INVERTEBRATE FAUNA OF THE CARAPACES OF THE TEXAS RIVER COOTER (*PSEUDEMYS TEXANA*) AND THE RED-EARED SLIDER (*TRACHEMYS SCRIPTA ELEGANS*)

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ABSTRACT

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SUPERVISING PROFESSOR: Thomas R. Simpson

Symbiotic relationships occur between many pairs of species of organisms. The relationship between algae and turtles recently has been quantified. The relationship between turtles and aquatic invertebrates is less known. This study described quantitatively the invertebrate fauna inhabiting the algal covering of the carapaces of 2 species of freshwater turtles, the Texas river cooter (*Pseudemys texana*) and the Red-eared slider (*Trachemys scripta elegans*) at Spring Lake, Hays County, Texas. Turtles were captured from August through November 2002 using hoop nets, basking traps, and dip nets. Invertebrate samples were obtained by scraping a small area of the carapace to completely remove the algae and accompanying invertebrates and by brushing through the algal covering to remove invertebrates from the entire carapace. Invertebrates from each sample were identified using dissecting stereomicroscopes and quantified by subsampling. Taxa of aquatic invertebrates identified included species of Rotifera, Nematoda, Crustacea, Gastropoda, Insecta, and Hirudinea. A comparison of the similarity and diversity of invertebrates on the carapaces of *P. texana* and *T. s. elegans* revealed similar communities. A positive correlation occurred between carapace size and number of invertebrate taxa, indicating that larger turtles may support more invertebrate taxa than smaller turtles, in accordance with Island Biogeoraphy Theory. Turtle carapaces represent a substrate type to be considered in studies of freshwater systems because they possess ecological variables providing space, food, and protection for aquatic invertebrates. Due to their mobile lifestyle, turtles may contribute to the spread of invasive exotic organisms between bodies of water and river drainage systems.

INTRODUCTION

Coevolutionary symbiotic relationships such as commensalism, mutualism, predation, parasitism, and competition occur in a wide variety of taxa (Krohne 1998). Barnacles attach to whales (Ridgway et al. 1997), sponges and anemones live on hermit crabs (Sandford 2003), remoras often are associated with fish and sharks (Castro 1996), and algae have been observed in the pelage of terrestrial sloths and on crabs (Harper 1950). These associations may be either facultative or obligate (Krohne 1998), having considerable or little effect on either participant.

Algae often are found attached to aquatic organisms, particularly turtles. A number of turtle species harbor algae on their carapaces, including the Texas river cooter, *Pseudemys texana*, and the red-eared slider, *Trachemys scripta elegans* (Dixon 1960, Preite 2002). The relationship between algae and turtles has been characterized as commensalism (Dixon 1960), but may be mutualistic (Preite 2002).

In addition to algae, the cyanobacterium, *Plectonema tenue*, was found covering the carapace of snapping turtles, *Chelydra serpentina* (Belusz and Reed 1969), and the cyanobacterium *Entophysalis rivularis* was found growing epiphytically on algae of turtle carapaces (Edgren et. al 1953).

Within the algal coverings of turtle carapaces resides a community of invertebrate herbivores and their predators. Herbivorous invertebrates often use algae as a principal food source (Resh and Rosenberg 1984) and have been shown to influence standing crop, species diversity, and successional rates of algae in freshwater environments.

Few studies have attempted to quantify the invertebrates associated with algae colonizing turtle carapaces. The bryozoan *Plumatella* sp. was found on the plastrons of *T. s. elegans* as well as on the common musk turtle, *Sternotherus odoratus*, and the false map turtle, *Graptemys pseudogeographica* (Dixon 1960). There is anecdotal mention of cladocerans, ostracods, and amphipods found in the algae on the carapace of an alligator snapping turtle, *Macrochelys temminckii* (Allen and Neill 1950). One study (Hernández-Vazquez and Valádez-Gonzalez 1998) identified the epizoa of female olive ridley sea turtles, *Lepidochelys olivacea*, but there is scant literature where invertebrate communities associated with freshwater turtles have been characterized with the exception of leeches. In a study focusing on the blood parasites of *T. s. elegans* and *P. texana* in central Texas, leeches in the genus *Placobdella* were found (Caskey 1998). *Trachemys scripta elegans* also has harbored the leeches *Placobdella multilineata* (Sawyer and Shelley 1976), *P. ornata* (Sawyer 1972), *P. parasitica* (Hendricks et. al 1971), and *P. rugosa* (Hendricks et. al 1971). Leeches have been examined in several turtle species, including common map turtles, *Graptemys geographica* (Graham et. al 1997), common snapping turtles, *C. serpentina* (Krawchuk et. al 1997), and the olive ridley sea turtle, *L. olivacea* (Hernández-Vazquez and Valádez-Gonzalez 1998).

This study examines invertebrate epizoites of freshwater turtles quantitatively. The objectives of this study were to identify, compare, and contrast the invertebrate fauna inhabiting the algal covering of the carapaces of *T. s. elegans* and *P. texana*. In addition, Island Biogeography Theory (MacArthur and Wilson 1967) was evaluated with respect to turtle carapace area and number of invertebrates present. The results of this research contribute to the knowledge of relationships between turtles and aquatic invertebrates and present turtles as a substrate upon which aquatic invertebrates may be found.

