2	93	7	0	0	0	0	0	0	0
pool2	P2-3	30	64	0	0	1	0	5	0	0
pool2	P2-4	0	0	0	30	5	0	41	5	19
pool2	P2-5	86	13	0	0	0	1	0	0	1
pool2	P2-6	35	33	0	0	3	0	23	2	5
Laguna Chara	C-A1	19	81	0	0	0	0	0	0	0
Laguna Chara	C-A2	26	74	0	0	0	0	0	0	0
Laguna Chara	C-A3	45	54	0	0	0	0	0	0	0
Laguna Chara	C-A4	40	59	0	0	0	0	1	0	0
Laguna Chara	C-A5	42	57	0	0	1	0	0	0	0
Laguna Chara	C-A6	25	74	0	0	1	0	0	0	0
Laguna Chara	C-B1	39	60	0	0	0	0	0	0	0
Laguna Chara	C-B2	21	78	0	0	0	0	0	1	0

Laguna Chara	C-B3	47	51	0	0	0	0	0	2	0
Laguna Chara	C-B4	82	18	0	0	0	0	0	0	0
Laguna Chara	C-B5	77	23	0	0	0	0	0	0	0
Laguna Chara	C-B6	0	87	0	0	0	0	8	6	0
Laguna Chara	C-C1	86	14	0	0	0	0	0	0	0
Laguna Chara	C-C2	85	14	0	0	0	0	0	1	0
Laguna Chara	CC3	91	9	0	0	0	0	0	0	0
Laguna Chara	C-C4	81	13	0	0	0	0	0	6	0
Laguna Chara	C-C5	83	14	0	0	0	0	3	0	0
Laguna Chara	C-C6	82	18	0	0	0	0	0	0	0
Laguna Chara	C-C7	1	90	0	0	0	0	8	1	1
Laguna Chara	C-D1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Laguna Chara	C-D2	93	7	0	0	0	0	0	0	0
Laguna Chara	C-D3	95	5	0	0	0	0	0	0	0
Laguna Chara	C-D4	84	16	0	0	0	0	0	1	0

Laguna Chara	C-D5	95	4	0	0	0	0	0	0	0
Laguna Chara	C-D6	96	4	0	0	0	0	0	0	0
Laguna Chara	C-D7	88	12	0	0	0	0	0	0	0
Laguna Chara	C-D8	0	72	0	0	0	0	28	0	0
Laguna Chara	C-E1	67	33	0	0	0	0	0	0	0
Laguna Chara	C-E2	85	15	0	0	0	0	0	0	0
Laguna Chara	C-E3	90	9	0	0	0	0	0	0	0
Laguna Chara	C-E4	100	0	0	0	0	0	0	0	0
Laguna Chara	C-E5	94	6	0	0	0	0	0	0	0
Laguna Chara	C-E6	92	8	0	0	0	0	0	0	0
Laguna Chara	C-E7	92	8	0	0	0	0	0	0	0
Laguna Chara	C-E8	91	9	0	0	0	0	0	0	0
Laguna Chara	C-E9	0	100	0	0	0	0	0	0	0
Laguna Chara	C-F1	0	17	0	17	0	0	58	8	0
Laguna Chara	C-F2	86	14	0	0	0	0	0	0	0

Laguna Chara	C-F3	92	8	0	0	0	0	0	0	0
Laguna Chara	C-F4	93	7	0	0	0	0	0	0	0
Laguna Chara	C-F5	87	13	0	0	0	0	0	0	0
Laguna Chara	C-F6	90	10	0	0	0	0	1	0	0
Laguna Chara	C-F7	90	10	0	0	0	0	0	0	0
Laguna Chara	C-F8	85	14	0	0	1	0	0	0	0
Laguna Chara	C-F9	NA	NA	NA	NA	NA	NA	NA	NA	NA
Laguna Chara	C-G1	0	100	0	0	0	0	0	0	0
Laguna Chara	C-G2	68	32	0	0	0	0	0	0	0
Laguna Chara	C-G3	84	16	0	0	0	0	0	0	0
Laguna Chara	C-G4	91	8	0	0	0	0	0	1	0
Laguna Chara	C-G5	95	5	0	0	0	0	0	0	0
Laguna Chara	C-G6	93	7	0	0	0	0	0	0	0
Laguna Chara	C-G7	89	11	0	0	0	0	0	0	0
Laguna Chara	C-G8	94	6	0	0	0	0	0	0	0

Laguna Chara	C-G9	81	19	0	0	0	0	0	0	0
Laguna Chara	C-G10	NA	NA	NA	NA	NA	NA	NA	NA	NA
Laguna Chara	C-H1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Laguna Chara	C-H2	15	84	0	0	0	0	0	2	0
Laguna Chara	C-H3	85	14	0	0	0	0	0	0	0
Laguna Chara	C-H4	96	4	0	0	0	0	0	0	0
Laguna Chara	C-H5	90	10	0	0	0	0	0	0	0
Laguna Chara	C-H6	87	12	0	0	0	0	1	0	0
Laguna Chara	C-H7	88	12	0	0	0	0	0	0	0
Laguna Chara	C-H8	3	50	0	0	0	0	45	3	0
Laguna Chara	C-I1	24	76	0	0	0	0	0	0	0
Laguna Chara	C-I2	43	56	0	0	0	0	0	1	0
Laguna Chara	C-I3	48	51	0	0	0	0	0	0	0
Laguna Chara	C-I4	89	11	0	0	0	0	0	0	0
Laguna Chara	C-I5	87	12	0	0	0	0	0	0	0

Laguna Chara	C-I6	18	82	0	0	0	0	0	0	0
Laguna Chara	C-I7	100	0	0	0	0	0	0	0	0
Laguna Chara	C-J	NA	NA	NA	NA	NA	NA	NA	NA	NA
channelA	CHA-1	78	22	0	0	0	0	0	0	0
channelA	CHA-2	84	16	0	0	0	0	0	0	0
channelA	CHA-3	79	21	0	0	0	0	0	0	0
channelA	CHA-4	79	21	0	0	0	0	0	0	0
channelA	CHA-5	83	17	0	0	0	0	0	0	0
channelA	CHA-6	27	73	0	0	0	0	0	0	0
channelA	CHA-7	10	90	0	0	0	0	0	0	0
channelA	CHA-8	21	79	0	0	0	0	0	0	0
channelA	CHA-9	17	83	0	0	0	0	0	0	0
channelA	CHA-10	2	98	0	0	0	0	0	0	0
channel2	CH2-2M	51	48	0	0	0	0	1	0	0
channel3	CH3-2M	46	31	0	0	4	0	19	0	0
channel3	CH3-3M	49	36	0	0	2	0	13	0	0
channel3	CH3-6M	44	53	0	0	3	0	0	0	0
channel2	CH2-2S	57	35	0	0	7	0	0	0	0
channel3	CH3-2S	44	39	0	0	5	0	13	0	0
channel3	CH3-3S	47	41	0	0	0	0	12	0	0
channel3	CH3-6S	49	46	0	0	5	0	0	0	0
Bee	BEE1	77	17	0	0	5	0	1	1	0
Bee	BEE2	86	11	0	0	4	0	0	0	0
Bee	BEE3	32	58	0	0	6	0	3	0	0
Bee	BEE4	23	49	0	0	2	0	26	0	0
Bee	BEE5	16	79	0	0	5	0	0	0	0

