TOWSON UNIVERSITY
COLLEGE OF GRADUATE STUDIES AND RESEARCH

Spatial ecology and diet of Maryland endangered Northern Map Turtles (*Graptemys geographica*) in an altered river system: Implications for conservation and management

by

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Thesis Approval Page

This is to certify that the thesis prepared by Teal M. Richards-Dimitrie entitled

Spatial ecology and diet of Maryland endangered Northern Map Turtles (*Graptemys geographica*) in an altered river system: Implications for conservation and management

has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree of Masters of Biology.

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Abstract

Spatial ecology and diet of Maryland endangered Northern Map Turtles (*Graptemys geographica*) in an altered river system: Implications for conservation and management

Teal M. Richards-Dimitrie

Riverine turtle species are declining worldwide and many populations have been extirpated due to anthropogenic impacts. Last officially recorded in Maryland in the early-1990's, the Northern Map Turtle (*Graptemys geographica*) is listed as state endangered and is currently only known from the lower Susquehanna River in northern Maryland with a few records from nearby waterways (Elk and Bush Rivers). The Susquehanna River is divided by a hydroelectric dam, is used for recreation, and has increasing shoreline development, all of which may negatively impact this population. Given the absence of basic ecological data of map turtles in Maryland, I used trapping and radio-telemetry techniques to examine home range, movement patterns, and diet of *G. geographica*. My data will assist biologists, managers, and others interested in conserving this species in Maryland as well as provide insights for riverine turtles facing similar threats.

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CHAPTER 1

Home range, movements, and conservation of Northern Map Turtles (*Graptemys geographica*) in Maryland

Abstract

Riverine turtle species are declining worldwide and many populations have been extirpated due to anthropogenic stressors. Last officially recorded in Maryland in the early-1990's, the Northern Map Turtle (*Graptemys geographica*) is listed as state-endangered and is currently only known from the lower Susquehanna River, Maryland with a few records from nearby waterways (Elk and Bush Rivers). The Susquehanna River is divided by a hydroelectric dam and has increasing shoreline development, which may negatively impact this population. Given the absence of basic ecological data of map turtles in Maryland, I used radio-telemetry to examine home range size and seasonal movement patterns of individuals in this population. Female home range size varied from 18.9-283.8 ha. I found substantial home range overlap among individual turtles. For much of the activity season map turtles are concentrated in a 230 ha area across from Susquehanna State Park. The longest distances moved by adult females occurred during nesting excursions, when some make large movements out of the island complex to nest. Tracking movements allowed me to find critical habitat areas (hibernacula, nesting sites). My data suggest that impacts of dam operations on river water levels are dramatic and that high flows from the dam hinder basking activity, but may not heavily impact movements of turtles. Basking sites are submerged during high flows, reducing the availability of suitable basking habitat. Dam activities have also hindered the natural deposition of sand, impacting the number of available nesting beaches, which may be partial causation of the large nesting movements observed. I suggest the turtle's reaction to sudden changes in river flow and depth and future management for optimal nesting conditions is crucial in mitigating impacts on this population.

Introduction

Turtles are found in rivers throughout the world (Ernst and Barbour, 1989), and many of these riverine turtle species have been extirpated from large areas of their range (Moll and Moll, 2000, 2004a). Other than direct exploitation (Klemens and Thorbjarnarson, 1995; Moll and Moll, 2004b) habitat loss and modification are arguably the largest stressors for river turtle populations in the United States (Klemens, 1997; Gibbons et al., 2000; Mitchell and Klemens, 2000; Moll and Moll, 2004c). These losses and modifications have a large impact on a river turtle's ability to find and utilize suitable habitat (Moll, 1980; Mitchell and Klemens, 2000; Moll and Moll, 2004c). Riverine turtle species are highly susceptible to habitat modifications because turtles use different portions of a river for different activities, such as nesting, mating, basking, and hibernation (Moll and Moll, 2004d).

River systems have become increasingly degraded as a result of agriculture, land clearing, development, and regulation of river flow (Groom et al., 2006). Rivers are modified through water diversions and dams to provide human services (e.g., power production, crop irrigation, drinking water) (Poff et al., 1997). Less than one-third of the world's rivers run without some form of impoundment, and only two percent of all the rivers in the U.S. run unobstructed (Palmer, 1994; Abramovitz, 1996). When a free flowing river is impounded, a portion of that river turns from lotic into lentic, which may change the turtle species and population composition in the created habitat (Moll, 1980; Thirakhupt and van Dijk, 1994). Dams create reservoirs where only generalist species are able to persist (Vandewalle and Christiansen, 1996). Dams also capture sediment moving down river, preventing it from replacing beaches that are eroded overtime (Petts, 1984).

These beaches are often crucial nesting sites for riverine turtles (Gordon and MacCulloch, 1980; Moll and Moll, 2004e). Several fish species are known to change habitat use with changes in flow (Pert and Erman 1994, Bunt et al. 1999), but there is limited data on riverine turtles exhibiting the same behavior (Netting, 1944; Thirakupt and van Dijk, 1995). Dams completely divide rivers, and the resulting smaller fragmented populations are vulnerable to environmental stochasticity and inbreeding depression (Groom et al., 2006; Bennett et al., 2010). Isolation created by the impoundment of rivers have caused declines in populations of Cagle's Map Turtles (*Graptemys caglei*), Ringed Map Turtles (*G. oculifera*), Flattened Musk Turtles (*Sternotherus depressus*), Blanding's Turtles (*Emydoidea blandingii*), and Western Pond Turtles (*Clemmys (Actinemys) marmorata*) (U.S.F.W.S., 1988; Moll, 1980; Dodd, 1990; Reese, 1996; Federal Register, 2005). Fragmentation by damming of rivers has also been shown to affect sex ratios, growth rates, and movement patterns of populations of map turtles (Bennett et al., 2009, 2010).

In Maryland, the Northern Map Turtle is a state-endangered species with all known populations occurring within the Susquehanna River and its tributaries. The entire genus *Graptemys* has been listed under Appendix III of CITES as many populations are thought to be declining (Federal Register, 2005). Northern Map Turtle populations in Maryland are of special interest because they are exposed to extreme fluctuation in river stage and flow rates caused by a large dam (the Conowingo Hydroelectric Dam) which fragments the Susquehanna River in Maryland (Figure 1). When completed in 1928 the Conowingo Hydroelectric Dam was the second only to Niagara Falls as the largest hydroelectric project by power output in the United States (Power Plant Research

Program, 2008). Data on the response of map turtles to a modified flow regime is much needed to understand how these river modifications may be affecting this population.

Given the absence of basic ecological data of Northern Map Turtles in Maryland, the purpose of my paper is to describe the spatial ecology of Northern Map Turtles in the lower Susquehanna River, Maryland. The spatial ecology of a species indicates what portions of a site are used and the scale on which management should focus (Tilman and Kareiva, 1997). Movement data and home range size are important components of the spatial ecology of a species, and data on these components aid in enacting appropriate management strategies. Tracking individuals of the species of concern permits an objective way to quantify critical areas of habitat (i.e. nest sites and hibernacula). Home ranges are typically defined as the area traversed by an individual during its normal activities (Burt, 1943). Obtaining home range estimates for species of special concern allows detailed insight into the size and intensity of use of areas that need to be protected (Linnell, et al., 2004; Knapp and Owens, 2005). Furthermore, specific fidelity to certain aspects of the habitat by one or more individuals of the population can cause susceptibility to declines in the population if those habitats are modified or destroyed (Warkentin and Hernandez, 1996; Parra et al., 2006). Such data aid in further delineating potential threats to population viability.

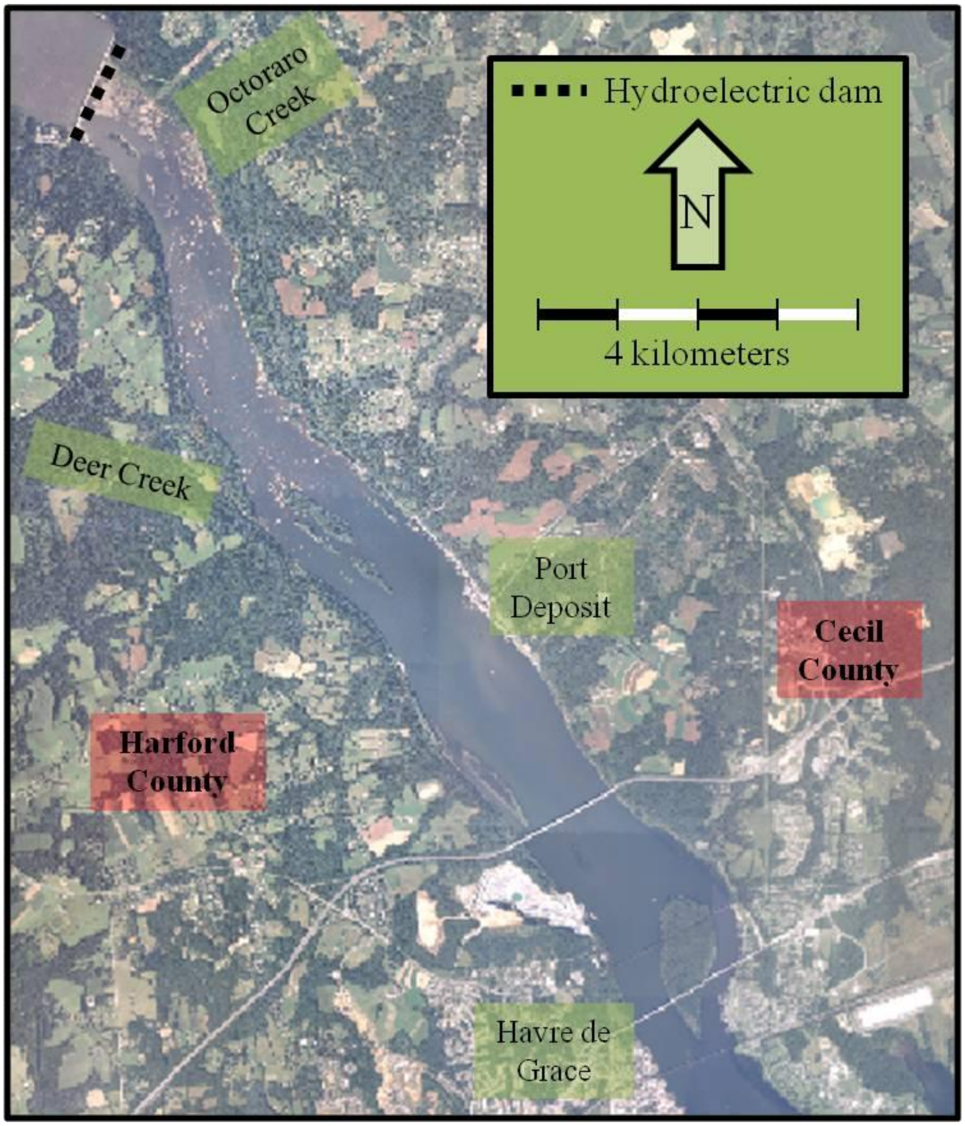
I addressed the following questions: (1) Does movement differ seasonally? (2) Does movement differ between males and females? (3) Do the methods used to calculate home range give different results? (4) Does individual home range size differ from year to year, and if so, do individuals exhibit site fidelity? (5) How much overlap in home ranges is there among individuals, and are there core habitat use areas?

Materials and Methods

Study site. The Susquehanna River watershed is the 16th largest in the U.S. and the river is the longest on the U.S. East Coast that drains into the Atlantic Ocean (National Research Council, 1999). In Maryland, the river runs through both Cecil and Harford counties and empties into the northern end of the Chesapeake Bay approximately 50 km northeast of Baltimore, providing half of the freshwater inflow to the Bay (Risser and Siwiec, 1996). The focal area for my study of Northern Map Turtles was the 15 km portion of the river below the Conowingo Dam where it joins the northern end of the Chesapeake Bay at Havre de Grace (Figure 1) covering an aquatic area of 1849 ha. The 1416.7 m x 31.7 m dam is the furthest downstream of five hydroelectric projects located on the lower Susquehanna River. Conowingo Dam produces flow rates from 141.6 m^3/s to 2600.6 m^3/s during full power generation, with much higher flow rates produced during spill conditions (Exelon Generation Company, 2009). The river becomes tidal 6.4 km downstream of the Conowingo Dam, up to Port Deposit, MD.