The null hypothesis for this study was: No difference exists between the invertebrate species found on *T. s. elegans* and *P. texana*. Following the null, I expected to find the same species of invertebrates inhabiting both species of turtles. However, Preite (2002) reported that the algal assemblages on the carapaces of *T. s. elegans* and *P. texana* in Hays County, Texas, were significantly different. Thus, the invertebrate species inhabiting the algae also may differ.

When comparing invertebrates inhabiting turtles of various sizes, the null hypothesis was: No difference existed between invertebrate number or diversity found on turtles of various sizes. Following the null, I expected to find that invertebrate species richness was not any greater for larger turtles than for smaller ones. However, larger turtles may provide a greater area upon which algae may grow, and may presumably house more invertebrates, than smaller turtles. Thus, more invertebrate species may be present on larger turtles than on smaller turtles.

MATERIALS AND METHODS

Study Site

San Marcos Springs is comprised of 200 individual springs (Brune 2002) that release 150 million gallons (568 million L) of water per day from the Edwards Aquifer (Arsuffi et al. 2000). In 1847 a dam was constructed just downstream from the springs (Stovall et al. 1986), creating Spring Lake (Figure 1), a 7.9 ha reservoir (Seaman 1997) in San Marcos, Hays County, Texas. The lake serves as the headwaters for the San Marcos River and is thermally constant at 22°C (Arsuffi et al. 2000). In 1964 the area was developed into an amusement park known as Aquarena Springs. In 1994 the park was acquired by Southwest Texas State University and since has become a center for environmental education and research (Arsuffi et al. 2000).

The majority of the springs are located in the main lake. In this lotic portion of the lake, water flows rapidly to the southern end of the lake, where the dam and spillway are located. Much of the main lake is surrounded by concrete put in place when the amusement park was in operation. The western edge, however, is heavily vegetated. The eastern part of the lake is a shallow slough bordered by a golf course. A boardwalk was under construction in the slough during this study as a part of the wetland education program. This portion of the lake is lentic, and has dense beds of aquatic vegetation.

Because of the constancy of spring flow and water temperature, the springs, lake and associated wetland area possess a great diversity of organisms and endemic species (U.S. Fish and Wildlife Service 1996). Five federally endangered species and one threatened species are found within the lake and the first few kilometers of the river.

Figure 1. Aerial photograph of Spring Lake, Hays County, Texas

These include the San Marcos gambusia (*Gambusia georgei*), fountain darter (*Etheostoma fonticola*), Texas blind salamander (*Typhlomolge rathbuni*), Texas wild rice (*Zizania texana*), Comal Springs riffle beetle (*Heterelmis comalensis*) and the San Marcos salamander (*Eurycea nana*). Many species of non-native plants and animals also occupy the lake, including elephant ear (*Colocasia esculenta*), hydrilla (*Hydrilla verticillata*), nutria (*Myocastor coypus*), and blue tilapia (*Tilapia aurea*).

The lake also hosts a rich turtle fauna. The most common turtle species include the red-eared slider (*Trachemys scripta elegans*), Texas river cooter (*Pseudemys texana*), common snapping turtle (*Chelydra serpentina*), common musk turtle (*Sternotherus odoratus*), and the spiny softshelled turtle (*Apalone spinifera*).

Turtle Collection

Thirty *T. s. elegans* and 30 *P. texana* were captured using basking traps (Figure 2), hoop traps (Figure 3), and dip nets (Texas State University IACUC permit J6R1Qa) at Spring Lake, Hays County, Texas, from August through November 2002. To attract the omnivorous *T. s. elegans*, hoop traps were baited with chicken and suspended at the edge of the water in the slough. Basking traps were positioned in open water in the slough as well as at the junction of the slough with the main lake. Because *P. texana* is an herbivorous basking turtle (Ernst et al. 1994), basking traps were unbaited. Both species also were captured by dip nets in various parts of the lake.