Jacuzzi1	J1	57	36	0	0	4	0	2	0	0
Jacuzzi2	J2	61	36	0	0	2	0	0	0	0
Playa1	FP1	22	48	0	0	21	0	4	2	4
Playa2	FP2	54	30	0	0	13	0	3	1	0
Playa3	FP3	82	17	0	0	1	0	0	0	0
Playa4	FP4	85	14	0	0	1	0	0	0	0
Playa5	FP5	54	42	0	0	2	0	1	1	0
Playa6	FP6	33	58	0	0	2	0	4	3	0
Playa7	FP7	43	49	0	0	0	0	6	1	0

9.5 Springhead samples (raw data).

Sample	Area	Weight	*Mexipyrgus*	*Nympho-philus*	*Coahuilix*	*Cocliopina*	*Mexi-thauma*	*Paludiscala*	*Durangonella*	*Physa*	*Gastrocopta*
S1-1	Posa Regrasando	100	25	71	58	4	5	0	63	3	1
S1-2	Posa Regrasando	120	13	19	0	0	0	0	1	0	0
S1-3	Posa Regrasando	100	15	16	0	0	0	0	0	0	0
S2-1	Laguna Garabatal	100	5	5	0	0	0	1	0	0	0
S2-2	Laguna Garabatal	310	54	13	0	0	1	0	3	1	0
S2-3	Laguna Garabatal	300	53	27	0	0	3	0	4	0	0
S2-4	Laguna Garabatal	350	78	28	0	0	5	0	1	0	0
S3	Bee Pool	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
S4-1	Unnamed	100	0	11	0	1	0	0	10	0	0
S4-2	Unnamed	100	3	8	0	0	0	0	15	2	0
S-3		100	3	11	0	0	0	0	2	3	1
S5-1	Active, unnamed	115	127	87	0	0	12	0	7	4	0
S5-2	Active, unnamed	100	7	50	0	0	0	0	3	0	0
S5-3	Active, unnamed	110	84	60	0	0	4	0	2	3	0
S6-1	Active, unnamed	675	0	0	0	0	0	0	0	0	0
S6-2	Active, unnamed	600	0	0	0	0	0	0	0	0	0
S6-3	Active, unnamed	580	0	0	0	0	0	0	0	0	0
S7	Laguna Garabatal	100	9	41	0	0	0	0	0	0	0

9.6 Springhead samples (per 1kg).

Sample	Area	Weight	*Mexipyrgus*	*Nymphophilus*	*Coahuilix*	*Cochliopina*	*Mexi-thauma*	*Paludiscala*	*Durangonella*	*Physa*	*Gastrocopta*
S1-1	Posa Regrasando	1kg	250	710	580	40	50	0	630	30	10
S1-2	Posa Regrasando	1kg	108	158	0	0	0	0	8	0	0
S1-3	Posa Regrasando	1kg	150	160	0	0	0	0	0	0	0
S2-1	Laguna Garabatal	1kg	50	50	0	0	0	10	0	0	0
S2-2	Laguna Garabatal	1kg	174	42	0	0	3	0	10	3	0
S2-3	Laguna Garabatal	1kg	177	90	0	0	10	0	13	0	0
S2-4	Laguna Garabatal	1kg	223	80	0	0	14	0	3	0	0
S3	Bee Pool	1kg	NA	NA	NA	NA	NA	NA	NA	NA	NA
S4-1	Unnamed	1kg	0	110	0	10	0	0	100	0	0
S4-2	Unnamed	1kg	30	80	0	0	0	0	150	20	0
SH-3		1kg	30	110	0	0	0	0	20	30	10
SH5-1	Active, unnamed	1kg	1104	757	0	0	104	0	61	35	0
SH5-2	Active, unnamed	1kg	70	500	0	0	0	0	30	0	0
SH5-3	Active, unnamed	1kg	764	545	0	0	36	0	18	27	0
SH6-1	Active, unnamed	1kg	0	0	0	0	0	0	0	0	0
SH6-2	Active, unnamed	1kg	0	0	0	0	0	0	0	0	0
SH6-3	Active, unnamed	1kg	0	0	0	0	0	0	0	0	0
SH7	Laguna Garabatal	1kg	90	410	0	0	0	0	0	0	0

9.7 X-Ray Diffraction samples.

Sample #	**Species**	**Description**
1	*M. carranzae*	Shell from active system directly north of the field site, next to road1. Living specimen collected.
5	*N. minckleyi*	Shell from active system, Rio Mesquites system on eastern lobe of basin. Living specimen collected.
9	*M. quadripaludium*	White shell, from Lobe. Surface of dried pool.
9D	*N/A*	Substrate matrix from inside shell
10	*M. quadripaludium*	Pink shell, from Lobe. Surface of dried pool.
11	*M. carranzae*	Laguna Chara pit sample, collected at 10cm depth
12	*N. minckleyi*	Laguna Chara pit sample, collected at 10cm depth
29	*M. carranzae*	Laguna Chara pit sample, collected at 100cm depth
30	*N. minckleyi*	Laguna Chara pit sample, collected at 100cm depth

9.8 Possible associations for Association Analysis.

Association #	*Mexipyrgus (1)*	*Nymphophilus (2)*	*Mexithauma (4)*	*Durangonella (8)*	*Cochliopina (16)*	*Physa (32)*
1	X					
2		X				
3	X	X				
4			X			
5	X		X			
6		X	X			
7	X	X	X			
8				X		
9	X			X		
10		X		X		
11	X	X		X		
12			X	X		
13	X		X	X		
14		X	X	X		
15	X	X	X	X		
16					X	
17	X				X	
18		X			X	
19	X	X			X	
20			X		X	
21	X		X		X	
22	X	X	X		X	
23	X	X	X		X	
24				X	X	
25	X			X	X	
26		X		X	X	
27	X	X		X	X	
28			X	X	X	
29	X		X	X	X	
30		X	X	X	X	
31	X	X	X	X	X	
32						X
33	X					X
34		X				X
35	X	X				X
36			X			X
37	X		X			X
38		X	X			X
39	X	X	X			X
40				X		X