Capture and handling. To obtain turtles for tracking in this study, basking traps (fashioned similar to Horne et al., 2003), dipnets (Lager, 1943), and hand capture (Marchand, 1945) were used. Hand captures were made by swimming or kayaking up to basking aggregations, and if not immediately catching turtles, then using a mask and snorkel to obtain individuals off the bottom of the river. Preliminary distribution data from observations using a high powered spotting scope in 2008 showed where concentrations of basking turtles occurred. Therefore, much of my capture efforts were focused in a 230 ha complex of islands. However, individual map turtles were observed and caught throughout the Lower Susquehanna River (Figure 1). Upon capture, straight-

Figure 1. Study site for conservation research of *Graptemys geographica* in the Susquehanna River, MD.



line plastron length (PL) and carapace length (CL) were measured with tree calipers (±0.5 mm). Body mass was measured using a Pesola® scale (5 kg scale for females and 1 kg scale for males and small juveniles; ±10 g). All turtles were given a permanent mark by drilling a hole in specified marginal scute(s) with a Black & Decker® 14.4v power drill for use in individual identification (Ernst et al., 1974). It was assumed that maturity is reached in males at 66 mm PL and in females at 169 mm PL (Lindeman, 2006a). Males were identified by the presence of an enlarged tail and cloacal opening posterior to the carapacial rim (Ernst et al., 1994). All turtles between 66-169 mm PL that were not determined to be males by secondary sexual characteristics were considered juvenile females.

Radio-telemetry. On the outset of telemetry in May/June 2009 only adult females (n = 10) were outfitted with radio transmitters (L.L. Electronics LF-1-2/3A-RS-12"T, 20g, battery life 24 months) to assess the viability of the technique in a large and sometimes fast flowing river system (river width 0.8-1.9 km). Tracking gravid females was imperative to locating active nesting beaches. Use of at least 10 females would allow valid statistical inferences to be made for this gender. In September 2009 two additional adult females and eight adult males were added to the telemetry study (Transmitters: ATS R1545, 24g, battery life 28 months; and ATS R1680, 3.6g, battery life 24 months). Males were added at this time because I had validated that tracking in this system was feasible and to obtain hibernacula localities for both sexes. To increase sample size I added five females to the telemetry study in May/June 2010. After drilling holes in the rear marginal scutes (with the same method as for individual marks), I used plastic zip ties to attach transmitters to the carapace of adult females. Non-toxic marine epoxy (PC-11, PC-Products®) was used to cover the zip tie locks and under the transmitter for extra adhesion and to reduce the possibility of snags on aquatic vegetation. Due to the much smaller size of male turtles compared to females, male transmitters were attached to the left or right rear pleural scute with marine epoxy and then covered by the epoxy.

Transmitters and their attachment materials never exceeded 5 % of the turtle's body mass.

Individual turtles were never held for longer than 48 hours (when kept for diet analyses, see Chapter 2) and were released at their points of capture. All turtles were tracked from a 2.7 m kayak (Frenzy, Ocean Kayak ®) or 4.6 m jon boat with 8 hp Johnson® motor every 1-3 days from May-September. Turtles were also tracked at least once per week starting in October and until hibernation. Exceptions to these tracking intervals occurred only when an animal could not be located. Tracking was conducted using a Communication Specialists, Inc. R1000 telemetry receiver, a Wildlife Materials, Inc. TRX-64S receiver, or a Wildlife Materials, Inc. 1000S receiver, and a Yagi 3-element collapsible antenna. At each location, I recorded Universal Transverse Mercator (UTM) coordinates (NAD 83 Datum) with a GPS 60 at an estimated error in accuracy of < 15 m (Garmin International, Inc., Olath, KS). My actual accuracy is most likely considerably less than 15 m as points were taken on open water with clear unobstructed skies (Weih et al., 2009). Visual confirmation of the turtle was recorded when possible. However, if this was not possible, the location was determined by kayaking or boating over the turtle's position. At each telemetry location I also recorded behavior (basking on rock or log, swimming, surface swimming/basking, or immobile underwater).

Discharge rates and stage data from the Conowingo Hydroelectric dam were collected from the United States Geological Survey (USGS) Instantaneous Data Archive (IDA). Water temperatures were collected from the Maryland Department of Natural Resources Continuous Monitoring Susquehanna River Water Quality Meter suspended 1 m below the river surface. Though there is the potential for some movement through the winter (Newman, 1906; Evermann and Clark, 1916; Graham and Graham, 1992), radio-equipped turtles were tracked once per winter (15 January 2010 and 19 January 2011) in order to obtain hibernacula locations.

Movement Patterns and Seasonal Activity. *Graptemys geographica* are highly aquatic and many researchers assume that they only use land to nest or bask. This assumption has lead other researchers to calculate modified distances by measuring the shortest distance in water between location points (Carriére et al., 2009; Bennett et al., 2009a). I have observed non-gravid turtles on land (on islands in the river, not on the mainland) with no signs of nesting and therefore this assumption may be false for map turtles in the Susquehanna River. Thus, movement was calculated two ways: 1) straight-line distance between two points and 2) shortest distance in water between points. These modifications were made by measuring the adjusted movement patterns in ArcMap 9.3 (ESRI ®). I calculated distances moved per day as the distance moved between relocations divided by the number of days elapsed since the last location. I averaged the distances moved overall for each individual before analysis. I also averaged distances for mean distance moved per day across spring (15 April-30 April), nesting season (1 May-15 July), summer (16 July-31 August), and fall (1 September - 30 November) periods. The nesting season was determined to begin when the first predated nest was discovered and end at the last known nesting event across both the 2009 and 2010 seasons.

An information theoretic approach to modeling movement patterns of females. An information theoretic approach (Burnham and Anderson, 2002) was used to see if discharge from the Conowingo Hydroelectric Dam is an important factor in the movement patterns observed. I limited the number of variables included in the models *a* *priori* to avoid over-parameterization of the models by putting season (as previously defined), minimum water temperature, maximum water temperature, minimum discharge, maximum discharge, and average discharge into a correlation matrix. If variables were highly correlated ($r > 0.5$) only one variable was used to meet the colinearity assumption of the models. The variables retained for use in modeling included minimum water temperature (C°), minimum flow rate (m^3/sec), and maximum flow rate (m^3/sec). To accomplish my goal of relating these variables to individual movement per day I used a series of linear mixed effects models including these variables as fixed effects. I used the lme function in the nlme library of R (The R Foundation for Statistical Computing, 2009) to fit the models. To account for pseudoreplication, each individual was treated as a random effect in a repeated measures approach. Plastron length of each individual was also treated as a random effect because body size affects swimming ability (Pluto and Bellis, 1986) and therefore is a covariate. I compared the best models using Akaike's Information Criterion (AIC) after correction for small sample size (AICc). I calculated Akaike weights (w_i) to assess the plausibility of each model because models with similar weights are considered equally probable (Royall, 1997).

Home range size. Home range size was estimated using three methods: Minimum Convex Polygons (MCPs), Fixed Kernel Analysis with a least squares cross validation to determine the smoothing factor (h), and Fixed k Local Convex Hulls (LoCoH). Minimum Convex Polygons are derived by creating the smallest convex polygon that connects the outermost locations where an individual was observed, and includes all observations (Schoener, 1981). Fixed kernels are a parametric home-range estimator that uses a probability density approach (Worton 1987, 1989). The LoCoH method is an extension of MCP to a union of set local MCPs which tend to perform well in habitats with sharp edges (e.g. rivers) (Getz and Wilmers, 2004). Home ranges were modified to exclude mainland landmass but not islands. I calculated MCPs and Kernels using ABODE beta v.2 (Laver, 2005) for ArcGIS 9. LoCoHs were created in R (R Foundation for Statistical Computing, 2011). All home ranges were projected in ArcMap 9.3 (ESRI ®).

To assure the accuracy of my home range estimates I randomly removed some points to maintain as close to a fixed sampling interval as possible (2-3 days April-September; one per week October-December). Though there is some autocorrelation, shorter time intervals increase the accuracy and biological relevance of these home range estimators (De Solla et al., 1999). Asymptote analysis of MCPs resulted in both a series of plateaus (n = 8) or an asymptote (n = 6). The accuracy of a home range estimates will increase with more data points until home range size reaches an asymptote (Swihart and Slade 1985, Seaman et al. 1999). Therefore, home ranges were only calculated for those individuals that were tracked for > 75 % of the active season and that had > 40 locations.

Habitat Use, Core Areas, and Home Range Overlap. Though MCP's are accurate estimates of home range (Row and Blouin-Demers, 2006) they ignore habitat utilization and core areas of use (Seaman and Powell, 1996; Powell 2000, Carriére and Blouin-Demers, 2010). Therefore, I followed the method suggested by Row and Blouin-Demers (2006) and combined the MCP and kernel methods to analyze habitat utilization, home range overlap, and site fidelity. Similar to Carriére and Blouin-Demers (2010), I adjusted the smoothing factor (h) until the area of the 95 % kernel was equal to the area of the MCP only excluding mainland. This same h used to produce the 95 % kernel was utilized to produce 50 % kernels to examine core areas of habitat use. Home range overlap, defined here as the area of a kernel of one individual turtle overlapping the kernel of another individual, was measured by plotting all the kernels together. I also compared kernel home range overlap between years to examine site fidelity for the three adult females tracked consistently through both seasons. Using similar techniques, 100 % and 50 % LoCoHs were also used to examine habitat use, core areas, and site fidelity, as this estimator tended to stay within the confines of the river and thus use of LoCoH may be better suited for this system.

Statistical Analyses. I used repeated measures Analysis of Variance (ANOVA) to examine differences in straight-line and aquatic average movement per day, seasonal differences in movement patterns, and differences in home range size estimators. For all significant ANOVAs, Tukey's HSD test was used post-hoc to test for specific group comparisons. Chi-squared contingency analysis blocked on individuals was used to evaluate differences in frequency of behavior at location between radio-telemetered males and females. These analyses were performed with JMP version 8.0.2 (SAS Institute Inc.). Log transformations were performed on variables when needed to meet the assumptions of equal variances and normality. All means are reported +/- 1 SE. I accepted significances at $\alpha = 0.05$.

Results

Movement and seasonal activity patterns. I derived movement data from 36 turtles (17 adult females and 15 adult males). Premature transmitter failure, shedding of transmitters, and predation did not allow collection of sufficient data for some individuals (see Table 1 for number of locations, tracking duration, and fate). Male movement data

Table 1. Summary of *Graptemys geographica* equipped with radio transmitters in the lower Susquehanna River, MD. * = transmitter failure or signal loss, ** = transmitter shed, *** = mortality by raccoon

Turtle ID	Sex	Number of locations	Dates Monitored
5	F	64	15 May 2009-15 Jan. 2010
5	F	81	27 March 2010-19 Jan. 2011
6*	F	41	20 May 2009-24 Aug. 2009
7	F	18	5 Sept 2009-15 Jan. 2010
7	F	78	27 March 2010-19 Jan. 2011
8	F	60	16 May 2009-15 Jan. 2010
8***	F	31	27 March 2010-29 June 2010
16*	F	20	27 May 2009-9 July 2009
17	F	51	27 May 2009-22 Nov. 2009
18	F	47	27 May 2009-19 Jan. 2010
21	F	53	31 May 2009-19 Jan. 2010
21	F	64	27 March 2010-19 Jan. 2011
22	F	59	31 May 2009-19 Jan. 2010
22**	F	11	27 March 2010-20 May 2010
23	F	49	3 June 2009-19 Jan. 2010
23	F	64	27 March 2010-19 Jan. 2011
25*	F	43	8 June 2009-25 Oct. 2009
29	F	57	16 June 2010-19 Jan. 2011
55	F	2	15 Nov. 2009-15 Jan 2010
55*	F	37	27 March 2010-1 Sept 2010.
67	F	66	7 April 2010-19 Jan. 2011
69**	F	15	7 April 2010-22 July 2010
70**	F	10	7 April 2010-15 June 2010
79	F	63	4 June 2010-18 Jan 2011
46	M	17	26 Aug. 2009-15 Jan. 2010
48	M	15	26 Aug. 2009-15 Jan. 2010
49	M	14	26 Aug. 2009-15 Jan. 2009
50**	M	16	28 Aug. 2009-29 Nov. 2009
51	M	17	1 Sept. 2009-15 Jan. 2010
53	M	14	5 Sept. 2009-15 Jan. 2010
54	M	15	25 Oct. 2009-15 Jan. 2010
87	M	16	15 Sept. 2010-19 Jan. 2011
92	M	13	24 Sept. 2010-19 Jan. 2011
93*	M	6	8 Oct. 2010-10 Nov. 2010
94*	M	6	8 Oct. 2010-14 Nov. 2010
95*	M	4	8 Oct. 2010-31 Oct. 2010
97	M	8	8 Oct. 2010-19 Jan. 2011
99*	M	5	10 Oct. 2010-14 Nov. 2010
100*	M	5	10 Oct. 2010-14 Nov. 2010

are presented but only compared to females in the fall, as no males were tracked for an entire active season. Individuals tracked for two seasons were considered independent (causing some pseudoreplication), but excluding data for pseudoreplicated individuals did not change my results. Seasonal comparisons of movement are completed twice: one with all four seasons ($n = 8$) and one with spring excluded to increase sample size ($n = 14$).