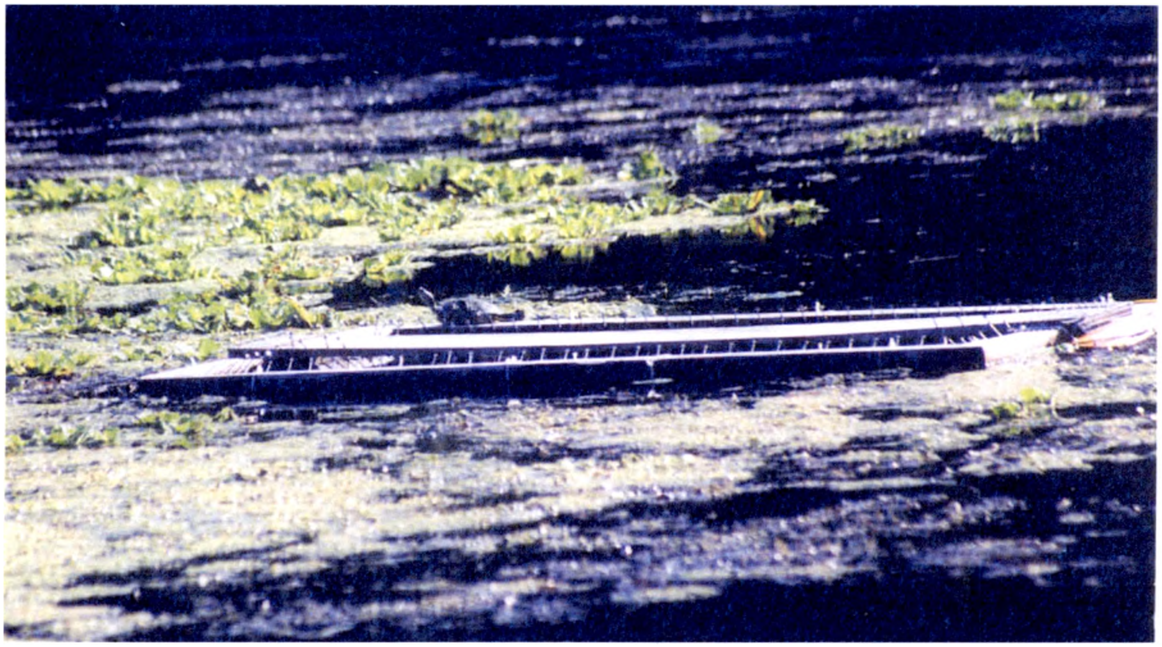

Figure 2. Basking trap in the water with *Pseudemys texana* on the edge.

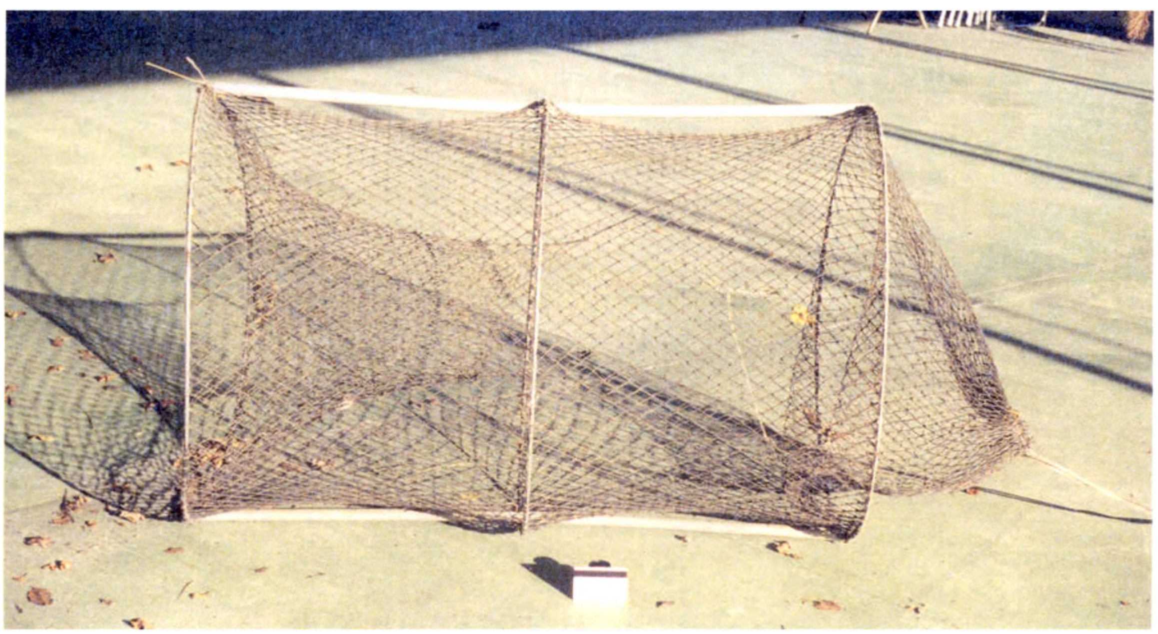

Figure 3. Hoop trap used to capture *Trachemys scripta elegans*.

Data recorded for each captured turtle included sex, weight, carapace length, carapace width, and plastron length. Unmarked turtles were marked according to protocol developed by ongoing research projects at Spring Lake. Marking involved a unique series of notches in the marginal scutes of the carapace and in the gular and humeral scutes of the plastron. A Passive Integrated Transponder was injected into the forelimb of each turtle for further identification. Percent algal cover was visually estimated. I only collected samples from turtles with algae covering 50% or more of the carapace. Following sample collection, turtles were released at the capture site.

Invertebrate Collection

Because no technique for sampling invertebrates of freshwater turtle carapaces was found in the literature, I developed the sampling protocol used in my study. Thus, this may be the first time the following techniques have been applied. Algal samples, along with any attached invertebrates, were collected from the carapace of each turtle using 2 techniques. First, a scalpel was used to scrape a 6 cm^2 region (visually estimated) of the carapace. I removed this sample from as close to the center of the carapace as algal cover permitted. Samples were placed into a vial of 70% ethanol at the time of collection. Second, I used a stiff-bristled nylon brush to remove algae and associated invertebrates from the whole carapace. Using water, I then washed the collected organisms into graded sieves with U.S. Bureau of Standards mesh sizes of 120 and 230 (pore sizes of 125 μm and 63 μm, respectively). Materials adhering to the brush also were washed into the sieves. Material collected in the sieves was combined and placed into a vial with 70% ethanol. I removed all leeches attached to soft tissues of the turtle's body and placed them in 70% ethanol for storage and later identification.