41	X			X		X
42		X		X		X
43	X	X		X		X
44			X	X		X
45	X		X	X		X
46		X	X	X		X
47	X	X	X	X		X
48				X		X
49	X			X		X
50		X			X	X
51	X	X			X	X
52			X		X	X
53	X		X		X	X
54	X	X	X		X	X
55	X	X	X		X	X
56				X	X	X
57	X			X	X	X
58		X		X	X	X
59	X	X		X	X	X
60			X	X	X	X
61	X		X	X	X	X
62		X	X	X	X	X
63	X	X	X	X	X	X

Appendix 9.9 Association Analysis-# occurrences a) Sample data set b) Null data set.

a.)Sample data set

Assoc.-#	# occur.
0	4
1	2
2	3
3	46
7	15
10	1
11	9
14	1
15	18
19	1
23	1
35	14
39	4
42	1
43	4
47	13
50	1
51	1
58	1
59	2
60	1
63	3

b.)Null data set

Assoc. #	# occur.	divided 1000
0	147	0.147
1	1600	1.6
2	3165	3.165
3	31702	31.702
4	106	0.106
5	1042	1.042
6	2025	2.025
7	19948	19.948
8	103	0.103
9	901	0.901
10	1821	1.821
11	18312	18.312
12	59	0.059
13	622	0.622
14	1141	1.141
15	11640	11.64
16	14	0.014
17	112	0.112
18	224	0.224
19	2388	2.388
20	2	0.002
21	76	0.076
22	148	0.148
23	1492	1.492
24	7	0.007
25	77	0.077
26	134	0.134
27	1405	1.405
28	6	0.006
29	51	0.051
30	91	0.091
31	805	0.805
32	56	0.056
33	707	0.707
34	1341	1.341
35	14042	14.042
36	33	0.033
37	448	0.448
38	833	0.833
39	8774	8.774
40	46	0.046
41	414	0.414
42	832	0.832
43	8018	8.018
44	25	0.025
45	298	0.298
46	497	0.497
47	5229	5.229
48	3	0.003
49	43	0.043
50	94	0.094
51	1079	1.079
52	4	0.004
53	25	0.025
54	63	0.063
55	645	0.645
56	2	0.002
57	26	0.026
58	72	0.072
59	550	0.55
61	17	0.017
62	39	0.039
63	342	0.342

\# Assoc.= Association number
\# occur= Number of occurrences of the association
divide 1000= “# occur.” column is divided by 1,000

9.10 Association Analysis- Difference between sample and null data sets.

comb #	Ha (n=1)	Ha (p)	Ho(n=1000)	Ho (n=1)	Ho (p) (n=1)	Ha-Ho (n=1)	Ha-Ho (p)(n=1)
0	**4**	**0.027**	147	0.147	0.001	3.853	0.281652047
1	**2**	**0.014**	1600	1.6	0.012	0.4	0.029239766
2	3	**0.021**	3165	3.165	0.024	-0.165	-0.012061404
3	**46**	**0.315**	31702	31.702	0.240	14.298	1.045175439
7	15	**0.103**	19948	19.948	0.151	-4.948	-0.361695906
10	1	**0.007**	1821	1.821	0.014	-0.821	-0.06001462
11	9	**0.062**	18312	18.312	0.138	-9.312	-0.680701754
14	1	**0.007**	1141	1.141	0.009	-0.141	-0.010307018
15	**18**	**0.123**	11640	11.64	0.088	6.36	0.464912281
19	1	**0.007**	2388	2.388	0.018	-1.388	-0.101461988
23	1	**0.007**	1492	1.492	0.011	-0.492	-0.035964912
35	14	**0.096**	14042	14.042	0.106	-0.042	-0.003070175
39	4	**0.027**	8774	8.774	0.066	-4.774	-0.348976608
42	**1**	**0.007**	832	0.832	0.006	0.168	0.012280702
43	4	**0.027**	8018	8.018	0.061	-4.018	-0.29371345
47	**13**	**0.089**	5229	5.229	0.040	7.771	0.568055556
50	**1**	**0.007**	94	0.094	0.001	0.906	0.06622807
51	1	**0.007**	1079	1.079	0.008	-0.079	-0.005774854
58	**1**	**0.007**	4	0.004	0.000	0.996	0.072807018
59	**2**	**0.014**	550	0.55	0.004	1.45	0.105994152
60	**1**	**0.007**	0	0	0.000	1	0.073099415
63	**3**	**0.021**	342	0.342	0.003	2.658	0.194298246

Ho= null data set Ha= sampled data set

9.11. Association Analysis- Mean weighted % of occurrences (sample data set).

Comb #	#	M(mean)	N(mean)	T(mean)	D(mean)	C(mean)	P(mean)	M-w	N-w	C-w	T-w	D-w	P-w
1	2	100.0	0.0	0.0	0.0	0.0	0.0	200.0	0.0	0.0	0.0	0.0	0.0
2	3	0.0	100.0	0.0	0.0	0.0	0.0	0.0	300.0	0.0	0.0	0.0	0.0
3	58	70.9	28.9	0.0	0.0	0.0	0.0	4113.0	1679.0	0.0	0.0	0.0	0.0
7	18	53.6	41.3	5.1	0.0	0.0	0.0	965.0	744.0	91.0	0.0	0.0	0.0
10	1	0.0	72.0	0.0	28.0	0.0	0.0	0.0	72.0	0.0	28.0	0.0	0.0
11	9	58.4	38.9	0.0	2.8	0.0	0.0	526.0	350.0	0.0	25.0	0.0	0.0
14	1	0.0	17.0	13.0	70.0	0.0	0.0	0.0	17.0	13.0	70.0	0.0	0.0
15	14	38.5	48.5	5.4	7.5	0.0	0.0	539.0	679.0	76.0	105.0	0.0	0.0
23	1	7.0	16.0	61.0	0.0	16.0	0.0	7.0	16.0	61.0	0.0	16.0	0.0
35	10	59.6	38.9	0.0	0.0	0.0	1.7	596.0	389.0	0.0	0.0	0.0	17.0
39	3	33.3	58.0	6.0	0.0	0.0	3.0	100.0	174.0	18.0	0.0	0.0	9.0
42	1	0.0	87.0	0.0	8.0	0.0	6.0	0.0	87.0	0.0	8.0	0.0	6.0
43	4	12.5	69.3	0.0	16.3	0.0	2.0	50.0	277.0	0.0	65.0	0.0	8.0
47	11	36.3	45.2	7.0	8.8	0.0	1.7	399.0	497.0	77.0	97.0	0.0	19.0
50	1	0.0	38.0	0.0	0.0	12.0	31.0	0.0	38.0	0.0	0.0	12.0	31.0
51	1	30.0	67.0	0.0	0.0	3.0	1.0	30.0	67.0	0.0	0.0	3.0	1.0
58	1	0.0	17.0	0.0	58.0	17.0	8.0	0.0	17.0	0.0	58.0	17.0	8.0
60	1	0.0	0.0	5.0	41.0	30.0	5.0	0.0	0.0	5.0	41.0	30.0	5.0
63	2	27.0	41.0	2.0	12.0	3.0	12.0	54.0	82.0	4.0	24.0	6.0	24.0