Adjusted aquatic movements were significantly longer from straight-line measurements ($F = 23.3$, $df = 1$, $P = 0.0003$). However, the result using either measurement does not change my conclusions. Results using average straight-line movements are reported here. The results of the repeated measures ANOVA revealed a significant difference in average movement per day between the nesting, summer, and fall seasons ($F = 21.3$, $df = 2$, $P < 0.0001$). A Tukey's HSD multiple comparison procedure showed that summer and nesting movements are significantly larger than fall movements, but there was no difference between summer and nesting (Figure 2). When incorporating fall into the analysis there was a significant difference in seasonal movements ($F = 10.3$, $df = 3$, $P = 0.001$). A Tukey's HSD multiple comparison procedure showed similar results to the three season analysis (Figure 3). There was no significant difference between average fall movements of males and females ($F = 1.6$, $df = 1$, $P = 0.219$).

There was a significant difference in behavior at time of telemetry location between males and females ($\chi^2_{4,\ 1339} = 16.38$, $p = 0.0025$). All turtles were found underwater the majority of the time (65.1 %) outlining the importance of using radio-telemetry to obtain reliable information on movement patterns of aquatic turtles. Males were located underwater and basking on logs more often than females. Adult females were observed

Figure 2. Mean straight-line distances ± 1 SE moved per day in three of four defined seasons for 14 adult female *Graptemys geographica* in the Susquehanna River, MD. Spring (15 April-30 April), nesting season (1 May-15 July), summer (16 July-31 August), and fall (1 September - 30 November). Bars with a different uppercase letter are significantly different according to Tukey's HSD multiple comparison.

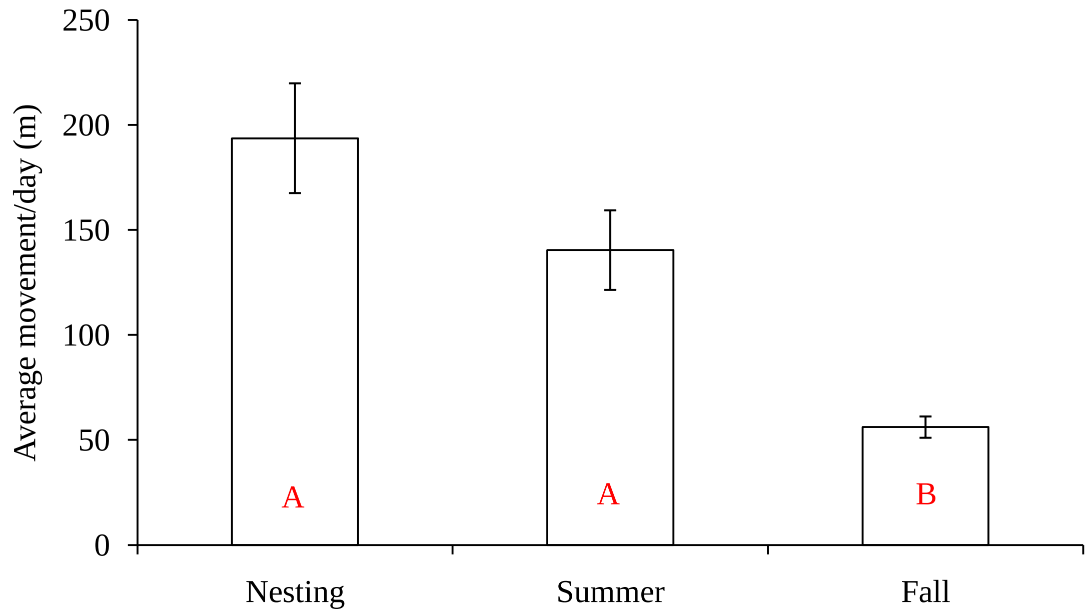
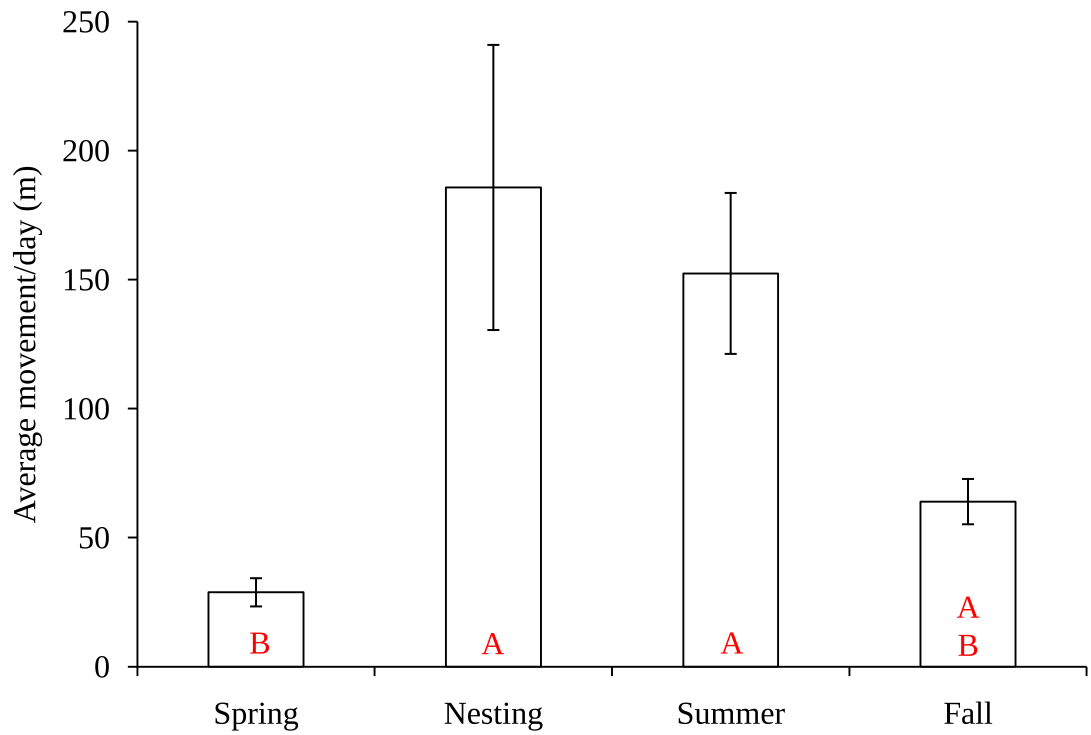


Figure 3. Mean straight-line distances ± 1 SE moved per day in four defined seasons for eight adult female *Graptemys geographica* in the Susquehanna River, MD. Spring (15 April-30 April), nesting season (1 May-15 July), summer (16 July-31 August), and fall (1 September - 30 November). Bars with a different uppercase letter are significantly different according to Tukey's HSD multiple comparison.



basking on rocks, swimming, or basking on the surface of the water more often than males (Figure 4).

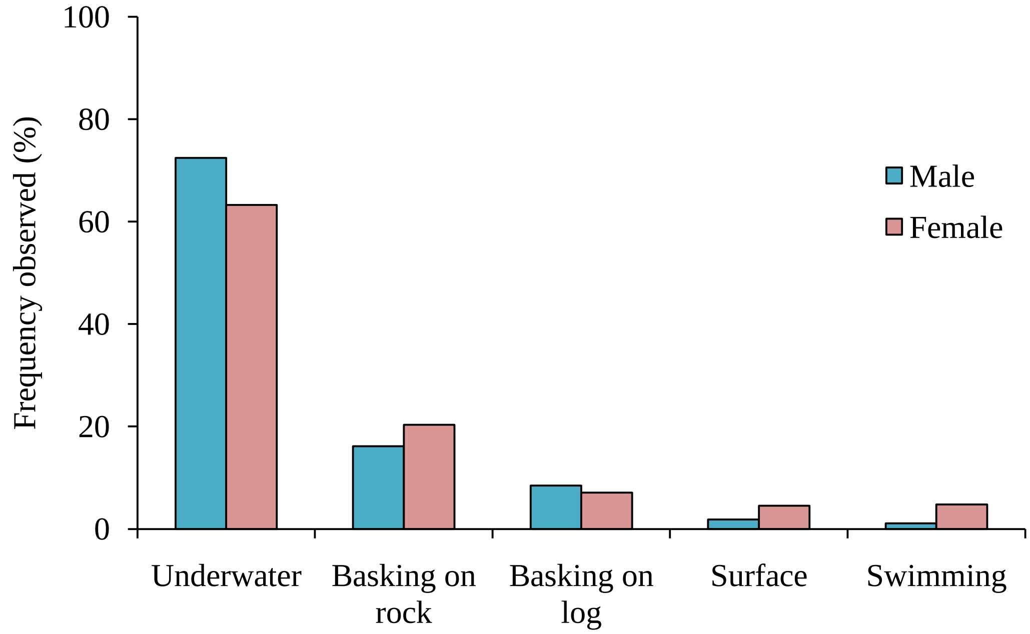
Variables that best explain female movement patterns. The linear mixed model with the lowest AICc (6765.8) only included minimum water temperature. It was the highest weighted model ($w_i = 0.342$). No other models were considered plausible ($w_i < 0.125$, Δ AICc > 2). The top ranked model took the form:

$$M = -123.9+10.6\ x_1$$

where M is movement per day and x_1 is minimum water temperature. Plotting the model suggests as minimum water temperature increases individuals are more likely to make large movements.

Home range size. I followed eight map turtles for one season and three for both seasons with enough locations (> 40) to estimate home range. Average female MCP home range size was 123.9 ± 35.0 ha. Home ranges varied among individuals, ranging from 18.9-283.8 ha based on MCP estimation. The larger home ranges (>100 ha) represent females who had nesting sites distant from their main area of activity (Figure 5). There was a significant difference in home range size across estimators ($F = 7.33$, $df = 2$, $P = 0.003$). LoCoH estimates were significantly smaller than MCPs and Kernels based on Tukey's HSD multiple comparison procedure (Table 2). There were no differences between MCP and Kernel estimates (Table 2). Significantly smaller LoCoH estimates were expected, as a LoCoH with k equal to the total number of locations would be equal to an MCP.

Figure 4. Behavior of *Graptemys geographica* fitted with transmitters in the Susquehanna River, MD at time of telemetry location (n = 1339). Nesting behavior has been excluded (n = 8) as it is not exhibited in both sexes.



Home range overlap, habitat use, and site fidelity. Using 95 % kernels with adjusted h to equal MCP size, adult females (n = 14) had an 87.9 % home range overlap, and 73.7 % of their home ranges occurred in the 230 ha area known as the island complex (Figure 6). According to LoCoH estimates, these females had an 83.8 % home range overlap, and 65.7 % of their home ranges occurred in the island complex (Figure 7). Ninety-five point five percent of the 50 % kernels and 100 % of the 50 % LoCoHs occurred in this area (Figures 6 and 7). All home range portions outside the island complex can be attributed to large movements for nesting (n = 7), though seven females did not leave the island complex to nest. Site fidelity was high in adult females sampled

Table 2. Home range size estimates (ha) for adult female *Graptemys geographica* in the lower Susquehanna River, MD. Range length is included as another proxy for home range (Bennett et al., 2010). Significantly different groups as determined by a Tukey's HSD multiple comparison procedure are represented by a different letter.

* indicates an individual that was tracked for two seasons

Turtle ID	**100 % MCP**	**95 % LSCV Kernel**	**100 % LoCoH**	**Number of locations used**	**Range Length (m)**
5*	18.9	27.1	14.8	53	880.0
5*	28.5	30.7	20.8	61	906.2
7	112.5	141.3	62.2	58	4,742.7
8	73.3	63.4	68.7	53	1,433.2
17	221.2	250.4	177.7	45	3,876.9
18	202.5	91.2	56.6	41	3,684.3
21*	87.0	96.8	70.6	46	1,488.7
21*	52.4	30.2	45.3	49	1,343.4
22	35.9	26.4	31.2	49	1,049.1
23*	146.0	80.7	72.4	44	3,165.8
23*	196.2	114.9	109.9	50	3,612.3
29	115.4	112.0	98.2	44	4,818.7
67	283.8	527.0	202.0	56	6,227.3
79	117.8	142.7	102.7	47	4,648.5
Mean	**120.8**	**123.9**	**80.9**	50	2,991.2
Group	**A**	**A**	**B**		

Figure 5. Comparison of larger MCP home ranges (>100 ha) represented by females who had nesting sites distant from their main area of activity (left) to those that stayed in the island complex (right). MCPs modified to exclude mainland landmass.