Invertebrate Identification

The contents of samples collected from the carapace of each turtle were placed into Petri dishes and examined under a dissecting stereo-microscope. I identified organisms, including leeches, to the lowest taxonomic unit possible, using taxonomic keys (Merritt and Cummins 1996, Thorp and Covich 2001).

Abundance of meiofauna (smaller than 1mm) was estimated using a 200 square grid, with each square being 4 mm x 4 mm. Organisms were counted in 10% of squares (20 squares) randomly chosen, and that number was multiplied by 10 to achieve the total number of invertebrates in the petri dish. This was done once for scraping samples (samples were about 10.5 ml each). Brushing samples were larger and divided into two 10.5 ml replicates. Each replicate was counted as above and then mean abundance was obtained for the two replicates. For macroinvertebrate species (larger than 1mm) total counts were conducted for each type of sample collected.

Data Analyses

Species composition and richness, density, and frequency of occurrence on turtles for microinvertebrates were determined for each turtle species. Samples obtained by scraping and by brushing the carapace were analyzed separately for each turtle species.

For macroinvertebrates, the species composition and richness and relative abundance were determined for each turtle species for scraping and brushing samples. I used Morisita's index of similarity to determine the similarity of macroinvertebrate communities on *P. texana* and *T. s. elegans*. I calculated diversity for macroinvertebrates on each turtle species using Brillouin's index of diversity (Krebs 1999).

I used a Wilcoxon rank-sum test (S-PLUS 4 1997) to determine whether differences existed for the mean number of leeches found on *T. s. elegans* and *P. texana*.

I used a t-test (Microsoft Excel 2000) to determine whether differences existed for carapace length between *T. s. elegans* and *P. texana*. I calculated carapace area by using a 2-dimensional approximation of an ellipse:

$$\text{Carapace area} = \frac{(\text{carapace length x carapace width x } \pi)}{4}$$

I used Pearson product moment correlation coefficients (Microsoft Excel 2000) to examine the relationship between carapace area and the number of macroinvertebrate taxa found on *T. s. elegans* and *P. texana* in brushing samples.

RESULTS

Microinvertebrates

Scraping samples produced 2 microinvertebrate taxa from *T. s. elegans* and 4 taxa from *P. texana*. Brushing samples showed *T. s. elegans* to have 4 microinvertebrate taxa, and *P. texana* had 3 taxa. Density and percent of turtles occupied for microinvertebrates on each turtle species are shown in Tables 1 and 2. Light micrographs of microinvertebrates are presented in Figures 4 and 5.

Macroinvertebrates

Scraping samples produced 11 taxa (30 individuals) from *T. s. elegans* and 8 taxa (18 individuals) from *P. texana*. Brushing samples produced 25 macroinvertebrate taxa (553 individuals) from *T. s. elegans*, along with 5 terrestrial insects. *P. texana* housed 16 taxa (250 individuals) and 5 terrestrial insects. The number of individuals and relative abundance of macroinvertebrates on each turtle species are listed in Tables 3 and 4. Light micrographs of selected macroinvertebrates are presented in Figures 6-13. Macroinvertebrates inhabiting the carapaces of the 2 turtle species were similar (*T. s. elegans*, $C_\lambda = 0.823$; *P. texana*, $C_\lambda = 0.916$). Brillouin's index of diversity (H) for macroinvertebrates on *T. s. elegans* and *P. texana* is presented in Table 5.

Table 1. Density (#/m^2) and frequency of occurrence on turtles (%) for microinvertebrates on *T. s. elegans* (N=30) and *P. texana* (N=30), obtained by scraping a portion of the carapace.

Taxa	***T. s. elegans*** **#/m²**	**%**	***P. texana*** **#/m²**	**%**
Phylum Rotifera	29533.3	93.3	33350	100
Phylum Nematoda	1933	6.67	2600	30.0
Class Ostracoda (Arthropoda: Crustacea)	-	-	66.7	10.0
Subclass Copepoda (Arthropoda: Crustacea)	-	-	16.7	3.0

Table 2. Density (#/m^2) and frequency of occurrence on turtles (%) for microinvertebrates on *T. s. elegans* (N=30) and *P. texana* (N=30), obtained by brushing the carapace.

Taxa	***T. s. elegans*** **#/m²**	**%**	***P. texana*** **#/m²**	**%**
Phylum Rotifera	3580.4	90.0	1208.8	70.0
Phylum Nematoda	1096.1	70.0	838.0	86.7
Class Ostracoda (Arthropoda: Crustacea)	493.0	66.7	93.9	26.7
Subclass Copepoda (Arthropoda: Crustacea)	27.3	6.7	-	-