M=Mexipyrgus D=Durangonella C=Cochliopina P=Physa N=*Nymphophilus* T=*Mexithauma*

9.12 Association Analysis- Mean weighted % (null data set).

Comb #	#	M (mean)	N(mean)	T(mean)	D(mean)	C(mean)	P(mean)	w-M	w-N	w-T	w-D	w-C	w-P
0.0	67.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	905.0	57.2	0.0	0.0	0.0	0.0	0.0	51.8	0.0	0.0	0.0	0.0	0.0
2.0	2916.0	0.0	39.0	0.0	0.0	0.0	0.0	0.0	113.8	0.0	0.0	0.0	0.0
3.0	42276.0	57.2	39.4	0.0	0.0	0.0	0.0	2417.1	1667.6	0.0	0.0	0.0	0.0
4.0	48.0	0.0	0.0	6.9	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
5.0	517.0	57.4	0.0	7.4	0.0	0.0	0.0	29.7	0.0	3.8	0.0	0.0	0.0
6.0	1698.0	0.0	39.9	6.7	0.0	0.0	0.0	0.0	67.8	11.4	0.0	0.0	0.0
7.0	23997.0	57.2	39.3	6.7	0.0	0.0	0.0	1372.4	943.9	160.9	0.0	0.0	0.0
8.0	28.0	0.0	0.0	0.0	14.5	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
9.0	415.0	58.1	0.0	0.0	11.8	0.0	0.0	24.1	0.0	0.0	4.9	0.0	0.0
10.0	1358.0	0.0	39.5	0.0	12.9	0.0	0.0	0.0	53.7	0.0	17.5	0.0	0.0
11.0	19042.0	57.1	39.5	0.0	11.7	0.0	0.0	1086.9	752.5	0.0	222.5	0.0	0.0
12.0	18.0	0.0	0.0	7.9	8.7	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0
13.0	240.0	55.9	0.0	6.8	10.1	0.0	0.0	13.4	0.0	1.6	2.4	0.0	0.0
14.0	740.0	0.0	38.8	5.8	12.5	0.0	0.0	0.0	28.7	4.3	9.2	0.0	0.0
15.0	11020.0	57.3	39.2	6.8	11.5	0.0	0.0	631.8	432.4	75.3	126.8	0.0	0.0
16.0	3.0	0.0	0.0	0.0	0.0	19.7	0.0	0.0	0.0	0.0	0.0	0.1	0.0
17.0	43.0	53.4	0.0	0.0	0.0	12.7	0.0	2.3	0.0	0.0	0.0	0.5	0.0
18.0	140.0	0.0	35.1	0.0	0.0	12.4	0.0	0.0	4.9	0.0	0.0	1.7	0.0
19.0	2162.0	56.5	39.1	0.0	0.0	12.0	0.0	122.2	84.6	0.0	0.0	26.0	0.0
20.0	3.0	0.0	0.0	21.7	0.0	21.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
21.0	29.0	60.7	0.0	5.8	0.0	11.7	0.0	1.8	0.0	0.2	0.0	0.3	0.0
22.0	90.0	0.0	37.2	7.2	0.0	11.2	0.0	0.0	3.4	0.6	0.0	1.0	0.0
23.0	1356.0	56.8	38.6	6.8	0.0	12.0	0.0	77.0	52.4	9.2	0.0	16.3	0.0
24.0	1.0	0.0	0.0	0.0	2.0	17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

25.0	17.0	57.3	0.0	0.0	7.8	13.8	0.0	1.0	0.0	0.0	0.1	0.2	0.0
26.0	64.0	0.0	33.8	0.0	12.7	13.7	0.0	0.0	2.2	0.0	0.8	0.9	0.0
27.0	982.0	58.1	40.3	0.0	11.3	12.0	0.0	57.0	39.5	0.0	11.1	11.8	0.0
28.0	1.0	0.0	0.0	3.0	21.0	17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29.0	15.0	70.7	0.0	5.9	10.1	11.8	0.0	1.1	0.0	0.1	0.2	0.2	0.0
30.0	38.0	0.0	37.1	5.4	15.2	12.8	0.0	0.0	1.4	0.2	0.6	0.5	0.0
31.0	586.0	57.1	39.9	6.5	11.3	11.4	0.0	33.5	23.4	3.8	6.6	6.7	0.0
32.0	16.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.1
33.0	299.0	57.7	0.0	0.0	0.0	0.0	3.5	17.2	0.0	0.0	0.0	0.0	1.0
34.0	894.0	0.0	41.7	0.0	0.0	0.0	3.7	0.0	37.3	0.0	0.0	0.0	3.3
35.0	13418.0	57.1	39.2	0.0	0.0	0.0	3.6	766.0	526.2	0.0	0.0	0.0	49.0
36.0	9.0	0.0	0.0	4.9	0.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0	0.0
37.0	160.0	54.8	0.0	5.8	0.0	0.0	3.1	8.8	0.0	0.9	0.0	0.0	0.5
38.0	518.0	0.0	41.4	7.2	0.0	0.0	3.7	0.0	21.4	3.7	0.0	0.0	1.9
39.0	7556.0	56.3	39.5	6.6	0.0	0.0	3.6	425.3	298.1	50.1	0.0	0.0	27.5
40.0	5.0	0.0	0.0	0.0	16.0	0.0	1.4	0.0	0.0	0.0	0.1	0.0	0.0
41.0	134.0	55.3	0.0	0.0	12.4	0.0	3.3	7.4	0.0	0.0	1.7	0.0	0.4
42.0	408.0	0.0	40.8	0.0	10.6	0.0	3.4	0.0	16.7	0.0	4.3	0.0	1.4
43.0	6102.0	57.4	39.5	0.0	11.9	0.0	3.6	350.3	240.8	0.0	72.8	0.0	22.3
44.0	3.0	0.0	0.0	4.0	3.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0
45.0	64.0	62.1	0.0	8.0	11.2	0.0	3.5	4.0	0.0	0.5	0.7	0.0	0.2
46.0	246.0	0.0	37.7	6.3	11.4	0.0	3.9	0.0	9.3	1.6	2.8	0.0	1.0
47.0	3520.0	56.3	39.9	6.9	11.8	0.0	3.7	198.1	140.6	24.4	41.4	0.0	13.2
48.0	1.0	0.0	0.0	0.0	0.0	3.0	21.0	0.0	0.0	0.0	0.0	0.0	0.0
49.0	14.0	71.6	0.0	0.0	0.0	13.2	2.5	1.0	0.0	0.0	0.0	0.2	0.0
50.0	33.0	0.0	27.6	0.0	0.0	12.9	3.2	0.0	0.9	0.0	0.0	0.4	0.1
51.0	688.0	57.9	39.0	0.0	0.0	12.4	4.0	39.8	26.9	0.0	0.0	8.5	2.7
53.0	7.0	50.6	0.0	18.7	0.0	10.1	1.9	0.4	0.0	0.1	0.0	0.1	0.0
54.0	26.0	0.0	44.9	6.9	0.0	12.1	3.7	0.0	1.2	0.2	0.0	0.3	0.1