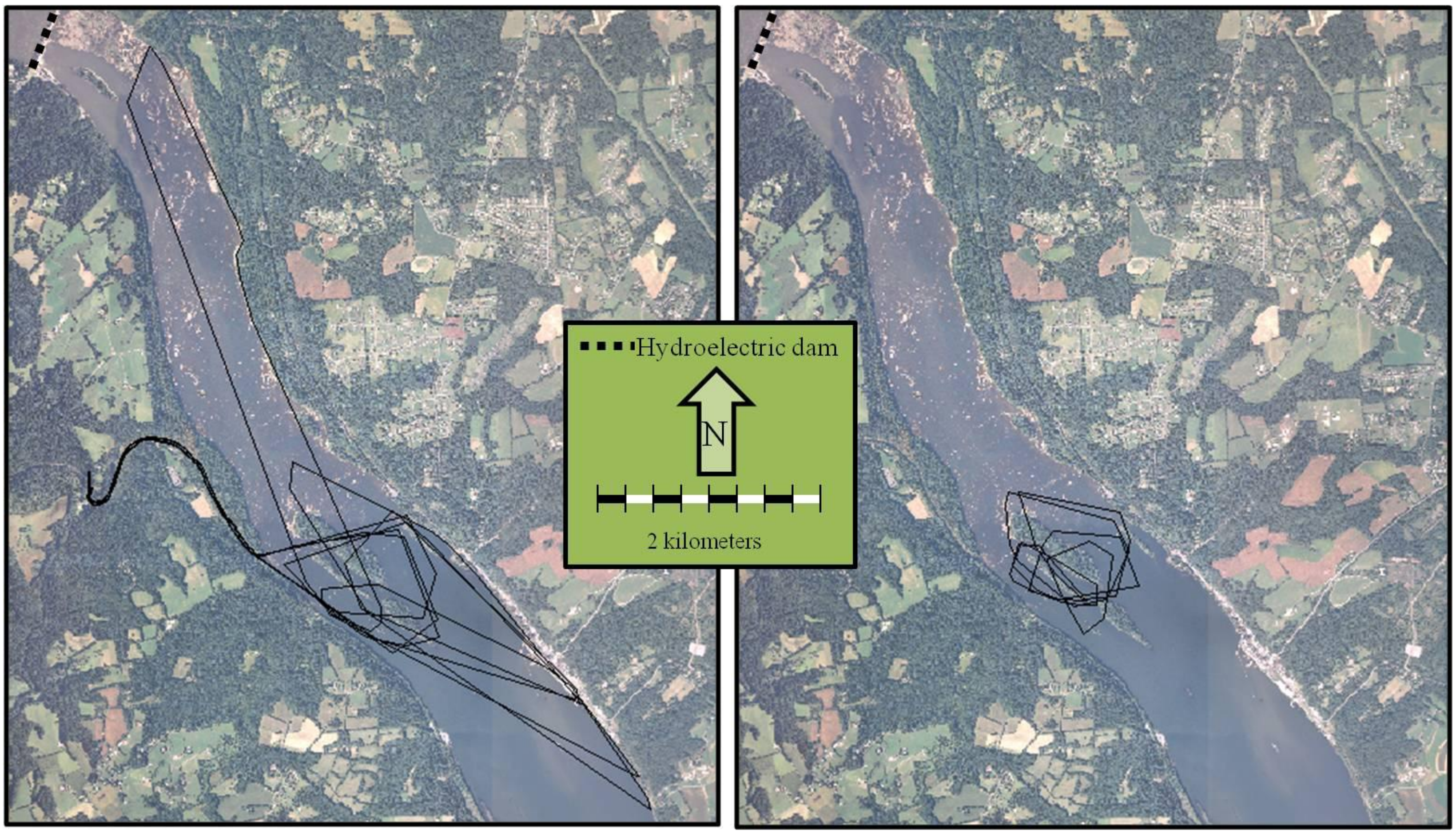


Figure 6. 95 % Kernels with smoothing factor (h) adjusted so kernel equaled MCP size (black). 50 % Kernels with same h in red. All modified to exclude mainland landmass.

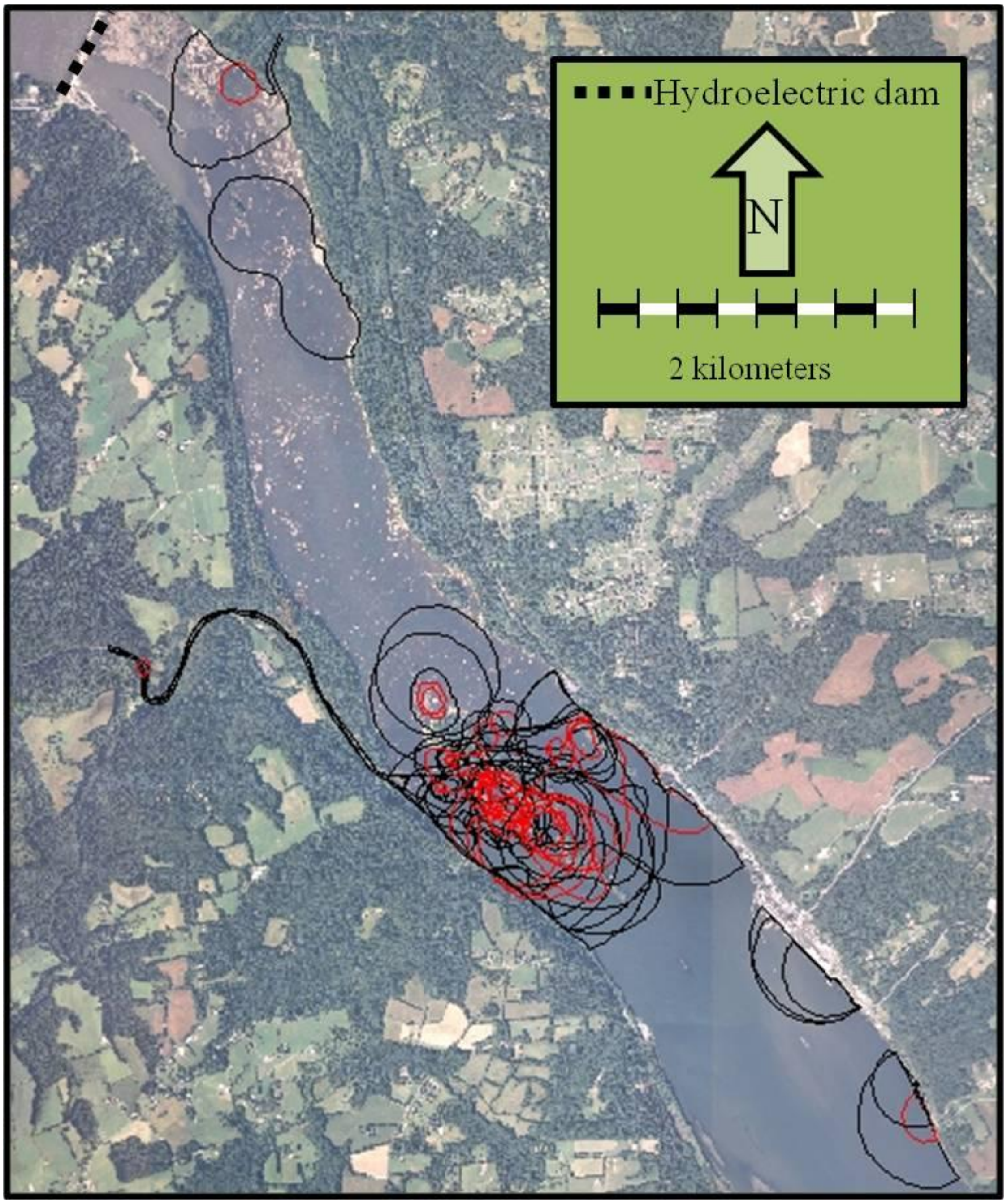
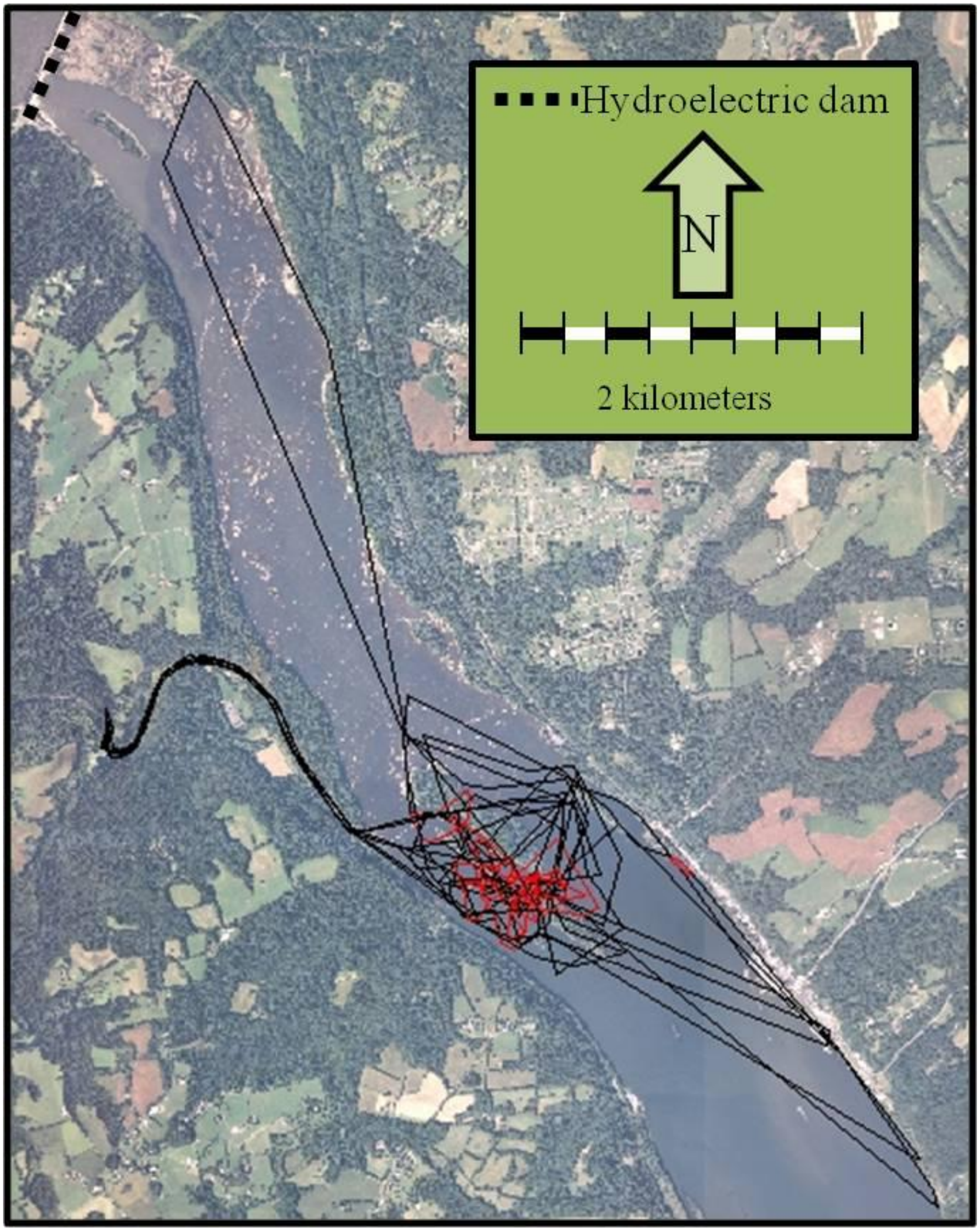


Figure 7. 95 % LoCoH isopleths in black. 50 % LoCoH isopleths in red. Three isopleths modified to conform to the sinuosity of deer creek. No other isopleths modified.