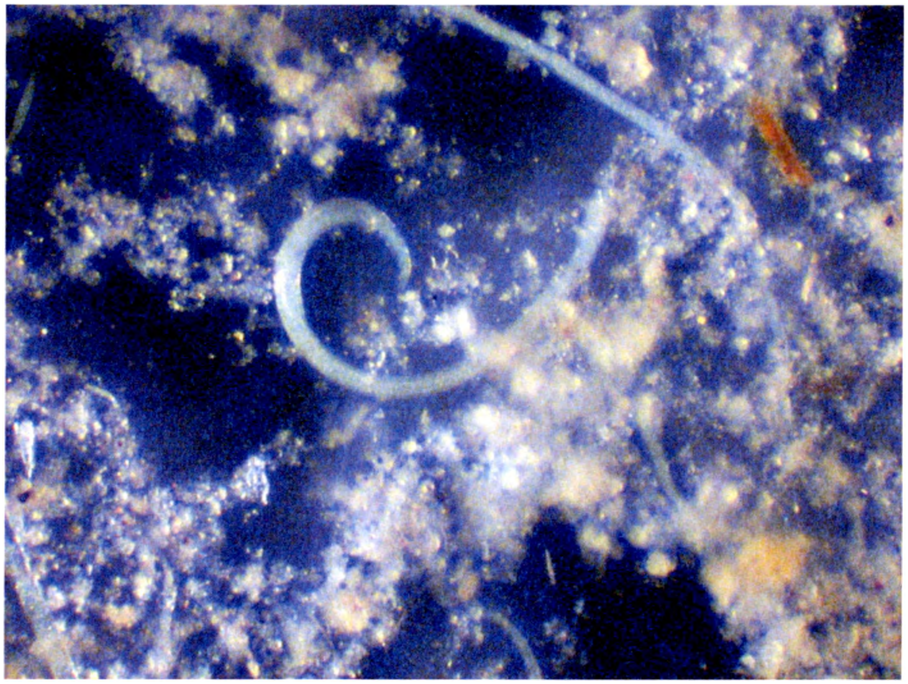

Figure 4. Light micrograph of nematodes (Nematoda) found in an algal sample collected from the carapace of a turtle

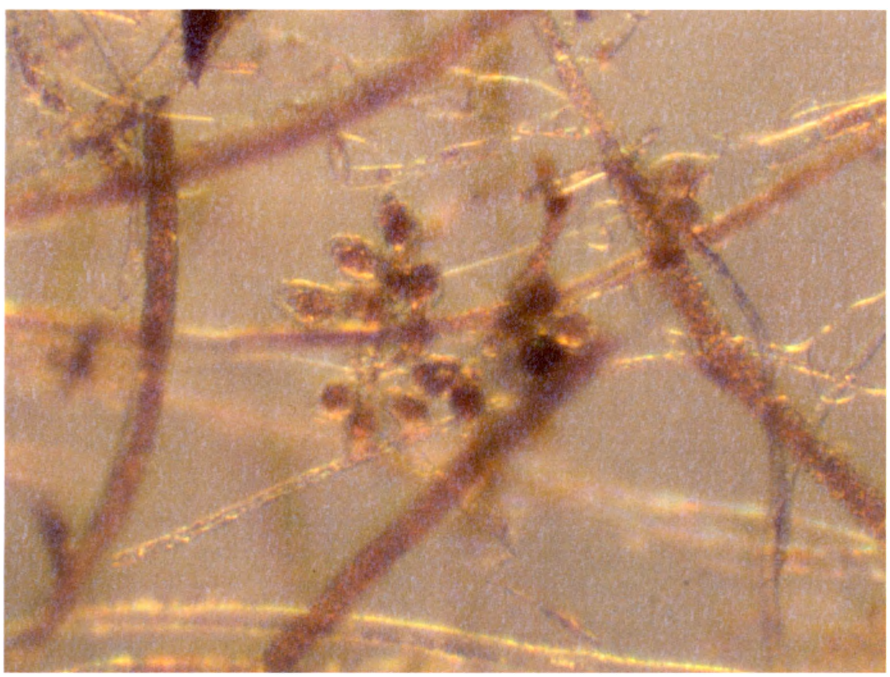

Figure 5. Light micrograph of rotifers (Rotifera) attached to filamentous algae collected from the carapace of a turtle

Table 3. Number of individuals (#) and relative abundance (%) of macroinvertebrates for *T. s. elegans* (N=30) and *P. texana* (N=30), obtained by scraping a portion of the carapace.

Common Name	**Classification**	***T. s. elegans*** #	%	***P. texana*** #	%
segmented worms	Aeolosomatidae (Annelida)	1	3.3	-	-
amphipods	Hyalellidae (Arthropoda: Amphipoda)	4	13.3	3	16.7
diving beetles	Dytiscidae (Arthropoda: Coleoptera)	1	3.3	1	5.6
beetles	Helophoridae (Arthropoda: Coleoptera)	1	3.3	-	-
beetles	Hydrochidae (Arthropoda: Coleoptera)	1	3.3	-	-
biting midges	Ceratopogonidae (Arthropoda: Diptera)	5	16.7	7	38.9
midges	Chironomidae (Arthroptera: Diptera)	6	20.0	-	-
dixid midges	Dixidae (Arthropoda: Diptera)	-	-	1	5.6
dung flies	Scathophagidae (Arthropoda: Diptera)	5	16.7	1	5.6
rattail maggots	Syrphidae (Arthropoda: Diptera)	3	10.0	3	16.7
mayflies	Caenidae (Arthropoda: Ephemeroptera)	2	6.7	-	-
mayflies	Isonychiidae (Arthropoda: Ephemeroptera)	-	-	1	5.6
gastropods	Lymnaeidae (Mollusca: Gastropoda)	1	3.3	-	-
asian clams	Corbiculiidae (Mollusca: Pelecypoda)	-	-	1	5.6
	Mean:	2.7 ± 2.0		2.3 ± 2.1	

Table 4. Number of individuals (#) and relative abundance (%) of macroinvertebrates on *T. s. elegans* (N=30) and *P. texana* (N=30), obtained by brushing the carapace.