55.0	413.0	57.9	39.0	6.4	0.0	12.7	3.7	23.9	16.1	2.6	0.0	5.2	1.5
56.0	1.0	0.0	0.0	0.0	4.0	3.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0
57.0	6.0	46.8	0.0	0.0	15.5	11.2	3.5	0.3	0.0	0.0	0.1	0.1	0.0
58.0	19.0	0.0	31.1	0.0	18.6	13.7	4.3	0.0	0.6	0.0	0.4	0.3	0.1
59.0	295.0	55.3	37.0	0.0	12.4	12.6	3.9	16.3	10.9	0.0	3.7	3.7	1.2
61.0	6.0	73.0	0.0	2.0	21.3	13.5	3.7	0.4	0.0	0.0	0.1	0.1	0.0
62.0	10.0	0.0	47.0	4.4	6.6	7.1	2.5	0.0	0.5	0.0	0.1	0.1	0.0
63.0	188.0	58.3	39.2	6.0	11.0	12.5	3.6	11.0	7.4	1.1	2.1	2.4	0.7

M=Mexipyrgus N=Nymphophilus T=Mexithauma D=*Durangonella* C=*Cochliopina* P=*Physa*

9.13 Association Analysis- Mean weighted # (sample data set)

Comb #	# occurrences	Mean M	Mean N	Mean C	Mean T	Mean D	Mean P	M w	N w	C w	T w	D w	P w
0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2.0	25.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0
2	3.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	33.0	0.0	0.0	0.0	0.0
3	46.0	796.7	247.7	0.0	0.0	0.0	0.0	36648.0	11392.0	0.0	0.0	0.0	0.0
7	15.0	262.9	136.1	0.0	12.6	0.0	0.0	3944.0	2041.0	0.0	189.0	0.0	0.0
10	1.0	0.0	94.0	0.0	0.0	36.0	0.0	0.0	94.0	0.0	0.0	36.0	0.0
11	9.0	230.7	101.8	0.0	0.0	7.1	0.0	2076.0	916.0	0.0	0.0	64.0	0.0
14	1.0	0.0	4.0	0.0	3.0	16.0	0.0	0.0	4.0	0.0	3.0	16.0	0.0
15	18.0	215.8	247.3	0.0	23.8	20.3	0.0	3885.0	4451.0	0.0	428.0	366.0	0.0
19	1.0	450.0	33.0	1.0	0.0	0.0	0.0	450.0	33.0	1.0	0.0	0.0	0.0
23	1.0	3.0	7.0	7.0	27.0	0.0	0.0	3.0	7.0	7.0	27.0	0.0	0.0
35	14.0	282.5	152.4	0.0	0.0	0.0	2.8	3955.0	2133.0	0.0	0.0	0.0	39.0
39	4.0	134.3	174.8	0.0	7.8	0.0	5.0	537.0	699.0	0.0	31.0	0.0	20.0
42	1.0	0.0	307.0	0.0	0.0	27.0	20.0	0.0	307.0	0.0	0.0	27.0	20.0
43	4.0	163.8	345.3	0.0	0.0	25.0	3.0	655.0	1381.0	0.0	0.0	100.0	12.0
47	13.0	282.4	232.8	0.0	33.6	35.5	6.1	3671.0	3027.0	0.0	437.0	462.0	79.0
50	1.0	0.0	10.0	3.0	0.0	0.0	8.0	0.0	10.0	3.0	0.0	0.0	8.0
51	1.0	47.0	106.0	4.0	0.0	0.0	2.0	47.0	106.0	4.0	0.0	0.0	2.0
58	1.0	0.0	4.0	4.0	0.0	14.0	2.0	0.0	4.0	4.0	0.0	14.0	2.0
59	2.0	202.5	635.5	3.5	0.0	56.0	18.5	405.0	1271.0	7.0	0.0	112.0	37.0
60	1.0	0.0	0.0	19.0	3.0	26.0	3.0	0.0	0.0	19.0	3.0	26.0	3.0
63	3.0	58.7	170.7	4.0	17.0	11.0	13.0	176.0	512.0	12.0	51.0	33.0	39.0

M=*Mexipyrgus* C=*Cochliopina* N=*Nymphophilus* P=*Physa* T=*Mexithauma* D=*Durangonella*