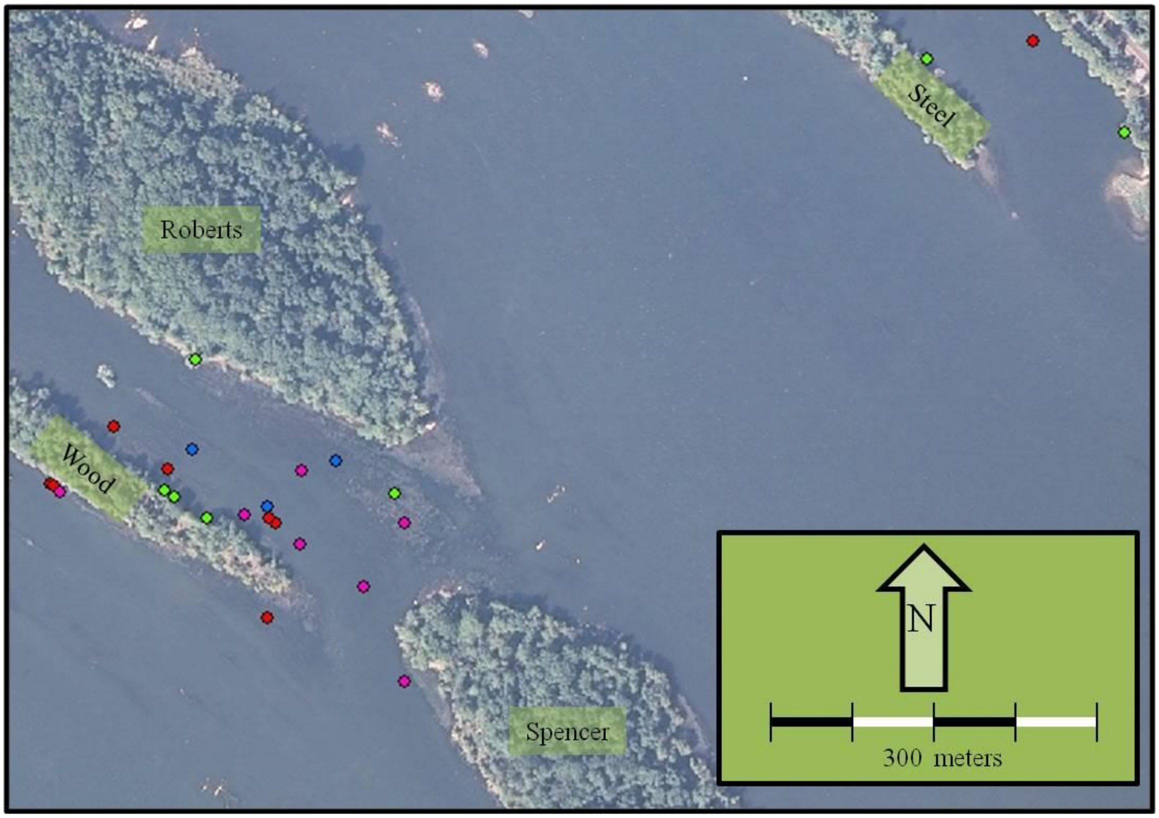
for both active seasons. Mean 95 % kernel overlap was 65.63 ± 2.57 % and mean 100 % LoCoH overlap was 62.63 ± 6.13 % (n = 3). These are minimum estimates as I only have a sample of the larger population.

Hibernacula. All radio-telemetered turtles (15 females, 10 males) overwintered in the island complex. I had visual confirmation of seven hibernating individuals in 2010 but none in 2011. This was due to my ability to see to the bottom based on low water levels in 2010 and inability due to high water levels in 2011. In January 2010, radio-telemetered turtles (eight females, seven males) averaged 53.2 ± 12.1 m (range 3-115 m) to the next closest radioed turtle and 13.4 ± 3.3 m to shore. Sixty percent of these individuals overwintered in a 3.8 ha area between Roberts and Wood islands (Figure 8). In January 2011, radio-telemetered turtles (seven females, three males) averaged 61.1 ± 11.3 (range 22-130 m) to the next closest radioed turtle and 22.8 ± 11.4 m to shore. Seventy percent of these individuals overwintered in the same 3.8 ha area as the majority of radioed turtles in 2010 (Figure 8). Of the seven individuals that I could see hibernating, only one was wedged in any sort of shelter (a large log snag). All other individuals (n = 6) were sitting motionless on the substrate (one on gravel, one on sand, and five on rock) fully visible through the water.

Discussion

Movement and seasonal activity patterns. Female *G. geographica* in the lower Susquehanna River made large movements during the nesting season and through the summer. This is consistent with observations of female *G. geographica* activity in other populations (Gordon and MacCulloch, 1980; Flaherty, 1982; Carriére et al., 2009). Male movement data were only compared to females in the fall, as no males were tracked for

Figure 8. Locations of 2009/2010 and 2010/2011 hibernacula for all radio-equipped turtles. 2010 Females in pink, 2009 Females in red, 2010 males in blue, and 2009 males in green.



an entire active season. Thus, I can make no overall comparisons of male and female movement, but I expect that, similar to past studies of *G. geographica* movement, females are making longer movements than males to access nesting areas. Females greatly reduced their movements as they returned to hibernacula in the fall, and their movements were not significantly different than males during this time. Other research on *G. geographica* movement has found males to be more sedentary than females (Flaherty, 1982; Gordon and McCulloch, 1980; Carriére et al., 2009). Though I do not have male movement data through the full activity season, the movement data I did collect are in accordance with these reports. I never observed males at the farthest nesting areas (2.8 km up deer creek and 4.9 km upriver from the island complex). Males in my population may not increase their movements during the active season to locate mates because Northern Map Turtles mate in the spring and fall at their communal hibernacula (Vogt, 1980; Graham and Graham, 1992; Graham et al., 2000).

It is well documented in turtles that large female movements can be attributed to finding suitable nesting sites (Obbard and Brooks, 1980; Piepgras and Lang; 2000; Jones, 1996; Litzgus and Mousseau, 2004) because the ability of females to find optimal nesting locations will result in higher fitness (Gibbons et al., 1990). Though I did not formally quantify nest site availability, there are very few sandy beaches available to this population, which may be a factor contributing to the long nesting movements observed. Dams capture sediment preventing it from replacing beaches (Petts, 1984). These sandy beaches are optimal habitats for nesting locations (Gordon and MacCulloch, 1980; Moore et al. 2006; Horne et al. 2003; Moll and Moll, 2004e). As suggested by Carriére et al. (2009), nest site availability may not be the only factor contributing to large nesting movements in female G. *geographica*. Natal homing has been demonstrated in the genus *Graptemys* (Freedburg et al., 2005). The large movements to nest sites observed by some (N =7) radio equipped females in this study may be a product of natal homing, or at the least, nest site fidelity (Vogt, 1980; Freedburg, 2005; Doody, 2009).

I cannot rule out that, in part, these large movements are explained by females having larger body size and swimming ability (Pluto and Bellis, 1986), and therefore high energy requirements because of body size (Andrews and Pogh, 1985), thus, traveling far distances to access suitable feeding areas. This hypothesis has largely been refuted in populations that feed on Zebra Mussels, because of the high abundance and widespread distribution of this food source (Lindeman, 2006; Bulte and Blouin-Demers, 2008a,b; Carriére et al., 2009). Zebra Mussels have only recently been introduced to the lower Susquehanna River, and I have no data on the abundances of the current prey communities (see Chapter 2 for diet analyses of this population) Thus, I cannot conclude that the movement patterns observed are also explained by prey distribution and abundance.

Home Ranges. I observed wide variation in individual home range size which is consistent with other studies on Northern Map Turtles (see Table 3 for summary of *G. geographica* home range data). This population can be considered fragmented, as there is no indication that individuals can disperse around or through the Conowingo Hydroelectric dam. Trying to place my home range estimates in the context of previous studies is complicated because there is a large amount of variation in methods used to collect locations, types of home range estimators, and in the type of habitat being studied (e.g. river, lake, or marsh). Reports of MCPs vary from as low as 17 ha to as high as 1075 ha (Carriére, 2007). My radio-equipped females varied greatly in their home range sizes (18.9-283.8 ha), though the mean home range is less than half of studies in unobstructed habitats (Carriére, 2007; Carriére et al. 2009). Reports of range lengths vary from 0 km (Pluto and Bellis, 1988) to 12.5 km (Flaherty, 1982). Again, my population's mean range length is more consistent with fragmented populations (Graham et al., 2000, Ryan et al. 2008; Bennett et al. 2010) or smaller bodies of water (Pluto and Bellis, 1988).

As discussed previously, there are many factors that contribute to the varying movements of individuals in a population. Beyond geographic differences in habitat of a

Table 3. Mean minimum convex polygon (MCP) home range (ha) ± 1 SE and mean range length (km) ± 1 SE estimates for female Graptemys geographica in multiple studies throughout their range. Size of site and range of estimates are in parentheses if reported. CMVR = color marking and visual recapture, RT = Radio telemetry, MR = mark-recapture

Study	Location	N	Method	MCP (ha)	Length (km)
Flaherty, 1982	Lake of two mountains Quebec, Canada, (42 km)	6	CMVR, RT	67.8 ± 37.68 (31-129)	12.5 ± 2.67 (3.22-19.5)
Pluto and Bellis, 1988	Raystown branch Pennsylvania, USA (6.6 x 0.045-0.09 km)	14	CMVR, MR		1.2 (0-5.29)
Graham et al., 2000	Lamoille River Vermont, USA	6	RT		3.5 ± 0.99 (1.5-8.0)
Carriére , 2007	St. Lawrence River Ontario, Canada, (11 x 4 km)	20	RT	247 ± 32 (17-1075)	
Tran et al., 2007	Ottawa National Wildlife Refuge, Ohio, USA, (1900 ha)	2003: 4 2004: 9	RT	2003: 75 ± 20 2004: 120 ± 40	
Ryan et al., 2008	Central Canal Indianapolis, Indiana, USA (11.2 x 0.0005-0.0025 km)	14	RT		3.0 ± 0.4
Carriére et al., 2009	St. Lawrence River, (2,890 ha) and Lake Opinicon, (788 ha) Ontario, Canada	Lotic: 20 Lentic: 19	RT	Lotic: 325 ± 75 Lentic: 150 ± 25	
Bennett et al. 2010	Trent-Severn Waterway Ontario, Canada	Fragmented: 9 Unfragmented: 7	RT		Fragmented: 1.53 ± 0.31 Unfragmented: 8.51 ± 1.59
This study	Susquehanna River Maryland, USA, (1849 ha, 15 x 0.9-1.7 km)	14	RT	120.8 ± 21.5 (18.9-283.8)	2.99 ± 0.47 (0.88-6.23)

wide-ranging species, the varying reports of *G. geographica* home range are most likely due to different combinations of degrees of fragmentation, limitations of nest sites, limitations of other habitat parameters (e.g. basking sites), food availability, and nest site fidelity or homing.

I found substantial home range overlap among individual turtles. Northern Map Turtles are known to bask collectively at select basking sites (Newman, 1906; Flaherty and Bider, 1984; Pluto and Bellis, 1986; Daigle et al., 1994; Ernst et al., 1994; Lindeman, 1999) and aggregate to hibernate (Flaherty, 1982; Pluto and Bellis, 1988; Graham and Graham, 1992; Graham et al., 2000; Ultsch et al., 2000). My results suggest the lower Susquehanna River population is no exception, as all individuals in this study intensively used the island complex. Not only does this area contain the hibernacula, but my observations also indicate that the island complex has the highest density of basking habitat and deadwood on the river which are critically important habitat characteristics for *Graptemys* (Fuselier and Edds, 1994; Pluto and Bellis, 1986; Jones 1996; Lindeman 1998, 1999). The adult females I was able to track for two seasons continued to use relatively the same home range area between years. The nesting information I was able to obtain from radio-telemetry also imply that adult females are faithful to their nesting sites. Both scales of fidelity make this population especially vulnerable to habitat modifications (Warkentin and Hernandez, 1996; Parra et al., 2006).

Impacts of the change in stage and flow rates from the Conowingo Hydroelectric dam. Though flow rates from the Conowingo Hydroelectric dam were included in modeling of female movement patterns, only minimum water temperature was a probable variable in explaining these patterns. Water temperature is highly correlated with time of year; therefore, season was not included in the models. Thus, this result could also be interpreted as a seasonal pattern. I tracked females three times from shore during high flow periods (spill/flood conditions, > 5500 m^3/sec) during winter and just before emergence from hibernation in 2010 and 2011. In all cases radio-equipped turtles were in the same locations (within 20 m) as their original hibernation site, further corroborating that flow rates are not causing involuntary movement. Northern Map Turtles are known to make small movements during hibernation (Evermann and Clark, 1916; Graham and Graham, 1992), and they most likely are able to take shelter behind rocks, log snags, or cut banks during flood events. During the majority of the activity season for Northern Map Turtles (May-December) the hydroelectric dam typically has a daily cycle from low flow overnight through mid-morning (approx. 141.6 m^3/sec) to full generation (approx. 1600.6 m^3/s) during peak electricity hours (1400-2100). Future work on the timing of movements would greatly improve our understanding of these results as individuals in the population may take advantage of the cyclic nature of flow rates and move when there is little power generation.

Although, high flow rates do not seem to be hindering movement, impacts of dam operations on river water levels are dramatic (changes in water levels of 1-2 m in a few hours), and my data demonstrate that high flows from the dam hinder basking activity. Basking sites are submerged during high flows, which reduce the availability of suitable basking habitat (Figure 9). This may be another factor explaining the high fidelity to the island complex, as the only exposed basking substrates during high flows are deadwood and trees on these islands. Gordon and Maculloch (1980) found similar behaviors during spring flood events on the Lake of Two Mountains in Quebec, Canada.