Common Name	Classification	*T. s. elegans* #	%	*P. texana* #	%
segmented worms	Oligochaeta (Annelida)	16	2.9	6	2.3
amphipods	Hyalellidae (Arthropoda: Amphipoda)	168	30.1	111	43.5
beetles	Curculionidae (Arthropoda: Coleoptera)	1	0.2	1	0.4
beetles	Elmidae (Arthropoda: Coleoptera)	2	0.4	1	0.4
beetles	Hydrophilidae (Arthropoda: Coleoptera)	7	1.3	-	-
beetles	Staphylinidae (Arthropoda: Coleoptera)	1	0.2	-	-
biting midges	Ceratopogonidae (Arthropoda: Diptera)	22	3.9	30	11.8
midges	Chironomidae (Arthropoda: Diptera)	186	33.3	80	31.4
dung flies	Scathophagidae (Arthropoda: Diptera)	100	17.9	7	2.8
fly larvae	Stratiomyidae (Arthropoda: Diptera)	1	0.2	-	-
rattail maggots	Syrphidae (Arthropoda: Diptera)	7	1.3	3	1.2
crane flies	Tipulidae (Arthropoda: Diptera)	-	-	1	0.4
fly larvae	unknown family (Arthropoda: Diptera)	2	0.4	-	-
mayflies	Ephemeridae (Arthropoda: Ephemeroptera)	3	0.5	-	-
mayflies	Isonychiidae (Arthropoda: Ephemeroptera)	2	0.4	2	0.8
mayflies	Potamanthidae (Arthropoda: Ephemeroptera)	3	0.5	1	0.4
dragonflies	Coenagrionidae (Arthropoda: Odonata)	1	0.2	-	-

Table 4 continued.

Common Name	Classification	*T. s. elegans*		*P. texana*	
		#	%	#	%
dragonflies	Corduliidae (Arthropoda: Odonata)	2	0.4	-	-
dragonflies	family unknown (Arthropoda: Odonata)	1	0.2	-	-
springtails	Collembola (Arthropoda)	4	0.7	1	0.4
caddisflies	Hydroptilidae (Arthropoda: Trichoptera)	-	-	3	1.2
terrestrial insects	Arthropoda	5	0.9	5	2.0
gastropods	Ancylidae (Mollusca: Gastropoda)	1	0.2	-	-
gastropods	Hydrobiidae (Mollusca: Gastropoda)	3	0.5	1	0.4
gastropods	Lymnaeidae (Mollusca: Gastropoda)	2	0.4	-	-
gastropods	Physidae (Mollusca: Gastropoda)	5	0.9	1	0.4
giant rams horn snails	Pilidae (Mollusca: Gastropoda)	10	1.8	-	-
asian clams	Corbiculiidae (Mollusca: Pelecypoda)	3	0.5	1	0.4
	Mean:	21.5 ± 49.8		15.0 ± 31.6	

Figure 6. Light micrograph of an amphipod (Amphipoda: Hyalellidae) collected from the carapace of a turtle

Figure 7. Light micrograph of a midge larva (Diptera: Chironomidae) collected from the carapace of a turtle

Figure 8. Light micrograph of a beetle (Coleoptera) collected from the carapace of a turtle

Figure 9. Light micrograph of a dragonfly larva (Odonata: Corduliidae: Macromiinae) collected from the carapace of a turtle

Figure 10. Light micrograph of a gastropod (Mollusca: Gastropoda) collected from the carapace of a turtle

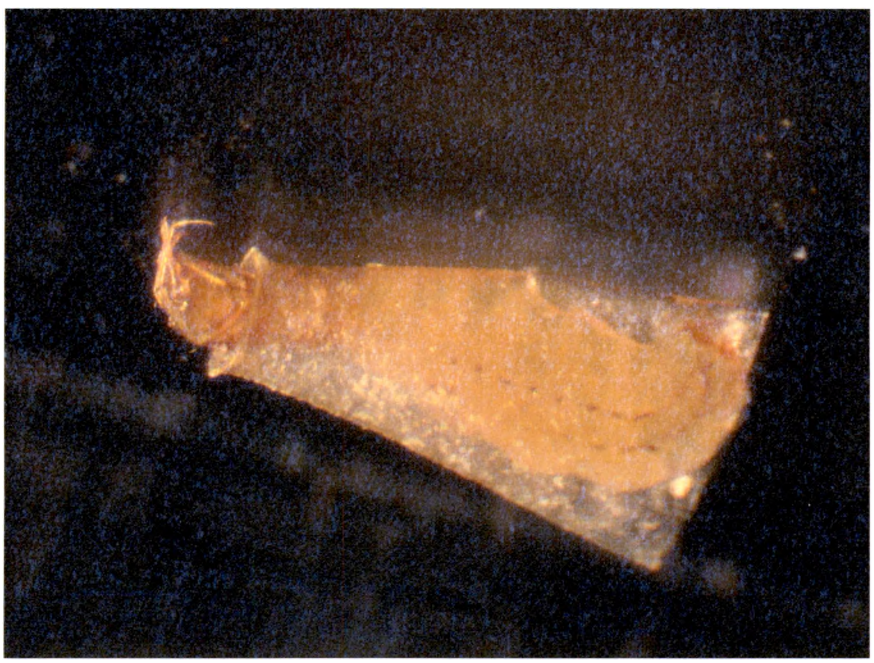

Figure 11. Light micrograph of a caddis fly larva (Trichoptera: Hydroptilidae) collected from the carapace of a turtle