9.14 Association Analysis- Mean weighted # (null data set)

Comb #	#	M (mean)	N(mean)	T(mean)	D(mean)	C(mean)	P(mean)	Mw	Nw	Tw	Dw	Cw	Pw
0.0	123.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	1590.0	412.6	0.0	0.0	0.0	0.0	0.0	656.0	0.0	0.0	0.0	0.0	0.0
2.0	3164.0	0.0	201.4	0.0	0.0	0.0	0.0	0.0	637.3	0.0	0.0	0.0	0.0
3.0	32069.0	426.8	203.0	0.0	0.0	0.0	0.0	13686.5	6511.1	0.0	0.0	0.0	0.0
4.0	114.0	0.0	0.0	20.6	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0
5.0	1014.0	421.2	0.0	21.5	0.0	0.0	0.0	427.1	0.0	21.8	0.0	0.0	0.0
6.0	1981.0	0.0	202.8	22.8	0.0	0.0	0.0	0.0	401.8	45.1	0.0	0.0	0.0
7.0	19985.0	425.2	204.9	20.8	0.0	0.0	0.0	8497.5	4094.7	416.5	0.0	0.0	0.0
8.0	81.0	0.0	0.0	0.0	16.4	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0
9.0	930.0	455.8	0.0	0.0	23.9	0.0	0.0	423.9	0.0	0.0	22.2	0.0	0.0
10.0	1825.0	0.0	203.0	0.0	23.9	0.0	0.0	0.0	370.4	0.0	43.5	0.0	0.0
11.0	18412.0	421.1	204.7	0.0	22.8	0.0	0.0	7752.8	3768.6	0.0	419.1	0.0	0.0
12.0	63.0	0.0	0.0	28.5	23.9	0.0	0.0	0.0	0.0	1.8	1.5	0.0	0.0
13.0	545.0	416.2	0.0	20.3	23.1	0.0	0.0	226.8	0.0	11.0	12.6	0.0	0.0
14.0	1105.0	0.0	196.2	21.4	22.2	0.0	0.0	0.0	216.8	23.6	24.6	0.0	0.0
15.0	11780.0	439.7	205.5	21.2	22.2	0.0	0.0	5179.7	2421.3	250.1	261.8	0.0	0.0
16.0	10.0	0.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0	0.0	0.1	0.0
17.0	123.0	538.9	0.0	0.0	0.0	4.9	0.0	66.3	0.0	0.0	0.0	0.6	0.0
18.0	242.0	0.0	177.9	0.0	0.0	5.6	0.0	0.0	43.1	0.0	0.0	1.4	0.0
19.0	2362.0	428.5	211.9	0.0	0.0	5.3	0.0	1012.1	500.4	0.0	0.0	12.6	0.0
20.0	12.0	0.0	0.0	11.3	0.0	4.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
21.0	74.0	369.9	0.0	16.5	0.0	5.5	0.0	27.4	0.0	1.2	0.0	0.4	0.0
22.0	139.0	0.0	235.3	20.9	0.0	5.2	0.0	0.0	32.7	2.9	0.0	0.7	0.0
23.0	1470.0	404.0	199.5	20.7	0.0	5.6	0.0	593.9	293.3	30.4	0.0	8.3	0.0
24.0	10.0	0.0	0.0	0.0	12.3	8.8	0.0	0.0	0.0	0.0	0.1	0.1	0.0
25.0	66.0	332.8	0.0	0.0	36.2	4.0	0.0	22.0	0.0	0.0	2.4	0.3	0.0

26.0	136.0	0.0	187.6	0.0	21.8	5.3	0.0	0.0	25.5	0.0	3.0	0.7	0.0
27.0	1292.0	400.9	208.4	0.0	22.3	5.6	0.0	518.0	269.3	0.0	28.8	7.2	0.0
28.0	8.0	0.0	0.0	22.0	13.6	5.1	0.0	0.0	0.0	0.2	0.1	0.0	0.0
29.0	37.0	233.9	0.0	22.8	23.1	5.3	0.0	8.7	0.0	0.8	0.9	0.2	0.0
30.0	79.0	0.0	248.3	18.0	18.3	4.5	0.0	0.0	19.6	1.4	1.4	0.4	0.0
31.0	835.0	443.2	204.5	19.0	24.1	5.5	0.0	370.1	170.8	15.9	20.2	4.6	0.0
32.0	61.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.3
33.0	747.0	411.1	0.0	0.0	0.0	0.0	6.0	307.1	0.0	0.0	0.0	0.0	4.5
34.0	1386.0	0.0	195.5	0.0	0.0	0.0	5.9	0.0	270.9	0.0	0.0	0.0	8.1
35.0	13898.0	419.0	203.6	0.0	0.0	0.0	5.8	5822.9	2829.9	0.0	0.0	0.0	80.1
36.0	26.0	0.0	0.0	11.0	0.0	0.0	7.2	0.0	0.0	0.3	0.0	0.0	0.2
37.0	408.0	439.3	0.0	20.2	0.0	0.0	5.6	179.2	0.0	8.2	0.0	0.0	2.3
38.0	833.0	0.0	188.0	22.3	0.0	0.0	5.9	0.0	156.6	18.6	0.0	0.0	4.9
39.0	8853.0	440.2	210.2	21.8	0.0	0.0	5.8	3897.5	1860.8	193.3	0.0	0.0	51.7
40.0	40.0	0.0	0.0	0.0	19.9	0.0	6.2	0.0	0.0	0.0	0.8	0.0	0.2
41.0	366.0	498.6	0.0	0.0	20.7	0.0	5.2	182.5	0.0	0.0	7.6	0.0	1.9
42.0	792.0	0.0	213.4	0.0	20.7	0.0	5.5	0.0	169.0	0.0	16.4	0.0	4.3
43.0	8067.0	439.7	199.7	0.0	22.0	0.0	5.8	3547.0	1611.1	0.0	177.7	0.0	46.6
44.0	28.0	0.0	0.0	29.6	21.7	0.0	4.1	0.0	0.0	0.8	0.6	0.0	0.1
45.0	269.0	502.8	0.0	19.9	20.8	0.0	5.8	135.3	0.0	5.3	5.6	0.0	1.6
46.0	514.0	0.0	196.5	19.7	23.6	0.0	6.0	0.0	101.0	10.1	12.1	0.0	3.1
47.0	4990.0	418.2	205.4	21.6	22.6	0.0	5.8	2086.7	1025.1	107.7	112.6	0.0	29.1
48.0	4.0	0.0	0.0	0.0	0.0	3.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0
49.0	48.0	344.7	0.0	0.0	0.0	4.6	6.1	16.5	0.0	0.0	0.0	0.2	0.3
50.0	105.0	0.0	133.7	0.0	0.0	5.5	5.4	0.0	14.0	0.0	0.0	0.6	0.6
51.0	1031.0	491.5	204.5	0.0	0.0	5.3	5.7	506.7	210.9	0.0	0.0	5.5	5.9
52.0	3.0	0.0	0.0	21.3	0.0	4.7	8.0	0.0	0.0	0.1	0.0	0.0	0.0
53.0	29.0	456.0	0.0	27.0	0.0	5.3	6.3	13.2	0.0	0.8	0.0	0.2	0.2
54.0	54.0	0.0	158.9	15.5	0.0	5.4	5.1	0.0	8.6	0.8	0.0	0.3	0.3