Figure 9. Comparison of same locality on the Susquehanna River, MD (up river of Roberts Island) at low generation (top) and full generation (bottom) from the Conowingo Hydroelectric Dam.

They found that individual map turtles would bask on anything available, including partially flooded trees and bushes. Another explanation for the fidelity of my population of Northern Map Turtles to the island complex may be that the islands obstruct flow and provide protection from high flow rates.

Conservation implications and mitigation recommendations. Overall, my results provided several important findings about a population of *G. geographica* in a dam-impacted river. First, for much of the activity season Northern Map Turtles in the lower Susquehanna River are concentrated in a 230 ha area across from Susquehanna State Park (Figure 1). Second, some individuals make large movements out of the island complex to nest. Nesting occurs from May-July along relatively open areas (some having heavy canopy cover) on both in-river islands, along the banks of Octoraro Creek and Deer Creek, and in the town of Port Deposit. My observations of nesting indicated that most map turtles were nesting in suboptimal habitats, either due to heavy herbaceous and canopy cover or poor soil conditions, which may result in nest temperatures lower than those required to produce a 1:1 sex ratio (Vogt and Bull, 1984). All of these sites are heavily disturbed and some are completely manmade (e.g. flowerbeds of condos in Port Deposit, Figure 10). Specific impacts include predation by human-subsidized predators (e.g. raccoons), camps and campfires on the islands, and recreational activities (e.g. boating) which disturb turtles during the actual nesting process (Moore et al., 2006). Finally, Northern Map Turtles bask on rock outcroppings, large woody debris, and manmade structures (e.g., bulkhead footing and rip-rap), but basking activity is heavily influenced by both water releases from the Conowingo Hydroelectric Dam and by recreational boating activities.

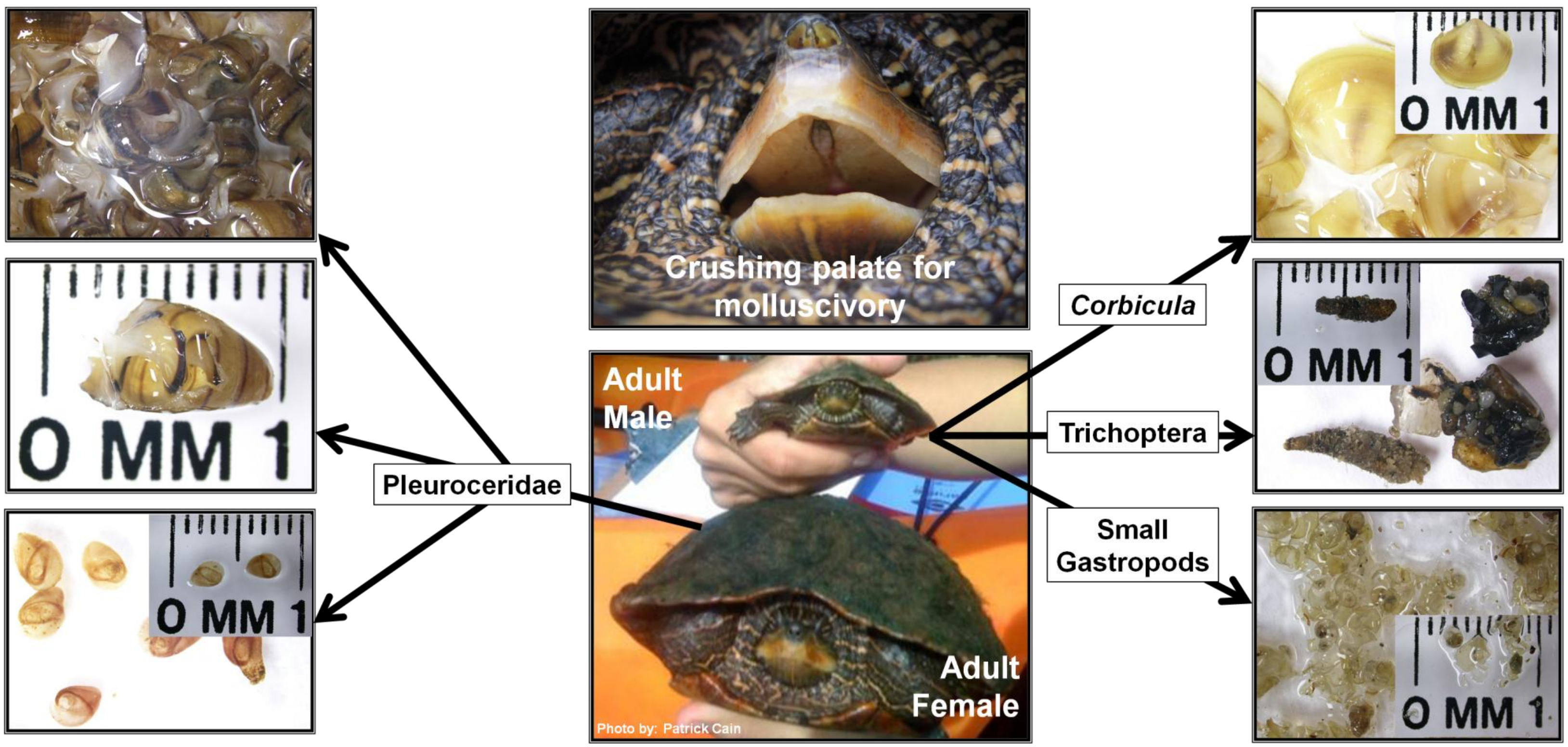
Figure 10. *Graptemys geographica* nesting in riverfront-condo flowerbed in Port Deposit, Maryland.

This identification of home range and core areas of use of this state-endangered species will help delineate protected areas. Specifically, the data on hibernation sites and preliminary data on nesting sites can be used by the Maryland Department of Natural Resources and Susquehanna State Park to protect this species. Additionally, the determination of when and where map turtles are moving will assist in mitigating development plans as well as potentially regulating the impact of visitors to Susquehanna State Park and other areas along the lower Susquehanna River. Future work should (1) document the exact timing, duration, and behaviors of Northern Map Turtles during nesting, (2) quantify nesting success, (3) determine if mitigation efforts to improve nesting areas found during this study can enhance nesting success, and (4) collect data on specific basking site use and impacts of human recreation on basking behavior, as well as whether unnatural flow regimes can be mitigated by creating artificial basking habitat.

These impacts are by no means site specific, as river impoundments (U.S.F.W.S., 1988; Moll, 1980; Dodd, 1990; Reese, 1996), altered flow regimes (Netting, 1944; Thirakupt and van Dijk, 1995), and human recreation (Garber and Burger, 1995; Smith et al. 2006; Moore and Seigel, 2006) are known to affect riverine turtle populations worldwide (Klemens, 2000; Moll and Moll, 2000, 2004a). Data on the extent that these impacts influence population viability and how these impacts can be mitigated will improve not only the conservation of this state-listed population, but also riverine turtles worldwide.

CHAPTER 2

Diet of Northern Map Turtles (*Graptemys geographica*): Relationship to sexual dimorphism and potential impacts of an altered river system in Maryland



Abstract

The diet of the Northern Map Turtle (*Graptemys geographica*) was studied in the dam-regulated Susquehanna River, Maryland. Gastropods, Trichopteran larvae, and *Corbicula* predominated across samples. Marked sexual and size-related differences occurred for these taxa, as adult males fed primarily on a group of small gastropod species (Planorbidae, Hydrobiidae, Physidae), Trichopterans, and *Corbicula*, while the females fed on Pleurocerid snails. Pleurocerids were almost exclusive in the adult female samples, and there seems to be little relationship with body size once female map turtles reach maturity. There was no association of volume of Trichopterans with male body size, but there was a significant negative correlation between male body size and the small gastropod group and significant positive correlation with *Corbicula*. Results are consistent with early reports in other populations of this species before the invasion of Zebra Mussels (*Dreissena* sp), relying heavily on gastropods. Virtually no overlap in the diets of the two sexes of *G. geographica* occurs on the Susquehanna River. This is of special conservation concern because there are two separate groups of prey items that are both needed to persist in order to support this population of Northern Map Turtles.

Introduction

Diet data has been collected since the origins of ecology (Forbes, 1887) and has been used to construct food webs, trace energy flow through ecosystems, and characterize niches. However, roles of turtles in riverine ecosystems have been largely neglected (Bodie, 2001; Moll and Moll, 2004). High levels of turtle biomass suggest considerable contribution to energy flow in these riverine systems (Odum, 1957; Iverson, 1982; Congdon et al., 1986; Souza and Abe, 2000). Characterizing an organism's diet not only will give insight to ecosystem level trophic interactions, but it is also the first step in ultimately understanding to what extent energy intake controls the biology and behavior of the individual organism, especially as it is related to growth and reproductive output. Riverine turtle diet research most commonly characterizes the diet of a species (e.g. Lagler, 1943a; Moll, 1976; Georges and Kennett, 1989; White and Moll 1992; Kennett and Tory, 1996; Bjorndal et al., 1997; Chen and Lue, 1999; Lindeman 2006a and 2006b; Lindeman, 2007; Bonino et al., 2009; Alacade, et al. 2010) and these characterizations become especially important when considering the viability of a population (Dodd, 1988 and 1990). Without an understanding of what prey items are important to the species there is no way to understand what processes, both natural and anthropogenic, may affect that prey base.

Recent studies have done much to increase knowledge of the diets of turtle genus *Graptemys* especially as they are related to the large degree of sexual size dimorphism exhibited in this group. All 13 species of map turtles show sexual size and trophic dimorphism (Ernst and Lovich, 2009; Ennen et al., 2010). Females are much larger than males and have wider heads. Juvenile females, also, have wider heads than males, even those of their same body size (Gibbons and Lovich, 1990; Lindeman, 2000a). Body size and head size dimorphism lends to the sexes occupying different feeding niches (Lindeman, 2000a). Head width evolution is related to varying dietary preferences of each sex, mollusks for females and smaller mollusks and insects for males, in many *Graptemys* species (Lindeman and Sharkey 2001). Twelve of the species were classified as megacephalic, mesocephalic, or microcephalic based on female head width, which is explained by the amount of mollusks incorporated into their diets (Lindeman 2000a). Collins and Lindeman (2006) confirmed these ideas by demonstrating the importance of trophic morphology in adapting Texas Map Turtles (*Graptemys versa*) to prey on mollusks. Bulte et al. (2008a) tested the hypothesis that reproductive role contributes to the sexual dimorphism in trophic morphology of *G. geographica*. Bite force analysis showed that females have stronger jaws than males, and dietary analysis revealed that females ingest snails closer to their maximum biting capacity than males. Reproductive output of females increased with relative head width, indicating that fitness is tightly linked to head size and bite force. The authors suggest females evolved larger heads and stronger bites to increase their energy intake and reproductive allocation (Bulte et al., 2008a; Bulte et al. 2008b).

The dimorphism in Northern Map Turtle diets is of special conservation concern because there are potentially two separate groups of prey items that could be altered by anthropogenic activities and affect females specifically. Animals that have specialized diets tend to be more vulnerable to habitat alterations that affect their prey base (Dodd, 1988 and 1990; Kennett and Tory, 1996). *G. geographica* are mostly molluscivorous (particularly females) but will also consume other invertebrates (Lagler, 1943a; Vogt, 1981; White and Moll, 1992). Anthropogenic alteration to the aquatic environment has been shown to drastically change the diet of the Northern Map Turtle. Specifically, introduced species alter habitat by dramatically affecting the distribution, abundance and reproduction of many native prey species (Strauss et. al, 2006). With these ecological effects, exotic species can also influence the evolution of native species through new interactions with invaders (Lindeman, 2006a, 2006b). Moll (1977) studied stomach contents of map turtle specimens taken over 80 years and found reduced consumption of mollusks in the more recent samples which coincided with increased pollution. The only mollusk found in high volumes in his later samples was the introduced Asian Clam (*Corbicula* sp). Map turtles will subsidize their diet with invasive mussels, specifically *Corbicula* and Zebra Mussels (*Dreissena* sp.), potentially decreasing dietary diversity (Serrouya et al., 1995; Lindeman, 2006a, 2006b; Bulte and Blouin-Demers, 2008c). Introduction of nonnative mollusk species is associated with a decline in natives, which in most cases are the main food source for Northern Map Turtles, and could have a long-term effect on the populations.

Little research has been conducted on the state-endangered, Maryland populations of *G. geographica,* which are currently only known in the lower Susquehanna River drainage. This river is divided by a hydroelectric dam and has increasing shoreline development, both of which may negatively impact this population and their prey community. The Susquehanna River contains both native and nonnative mollusks species (e.g. *Corbicula fluminea,* which has been documented in the lower Susquehanna since 1977; Stotts et al., 1977). Recently, Zebra mussels, a particularly invasive species known to have large effects on aquatic food webs and nutrient cycling, have been found in the lower Susquehanna (2010 MDDNR Susquehanna River mussel survey; Matt Ashton Pers. Comm.).