Figure 12. Light micrograph of a springtail (Collembola) collected from the carapace of a turtle

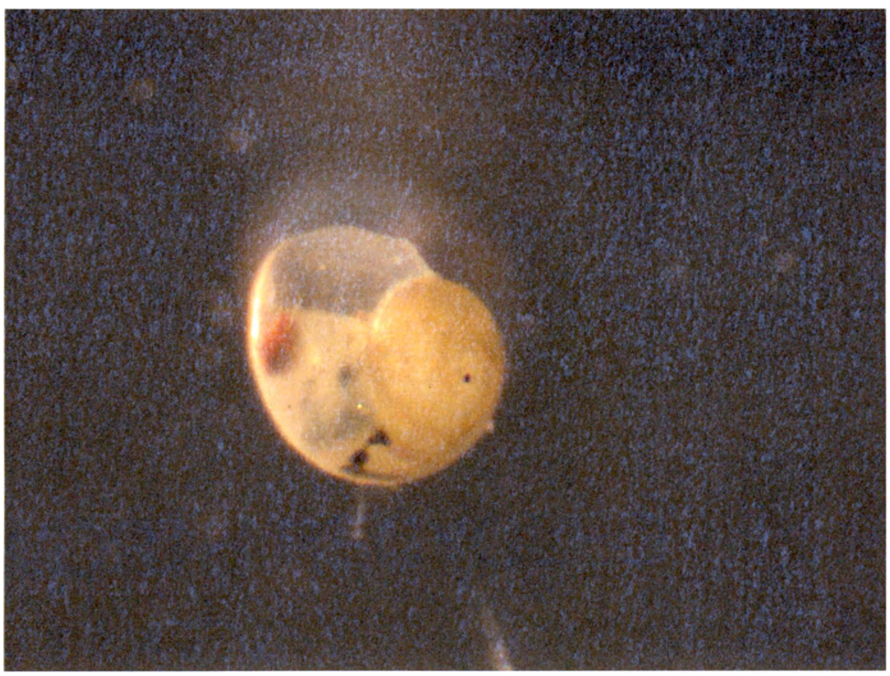

Figure 13. Light micrograph of a giant ram's horn snail (Gastropoda: Pilidae: *Marisa cornuarietis*) collected from the carapace of a turtle

Table 5. Brillouin's index of diversity (H) for macroinvertebrates on *T. s. elegans* and *P. texana* for samples obtained by scraping a portion of the carapace and by brushing the carapace.

Method of sample collection	***T. s. elegans***	***P. texana***
scraping	2.541	1.947
brushing	2.515	2.027

Leeches

There was a significant difference ($z = 2.9932$) in the mean number of leeches found on *T. s. elegans* and *P. texana* ($p = 0.0028$). Two species of leeches, *Placobdella parasitica* (Figure 14) and *P. ornata*, were found on both turtle species.

Miscellaneous Materials

I found empty or broken snail shells, exuviae, pieces of vascular plants, sediment from the lake bottom, and various types of debris on turtle carapaces.

Turtle Size

Results of a t-test revealed no significant difference ($t = -0.930$) in carapace length for *T. s. elegans* and *P. texana* used in this study ($p = 0.3601$). There is a weak positive correlation between carapace area and number of macroinvertebrate taxa for *T. s. elegans* ($r = 0.2361$) and a stronger positive correlation for *P. texana* ($r = 0.5025$).

Figure 14. Photograph of a leech (Hirudinea: *Placobdella parasitica*) collected from the carapace of a turtle

DISCUSSION

Invertebrates Found on Turtle Carapaces

I found more invertebrate taxa on turtles than had previously been listed in the literature. Allen and Neill (1950) found only 3 invertebrate taxa (cladocerans, ostracods, and amphipods) on the carapace of an alligator snapping turtle, *M. temminckii*. In contrast, I found a total of 36 taxa on *T. s. elegans* and *P. texana*, including those found by Neill and Allen.

Invertebrates associated with turtles likely possess adaptations that allow them to adhere to the surface of the carapace and resist being swept away either by the current or as the turtle swims through the water. Such adaptations may include having a streamlined or fusiform shape, friction pads or suckers, the use of silk for attachment to the substrate, or hooks to allow the organism to cling to carapacial algae (Williams and Feltmate 1992). Invertebrates identified include herbivores, detritivores, and carnivores; members of all of the functional feeding groups (Merritt and Cummins 1996) are represented.