55.0	658.0	463.9	197.2	18.9	0.0	5.3	5.8	305.2	129.8	12.4	0.0	3.5	3.8
57.0	28.0	474.8	0.0	0.0	24.7	5.2	5.2	13.3	0.0	0.0	0.7	0.1	0.1
58.0	51.0	0.0	178.1	0.0	16.2	5.9	4.6	0.0	9.1	0.0	0.8	0.3	0.2
59.0	595.0	482.9	189.7	0.0	24.9	5.3	5.6	287.3	112.9	0.0	14.8	3.1	3.4
60.0	2.0	0.0	0.0	27.5	20.5	3.5	5.5	0.0	0.0	0.1	0.0	0.0	0.0
61.0	17.0	335.9	0.0	14.2	22.4	6.8	5.9	5.7	0.0	0.2	0.4	0.1	0.1
62.0	37.0	0.0	210.4	18.4	15.1	5.6	6.3	0.0	7.8	0.7	0.6	0.2	0.2
63.0	384.0	498.5	214.0	21.1	22.1	5.4	5.9	191.4	82.2	8.1	8.5	2.1	2.3

M=Mexipyrgus N=Nymphophilus T=Mexithauma D=*Durangonella* C=*Cochliopina* P=*Physa*
Mw= weighted *Mexipyrgus* Nw=weighted *Nymphophilus* Tw=weighted *Mexithauma* Dw=weighted *Durangonella*
Cw=weighted *Cochliopina* Pw=weighted *Physa*

9.15 Association Analysis- Summary

a.) Ha Mean weighted %

Comb #	Mw	Nw	Cw	Tw	Dw	Pw
1	200.0	0.0	0.0	0.0	0.0	0.0
2	0.0	300.0	0.0	0.0	0.0	0.0
3	4113.0	1679.0	0.0	0.0	0.0	0.0
7	965.0	744.0	91.0	0.0	0.0	0.0
10	0.0	72.0	0.0	28.0	0.0	0.0
11	526.0	350.0	0.0	25.0	0.0	0.0
14	0.0	17.0	13.0	70.0	0.0	0.0
15	539.0	679.0	76.0	105.0	0.0	0.0
23	7.0	16.0	61.0	0.0	16.0	0.0
35	596.0	389.0	0.0	0.0	0.0	17.0
39	100.0	174.0	18.0	0.0	0.0	9.0
42	0.0	87.0	0.0	8.0	0.0	6.0
43	50.0	277.0	0.0	65.0	0.0	8.0
47	399.0	497.0	77.0	97.0	0.0	19.0
50	0.0	38.0	0.0	0.0	12.0	31.0
51	30.0	67.0	0.0	0.0	3.0	1.0
58	0.0	17.0	0.0	58.0	17.0	8.0
60	0.0	0.0	5.0	41.0	30.0	5.0
63	54.0	82.0	4.0	24.0	6.0	24.0

b.)Ho Mean weighted %

Comb #	Mw	Nw	Tw	Dw	Cw	Pw
1.0	51.8	0.0	0.0	0.0	0.0	0.0
2.0	0.0	113.8	0.0	0.0	0.0	0.0
3.0	2417.1	1667.6	0.0	0.0	0.0	0.0
7.0	1372.4	943.9	160.9	0.0	0.0	0.0
10.0	0.0	53.7	0.0	17.5	0.0	0.0
11.0	1086.9	752.5	0.0	222.5	0.0	0.0
14.0	0.0	28.7	4.3	9.2	0.0	0.0
15.0	631.8	432.4	75.3	126.8	0.0	0.0
23.0	77.0	52.4	9.2	0.0	16.3	0.0
35.0	766.0	526.2	0.0	0.0	0.0	49.0
39.0	425.3	298.1	50.1	0.0	0.0	27.5
42.0	0.0	16.7	0.0	4.3	0.0	1.4
43.0	350.3	240.8	0.0	72.8	0.0	22.3
47.0	198.1	140.6	24.4	41.4	0.0	13.2
50.0	0.0	0.9	0.0	0.0	0.4	0.1
51.0	39.8	26.9	0.0	0.0	8.5	2.7
58.0	0.0	0.6	0.0	0.4	0.3	0.1
60.0	0.0	0.0	0.0	0.0	0.0	0.0
63.0	11.0	7.4	1.1	2.1	2.4	0.7

Mw=weighted *Mexipyrgus* Nw=weighted *Nymphophilus* Tw=weighted *Mexithauma* Dw=weighted *Durangonella* C=weighted *Cochliopina* Pw=weighted *Physa*

c.) Ha-Ho Mean weighted %

Comb #	Mw	Nw	Tw	Dw	Cw	Pw
1	148.2	0.0	0.0	0.0	0.0	0.0
2	0.0	186.2	0.0	0.0	0.0	0.0
3	1695.9	11.4	0.0	0.0	0.0	0.0
7	-407.4	-199.9	-69.9	0.0	0.0	0.0
10	0.0	18.3	0.0	10.5	0.0	0.0
11	-560.9	-402.5	0.0	-197.5	0.0	0.0
14	0.0	-11.7	8.7	60.8	0.0	0.0
15	-92.8	246.6	0.7	-21.8	0.0	0.0
23	-70.0	-36.4	51.8	0.0	-0.3	0.0
35	-170.0	-137.2	0.0	0.0	0.0	-32.0
39	-325.3	-124.1	-32.1	0.0	0.0	-18.5
42	0.0	70.3	0.0	3.7	0.0	4.6
43	-300.3	36.2	0.0	-7.8	0.0	-14.3
47	200.9	356.4	52.6	55.6	0.0	5.8
50	0.0	37.1	0.0	0.0	11.6	30.9
51	-9.8	40.1	0.0	0.0	-5.5	-1.7
58	0.0	16.4	0.0	57.6	16.7	7.9
60	0.0	0.0	5.0	41.0	30.0	5.0
63	43.0	74.6	2.9	21.9	3.6	23.3

d.) % of each Mean weighted %

Comb #	Mw	Nw	Tw	Dw	Cw	Pw
1	7.1					
2		17.0				
3	81.2	1.0				
7						
10		1.7				
11						
14			7.2	25.3		
15		22.5	0.6			
23			42.8			
35						
39						
42		6.4		1.5		5.9
43		3.3				
47	9.6	32.6	43.5	23.1		7.5
50		3.4			18.7	39.9
51		3.7				
58		1.5		23.9	27	10.2
60			4.1	17	48.5	6.5
63	2.1	6.8	2.4	9.1	5.8	30.1