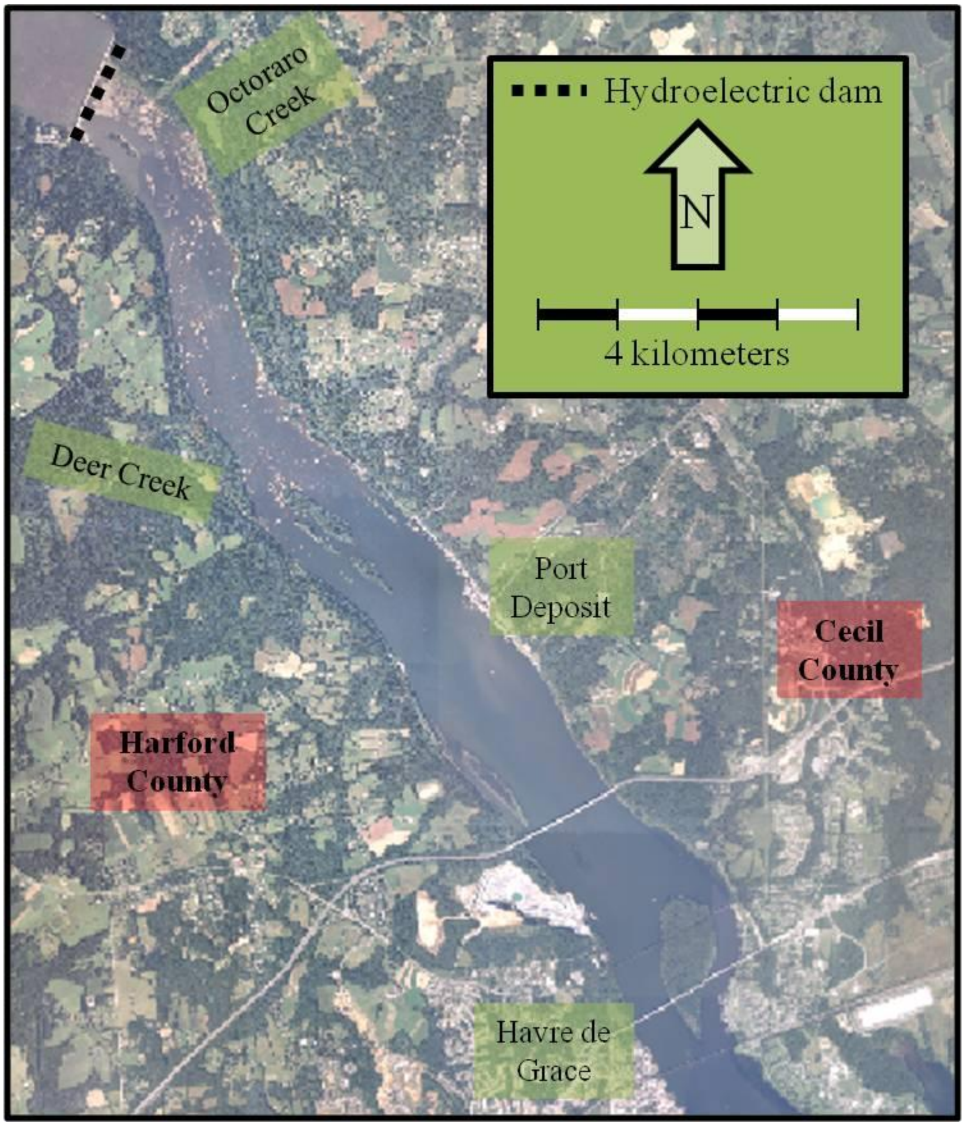
The goal of this study was to collect baseline data on this population's diet and begin to determine if alterations to the river affect their prey base. This investigation is part of a larger population level study to understand the species' current status in Maryland. Given the absence of basic data on Northern Map Turtle diets in Maryland, fecal samples of 52 turtles were examined to increase our knowledge of the natural history of the species, especially in a range-edge population, as well as aid in future management applications.

Materials and Methods

Study Site. The Susquehanna River watershed is the 16th largest in the U.S. and is the longest river on the U.S. East Coast that drains into the Atlantic Ocean (National Research Council, 1999). In Maryland, the river empties into the northern end of the Chesapeake Bay approximately 50 km northeast of Baltimore, providing half of the bay's freshwater inflow (Risser and Siwiec, 1996). The focal area for capture of Northern Map Turtles was the 15 km portion of the river below the Conowingo Dam where it joins the northern end of the Chesapeake Bay at Havre de Grace covering an aquatic area of 1849 ha (Figure 1).

Field collection. There were two periods of data collection. Initial trapping began 15 May 2009 and continued through 22 November 2009. The second season of trapping began 4 April 2010 and continued through 10 November 2010. Basking traps (fashioned similar to those of Horne et al., 2003), dip nets (Lagler, 1943b), and hand captures (Marchand, 1945) were used to obtain turtles for my study. Hand captures were made by

Figure 1. Study site for conservation research of *Graptemys geographica* in the Susquehanna River, MD.



swimming or kayaking up to basking aggregations. If turtles were not immediately caught, a mask and snorkel were used to obtain individuals when they swam to the bottom of the river. Upon capture, straight-line plastron length (PL) and carapace length (CL) were measured with tree calipers (± 0.5 mm). Body mass was measured using a

Pesola® scale (5 kg scale for females and 1 kg scale for males and small juveniles; ± 10 g). All turtles were given a permanent individual mark by drilling a hole in specified marginal scute(s) with a Black & Decker® 14.4v power drill (Ernst et al., 1974). I assumed that maturity is reached in males at 66 mm PL and in females at 169 mm PL (Lindeman, 2006b). Males were identified by the presence of an enlarged tail and cloacal opening posterior to the caparacial rim (Ernst et al., 1994). All turtles between 66-169 mm PL who were not determined to be males by secondary sexual characteristics were considered juvenile females.

Diet analyses were based on feces collected from 52 captured *G. geographica*. Stomach flushing (Legler, 1977) was not used due to concern for injury to the turtles (Lindeman, 2006b) and the technique's biased performance (Lindeman, 2006a, 2007). Turtles were kept in individual 94.6 L plastic basins (adult females) or 18.9 L plastic buckets (males and juveniles) in approximately four cm of river water at ambient temperature inside housing at Susquehanna State Park. The water was filtered through a 750 μm Nitex nylon mesh and was changed every 12 hours until there was a 12 hour period in which no fecal material passed. Individual turtles were not held for longer than 48 hours and were released at their points of capture. Fecal material was placed into 250 ml vials and preserved in 70 % ethyl alcohol for later analysis. Although there were recaptures throughout data collection, no turtle was used more than once for feces collection.

Laboratory analyses. Invertebrates in the fecal samples were sorted into operational taxonomic units (OTU's, Table 1) and placed into 1 dram shell vials. Diet fragments were identified using a dissecting stereoscope with 50x magnification. Bogan and Proch (1997), Smith (2001), and Merritt et al. (2008) were used as references for keying mollusks and other invertebrates. Intact specimens were field collected in July and August 2010 to aid in identification of fecal samples and to preserve as vouchers. The volume of each OTU was determined by displacement of water in a 25 ml graduated cylinder to the nearest 0.1 ml. Samples of a prey category displacing < 0.1 ml water were estimated to amount to 0.05 or 0.01 ml (Lindeman, 2006b). For each OTU within both sexes of turtles, mean percent of total volume and percent frequency of occurrence were used to calculate an Index of Relative Importance (IRI; Hyslop, 1980), as modified by Bjorndal et al., (1997) and used by Lindeman (2006b and 2007) and Patterson and Lindeman (2009).

*Statistical Methods***.** I used a suite of multivariate techniques (Roberts and Taylor, 2008) to determine if the diet composition of the sexes was significantly different and which variables (volumes of taxa in the diet) were responsible for the variation. Non-metric multidimensional scaling (NMS; Mather, 1976) was used to graphically visualize the diet composition of male and female Northern Map Turtles. Individual map turtles were the sample units, and they were ordered along axes describing the variation in the taxonomic composition of the diets. The NMS procedure outlined by McCune and Grace (2002) was followed using Sorensen distances for all sample units. To test the differences in diet between males and females I used a Multi-response Permutation Procedure (MRPP; Mielke and Berry, 2001). I used MRPP in conjunction with NMS and therefore used Sorensen distances to maintain integrity across the analyses. MRPP was also used to compare diet matrices across years to determine if these data could be pooled. Indicator species analysis (ISA; Dufrene and Legendre, 1997) was used to identify taxa that were

Table 1. List of operational taxonomic units (OTUs) *Graptemys geographica* fecal samples were separated into.

OTU	Description
Pleuroceridae	*Elimia virginica*, occurred in samples as fragments
Unionidae	Present as very few fragments, too small to identify beyond family, but most likely *Elliptio complanata*
Corbicula	*Corbicula fluminea*, frequently were present as single intact valves
Pleurocerid Opercula	Opercula of *Elimia virginica*
Small Gastropods	Planorbidae, Hydrobiidae, Physidae, occurred as fragments
Insect Parts	Present as legs, abdomens etc., never intact
Trichoptera	Represented by their cases and constituted at least 4 species
Plant Material	Stalks, leaves, and seeds
Mollusk Soft Tissue	Pieces of soft tissue that were unidentifiable
Unknown	Material that could not be identified based on condition
Sand	Product of crushed mollusks and incidentally taken during feeding

denotative of each sex. Similar to the variance components of an Analysis of Variance, ISA complements MRPP by showing which individual OTU's separate the groups. Thus, an ideal indicator for the sex of a Northern Map Turtle in the Susquehanna River would always occur in the diet of individuals of that sex. Previous work on the genus *Graptemys* demonstrates relationships between body size, volume of fecal sample, and the proportions of specific taxa (Lindeman, 2006a and 2006b). I examined both the association between total volume of sample with body size in all individuals and the association of high Importance Value taxa with body size by sex. My null hypothesis was that there was no association among these variables.

Body size correlations analyses were performed with JMP version 8.0.2 (SAS Institute Inc.). Log transformations were performed on some variables to meet the assumptions of equal variances and normality. PC-ORD was used for all non-parametric multivariate analyses. Microsoft Excel was used to calculate the IRI. Accepted significance levels were set at $\alpha = 0.05$.

Results

MRPP indicated no significant difference between the composition of adult map turtle diets between 2009 and 2010 ($p = 0.598$, $A = -0.006$), and these data were pooled for all analyses. Immature females ($n = 4$) and juveniles of unknown sex ($n = 2$) were omitted from the analyses due to the small number of samples (see Table 2 for descriptions of these samples). Of 46 adult samples, five were removed because they contained < 0.1 ml fecal material. Therefore, 41 samples are included in these analyses: 20 from adult males, 21 from adult females.

Table 2. Volumes (ml) of diet taxa found in samples from sexually immature *Graptemys geographica* (n=6) on the Susquehanna River, MD.

Turtle ID	Sex	Plastron Length (mm)	Pleuroceridae	Pleurocerid Opercula	Small Gastropods	Insect Parts	Trichoptera	Plant Material	Unknown	Sand
37	Female	123	1.5	0.01					0.05	
47	Female	123.5	3.0	0.01	0.01			0.01	0.05	0.01
72	Female	127			1.1			0.05	0.01	
76	Female	84	0.2	0.01	0.01	0.01	0.6		0.1	
31	Unknown	64			0.9	0.01		0.01	0.05	
82	Unknown	62			1.0	0.01	0.01	0.01	0.01	

Index of Relative Importance. Gastropods, Trichopteran larvae, and *Corbicula sp.* predominated across samples, making up 96.4 % of the volume of the individual samples and accounting for 94.9 % of the combined IRI values across all samples. Marked sexual differences occurred, as adult males fed primarily on a group of small gastropod species (Planorbidae, Hydrobiidae, Physidae; IRI=52.789), Trichopterans (IRI=27.975), and *Corbicula sp.* (IRI=13.912), while the females fed almost exclusively on Pleurocerid snails (IRI=93.385) (Table 3). At least one of these taxa were present in every sample. The gastropods were almost always present as fragments in the samples, although in rare cases smaller individuals were taken whole by males. The *Corbicula* were also found as fragments, but more frequently were present as single intact valves. The Trichopterans were most commonly represented by their cases and constituted at least four species based on the construction of the case; however, these were not classified further as case construction is not an accurate indicator of species.