Island Biogeography Theory (MacArthur and Wilson 1967) predicts that there should be greater species richness on larger islands compared to smaller islands and states that the number of species found on an island may be represented by equilibrium between immigration and extinction. Some attempts to broaden the application of the theory to systems other than oceanic islands include habitat remnants (Gilbert 1980, Doak and Mills 1994), host plants and herbivorous insects (Janzen 1968), parasites and their hosts (Kuris et al. 1980), and artificial substrates in an aquatic environment (Patrick

1967). Such situations have met with criticism in that strict application of the theory is not possible (Gilbert 1980, Kuris et al. 1980). Distance effects are a major tenet, and because the theory was constructed for fixed oceanic islands, application of the theory to turtle fauna would require modifications with regard to colonization. Due to the vagility of turtles in their aquatic medium, as well as over land (Ernst et al. 1994), distance to and between turtle "islands" fluctuates. However, size effects often are seen to apply to situations other than oceanic islands (Krohne 1998). A positive correlation existed between the estimated carapace area and number of taxa for both species of turtles examined in this study. This suggests that larger turtles support more invertebrate taxa than smaller turtles as a result of higher invertebrate colonization rates and lower extinction rates.

I found no difference in the carapace size for turtles collected in this study. This is in contrast to the literature, which typically shows *P. texana* to be larger than *T. s. elegans* (Ernst et al. 1994). Because no difference in size was found, the 2 turtle species should not show a difference in number of invertebrate taxa. In fact, *T. s. elegans* and *P. texana* were found to have very similar invertebrate communities and diversities.

A few terrestrial insects were found on each turtle species. These insects may have either crawled onto the turtle while on land and were carried into the water trapped in carapacial algae, or they may have been floating in the water and became entangled in the carapacial algae as the turtle swam by.

Debris and sediment commonly were found intermixed with algae on the carapace. This material was most likely acquired while the turtle was on the lake bottom, or some of these materials may have been picked up in the water column. This material, along with attached algae, makes the carapace a habitat for aquatic invertebrates. Some types of debris, including empty or broken snail shells, also may serve as microhabitats. Ward (1992) identifies many substrate types, including hydrophytes, wood, stones, gravel, sand, and mud. Turtle carapaces are not listed among these. However, carapaces provide the necessary ecological variables for characterization as a substrate, including physical structure, organic content, stability, and heterogeneity (Ward 1992). Habitat space, food, and protection may all be found within the algae and associated debris found on the carapaces of freshwater turtles. Thus, I propose that turtle carapaces represent a new substrate type to be considered in studies of freshwater systems.

Because a standard technique for collecting invertebrates from freshwater turtles had not been established, I collected 2 types of samples during this study. Scraping samples, although not large enough to capture the diversity of macroinvertebrate taxa present, were collected for examination of microinvertebrates because I was concerned that brushing the carapace might dislodge attached organisms, like rotifers, from carapacial algae. Brushing samples produced a more complete collection of organisms from the turtle by removing organisms from the entire carapace. In the examination of microinvertebrates, I did find that the scraping samples yielded higher numbers of individuals than brushing samples. Sieves used for the brushing technique had pores that were too large (63 µm) to capture smaller invertebrates. Mesh size recommended for collection of rotifers is 25-50 µm (Thorp and Covich 2001). For future study I recommend the brushing technique, but a sieve with a smaller pore size should be used.

Implications

Most aquatic insects complete a portion of their life cycle in the water, and spend the rest as winged adults, capable of dispersing via aerial travel (Merritt and Cummins 1996). However, many of the invertebrates found on turtles do not have such capability. Organisms such as leeches and molluscs cannot move from 1 body of water to another across terrestrial habitats without a dispersal agent. Turtles may be a means of dispersal for such organisms. Aquatic turtles travel over land to search for mates, nesting, feeding, basking, or hibernation sites (Ernst et al. 1994). *Trachemys scripta elegans* may have extensive home ranges and frequently move across land from 1 body of water to another (Cagle 1944, Parker 1984).

Two exotic molluscs, the giant ram's horn snail (*Marisa cornuarietis*) and the asian clam (*Corbicula fluminea*), were found on turtle carapaces. The giant ram's horn snail, an invasive organism, is characterized as a voracious herbivore (U. S. Fish and Wildlife Service 1996). In 1990, the giant ram's horn snail was added to the Texas Parks and Wildlife Department's list of harmful or potentially harmful exotic shellfish. This snail has the potential for tremendous impact on Spring Lake and the associated San Marcos River ecosystem by consuming large quantities of vegetation and competing with endemic herbivores. Large populations of the snail caused a significant loss of vegetation at Landa Lake in New Braunfels, Texas (U. S. Fish and Wildlife Service 1996). Turtles may represent an uninvestigated means of dispersal for exotic and invasive plants and animals.

Opportunities for Further Study

The identification of small, delicate organisms that do not preserve well in alcohol, such as rotifers, copepods, and bryozoans, could be increased by analysis of freshly collected samples. Although I thought I saw bryozoans in some samples, I could not make a positive identification because key characters were not visible.

Taxa with fast-seasonal life cycles may be missed when only 1 season is sampled. I only collected samples from August to November. Because most aquatic insects have rapid, seasonal life cycles, sampling in each season (Merritt and Cummins 1996) should be the protocol for future studies of turtle fauna. This protocol would provide a more complete picture of the invertebrates inhabiting turtle carapaces throughout the year.

Another area of investigation could involve the recolonization cycle of algae and invertebrates following shedding of the carapace scutes. Typically, artificial substrates have been used for observing invertebrate colonization (Cairns 1982, Preite 2002), but application of this vein of study to living turtles may allow easier observation of the recolonization of a natural substrate.

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