Mw= weighted *Mexipyrgus* Nw=weighted *Nymphophilus* Tw=weighted *Mexithauma* Dw=weighted *Durangonella* Cw=weighted *Cochliopina* Pw=weighted *Physa*

e.) Ha- Mean weighted Significance #

Comb #	Mw	Nw	Tw	Dw	Cw	Pw
1	50.0	0.0	0.0	0.0	0.0	0.0
2	0.0	33.0	0.0	0.0	0.0	0.0
3	36648.0	11392.0	0.0	0.0	0.0	0.0
7	3944.0	2041.0	189.0	0.0	0.0	0.0
10	0.0	94.0	0.0	36.0	0.0	0.0
11	2076.0	916.0	0.0	64.0	0.0	0.0
14	0.0	4.0	3.0	16.0	0.0	0.0
15	3885.0	4451.0	428.0	366.0	0.0	0.0
19	450.0	33.0	0.0	0.0	1.0	0.0
23	3.0	7.0	27.0	0.0	7.0	0.0
35	3955.0	2133.0	0.0	0.0	0.0	39.0
39	537.0	699.0	31.0	0.0	0.0	20.0
42	0.0	307.0	0.0	27.0	0.0	20.0
43	655.0	1381.0	0.0	100.0	0.0	12.0
47	3671.0	3027.0	437.0	462.0	0.0	79.0
50	0.0	10.0	0.0	0.0	3.0	8.0
51	47.0	106.0	0.0	0.0	4.0	2.0
58	0.0	4.0	0.0	14.0	4.0	2.0
59	405.0	1271.0	0.0	112.0	7.0	37.0
60	0.0	0.0	3.0	26.0	19.0	3.0
63	176.0	512.0	51.0	33.0	12.0	39.0

f.) Ho(#)- Mean weighted Significance #

Comb #	Mw	Nw	Tw	Dw	Cw	Pw
1.0	656.0	0.0	0.0	0.0	0.0	0.0
2.0	0.0	637.3	0.0	0.0	0.0	0.0
3.0	13686.5	6511.1	0.0	0.0	0.0	0.0
7.0	8497.5	4094.7	416.5	0.0	0.0	0.0
10.0	0.0	370.4	0.0	43.5	0.0	0.0
11.0	7752.8	3768.6	0.0	419.1	0.0	0.0
14.0	0.0	216.8	23.6	24.6	0.0	0.0
15.0	5179.7	2421.3	250.1	261.8	0.0	0.0
19.0	1012.1	500.4	0.0	0.0	12.6	0.0
23.0	593.9	293.3	30.4	0.0	8.3	0.0
35.0	5822.9	2829.9	0.0	0.0	0.0	80.1
39.0	3897.5	1860.8	193.3	0.0	0.0	51.7
42.0	0.0	169.0	0.0	16.4	0.0	4.3
43.0	3547.0	1611.1	0.0	177.7	0.0	46.6
47.0	2086.7	1025.1	107.7	112.6	0.0	29.1
50.0	0.0	14.0	0.0	0.0	0.6	0.6
51.0	506.7	210.9	0.0	0.0	5.5	5.9
58.0	0.0	9.1	0.0	0.8	0.3	0.2
59.0	287.3	112.9	0.0	14.8	3.1	3.4
60.0	0.0	0.0	0.1	0.0	0.0	0.0
63.0	191.4	82.2	8.1	8.5	2.1	2.3

Mw= weighted *Mexipyrgus* Nw=weighted *Nymphophilus* Tw=weighted *Mexithauma* Dw=weighted *Durangonella* Cw=weighted *Cochliopina* Pw=weighted *Physa*

g) (Ha-Ho) -Mean weighted Significance #

Comb #	M-w	N-w	T-w	D-w	C-w	P-w
1	-606.0	0.0	0.0	0.0	0.0	0.0
2	0.0	-604.3	0.0	0.0	0.0	0.0
3	22961.5	4880.9	0.0	0.0	0.0	0.0
7	-4553.5	-2053.7	-227.5	0.0	0.0	0.0
10	0.0	-276.4	0.0	-7.5	0.0	0.0
11	-5676.8	-2852.6	0.0	-355.1	0.0	0.0
14	0.0	-212.8	-20.6	-8.6	0.0	0.0
15	-1294.7	2029.7	177.9	104.2	0.0	0.0
19	-562.1	-467.4	0.0	0.0	-11.6	0.0
23	-590.9	-286.3	-3.4	0.0	-1.3	0.0
35	-1867.9	-696.9	0.0	0.0	0.0	-41.1
39	-3360.5	-1161.8	-162.3	0.0	0.0	-31.7
42	0.0	138.0	0.0	10.6	0.0	15.7
43	-2892.0	-230.1	0.0	-77.7	0.0	-34.6
47	1584.3	2001.9	329.3	349.4	0.0	49.9
50	0.0	-4.0	0.0	0.0	2.4	7.4
51	-459.7	-104.9	0.0	0.0	-1.5	-3.9
58	0.0	-5.1	0.0	13.2	3.7	1.8
59	117.7	1158.1	0.0	97.2	3.9	33.6
60	0.0	0.0	2.9	26.0	19.0	3.0
63	-15.4	429.8	42.9	24.5	9.9	36.8

h.) % of each -Mean weighted Significance #

Comb #	M-w	N-w	T-w	D-w	C-w	P-w
1						
2						
3	93.1	45.9				
7						
10						
11						
14						
15		19.1	32.2	17.0		
19						
23						
35						
39						
42		1.3				10.6
43						
47	6.4	18.8	59.5	56.9		33.7
50					6.2	5.0
51						
58				2.1	9.5	1.2
59	0.5	10.9		15.8	9.9	22.7
60			0.5	4.2	48.8	2.0
63		4.0	7.8	4.0	25.5	24.8

Mw= weighted *Mexipyrgus* Nw=weighted *Nymphophilus* Tw=weighted *Mexithauma* Dw=weighted *Durangonella* Cw=weighted *Cochliopina* Pw=weighted *Physa*