Multivariate analyses to explore sexual differences in diet. Male and female map turtles differed significantly in diet composition (MRPP: $p < 0.0001$, $A = 0.234$). Ordination highlighted two gradients in diet composition that cumulatively account for 91.0% of the variation in diet (stress = 4.967, instability < 0.000001 in 110 iterations). The final solution was significantly different than random (Monte Carlo procedure of 250 randomized runs, $p = 0.004$). Individuals separated along gradients based on the same taxa indicated by high IRI values: Trichopterans, the small gastropod group, *Corbicula*, and Pleurocerid snails (Figure 2). The horizontal axis explains 58.5% of the variation and is defined by a gradient from strong negative correlation with Pleurocerid snails ($r = -0.698$) to strong positive correlation with the small gastropod group ($r = 0.684$). The vertical axis explains 32.5 % of the variation and is again defined by a strong negative correlation with Pleurocerid snails (r = -0.874) to a positive correlation with *Corbicula* (r=0.396), Trichopterans (r = 0.356), and the small gastropod group (r = 0.344) (See Table 4 for correlations of OTUs with NMS axes). Female turtles exhibited diets strongly defined by Pleurocerid snails, whereas males are defined by the small gastropod group, *Corbicula*, and Trichopterans (Figure 2). Interestingly, female #79 is widely separated from the rest of the female group and fed primarily on *Corbicula*. This individual was captured in Deer Creek, a tributary to the main stem of the Susquehanna River, where Pleurocerids were not observed during this study.

Multivariate analysis to determine OTU's denotative of each sex. A Monte Carlo test of significance observed maximum indicator values (IV) from 4999 randomizations. ISA substantiates the results of the NMS and IRI in that Pleurocerid snails (IV = 100, p = 0.0002) and their opercula (IV = 90.5, p = 0.0002) were indicators of females while the small gastropod group (IV = 83.0, p = 0.0002), and Trichoptera (IV = 64.5, p = 0.0004) were indicators of males (Table 5). Sand also has a high IV and is significant for females (IV = 81.0, p = 0.0002), but it is likely a product, in part, of the crushed Pleurocerid shells. Though *Corbicula* was represented by a relatively high IRI value for males, it is not a significant indicator of either sex because it occurs in only 6 males and 1 female. For this female, *Coribicula* was the primary item in her diet sample (92.3 %).

Volumes of sample and proportion of taxa as they relate to body size. Total volume of sample was highly correlated with body size (r = 0.71, p < 0.0001). Correlations of proportions of Pleurocerid snails and female body size are not included due to a low range of body sizes and the inability to sort out outliers. Pleurocerids were

Table 3. Percent frequency of occurrence (% F), mean percent volume of a sample (% V), and Index of Relative Importance (IRI) of prey items in the diet of adult *Graptemys geographica* of the Susquehanna River, MD.

	Adult Females (n = 21)			Adult Males (n = 20)		
	% V	% F	IRI	% V	% F	IRI
Pleuroceridae	90.5	100.0	93.450			
Unionidae	0.05	23.8	0.012	0.1	10.0	0.017
Corbicula	2.4	4.8	0.116	31.8	25.0	13.912
Pleurocerid Opercula	3.9	90.5	3.670			
Small Gastropods	0.2	4.8	0.009	37.7	80.0	52.789
Insect Parts	0.1	42.9	0.038	1.2	55.0	1.156
Trichoptera	0.04	19.0	0.007	24.6	65.0	27.975
Plant Material	0.5	90.5	0.484	2.3	40.0	1.580
Mollusk Soft Tissue	0.2	23.8	0.042	0.0	5.0	0.004
Unknown	1.9	100.0	2.004	2.3	65.0	2.568
Sand	0.2	81.0	0.165			

Figure 2. Ordination (NMS 2-dimensional result) of male and female *Graptemys geographica* by diet taxa. Females = closed circle, Males = open circle. The X axis explains 58.5 % of the variation and is defined by a gradient from strong negative correlation with Pleurocerid snails (r = -0.698) to strong positive correlation with the small gastropod group (r = 0.684). The Y axis explains 32.5 % of the variation and is again defined by a strong negative correlation with Pleurocerid snails (r= -0.874) to a positive correlation with *Corbicula* (r = 0.396), Trichopterans (r = 0.356), and the small gastropod group.

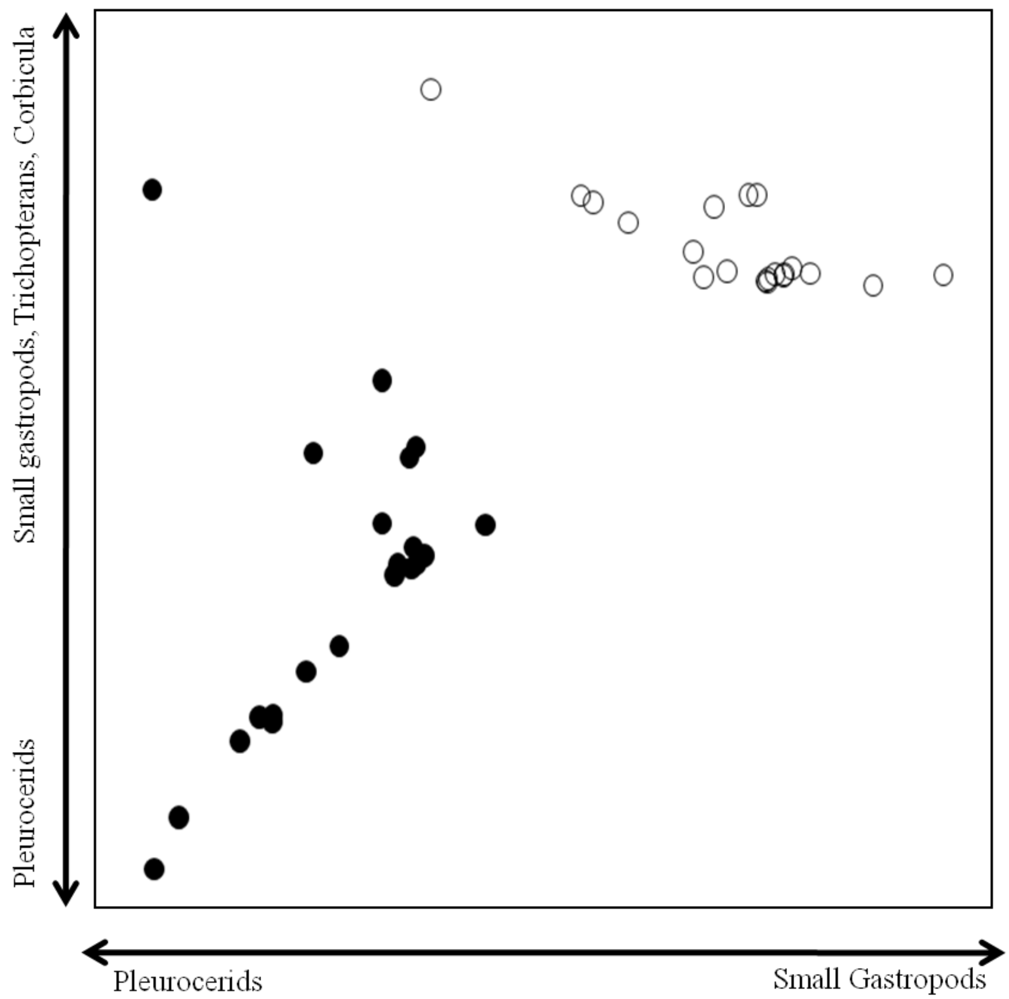


Table 4. Correlations of diet variables with NMS axes.

	Axis 1	Axis 2
Pleuroceridae	-0.698	-0.874
Unionidae	-0.298	-0.247
Corbicula	-0.169	0.396
Pleurocerid Opercula	-0.663	-0.741
Small Gastropods	0.684	0.344
Insect Parts	0.195	0.275
Trichopterans	0.323	0.356
Plant Material	0.038	-0.057
Mollusk Soft Tissue	-0.373	-0.006
Unknown	-0.457	-0.578
Sand	-0.581	-0.589

Table 5. Indicator Values (IV) for each diet variable with significance values.

	Sex	IV	P
Pleuroceridae	F	100	0.0002
Unionidae	F	16.8	0.4071
Corbicula	M	22.1	0.1526
Pleurocerid Opercula	F	90.5	0.0002
Small Gastropods	M	83.0	0.0002
Insect Parts	M	48.4	0.0502
Trichopterans	M	64.5	0.0006
Plant Material	F	47.7	0.4105
Mollusk Soft Tissue	F	22.5	0.1282
Unknown	F	80.7	0.0016
Sand	F	81.0	0.0002

almost exclusive in the adult female samples, and there seems to be little relationship with body size once female map turtles reach maturity. There was no correlation of volume of Trichopterans with male body size ($r = 0.101$, $p = 0.67$). However, there was a significant negative correlation between male body size and the small gastropod group ($r = -0.492$, $p = 0.03$). There was also a significant positive correlation between male body size and *Corbicula* ($r = 0.550$, $p = 0.01$).

Discussion

Graptemys geographica in this population show the typical pattern of sexual differences in diet previously described (Vogt, 1981; Lindeman, 1997, 2006b). As in other mesocephalic species my adult females ate more mollusks than males, but unlike previous studies on *Graptemys* my females did not show increased molluscivory with body size (Sanderson, 1974; Shealy, 1976; Porter, 1990; Lindeman, 2006b). In my population Pleurocerid gastropods were almost exclusive in the adult female samples, and there seems to be little relationship with body size once female map turtles reach maturity. As males increase in body size they show a decreased relationship with the small gastropod group and increased consumption of *Corbicula,* the introduced Asiatic Clam. Males with large proportions of *Corbicula* in their samples (N = 4) were all over 100 mm PL. This result may be due to their ability to ingest larger prey but would need to be confirmed experimentally. Juvenile females in my population are preying on items more similar to adult females than similar sized males (Table 2). The few juvenile female samples I have collected support previous explanations that trophic morphology, rather than body size, is important for molluscivory (Sanderson 1974; Shealy 1976; Porter

1990; Lindeman 2006b). It has been suggested the evolution of *Graptemys* has been characterized by changes in head and alveolar width in females but not in males, because of the more molluscivorous tendencies of females (Lindeman and Sharkey, 2001). I observed virtually no overlap in the diets of the two sexes on the Susquehanna River. This is of special conservation concern because there are two separate groups of prey items that both must persist in order to support this population of Northern Map Turtles.

Early studies of *G. geographica* diet report heavy consumption of gastropods (Garman, 1890; Newman, 1906). Lagler (1943a) reported snails, bivalves, crayfish, and aquatic insects in the diet of both males and females from Michigan. Vogt (1981) reported that the majority of the diet for adult females in Wisconsin consisted of mollusks while males fed on primarily aquatic insects. White and Moll (1992) reported both sexes feeding almost exclusively on small snails (*Elimia potosienis*, of the same genus as the Pleurocerids being consumed on the Susquehanna) in a stream in Missouri. Trichopteran larvae are the majority of aquatic insects in these studies. The population of *G. geographica* in the lower Susquehanna River, MD has a diet structured similarly to these earlier reports, relying heavily on gastropods and aquatic insect larvae, specifically Trichopterans. This is especially surprising due to the high level of alterations to the river from impoundment, shoreline development, and recreation. These activities alter natural flow regimes, increase pollution inputs, and cause species introduction and in turn alter the mollusk community assemblage (Moll, 1977; Watters, 1999; Brown et al., 2008). Though *Corbicula* has been present in the lower Susquehanna River since the late 1970’s (Stotts et al., 1977), only male *G. geographica* are consuming them. Specifically, *Corbicula* make up 31.8 % of their samples. Only one female sample contained

Corbicula, and she was captured outside of the main river channel where a different prey assemblage is likely to occur. Early studies also exhibit this pattern of *Corbicula* being part of more diverse diets (Moll, 1977; Lindeman, 2000b).

Though there are earlier records of female map turtles shifting their diets to almost exclusively non-native mollusks (Shealy, 1976; Shively and Verdine, 1984; Porter, 1990) this pattern has become increasingly common in more recent reports. In Lake Erie, where the introduction of Zebra and Quagga Mussels (*Dreissena polymorpha* and *D. bugegensis*, respectively) has dramatically altered the biological community, Northern Map Turtle females feed heavily on this food source (Lindeman, 2006b). Similar trends of diet are found in Canada populations (Bulté et al., 2008c). Bulté and Blouin-Demers (2008c) estimated that the average adult female annually consumes 33−137 kg of Zebra and Quagga Mussels, roughly 28 % of their dietary intake. Thus, this *G. geographica* population's gastropod-based diet has the potential to dramatically change, based on the recent introduction of Zebra Mussels to the lower Susquehanna River and the mussels' ability to cover and smother native gastropods (Bogan, 1998). Lindeman (2006b) suggests the impact of predation by *G. geographica* on *Dreissena* spp. may have a potential positive effect on *G. geographica* abundance throughout their range. Furthermore, it has recently been suggested that the scientific community may need to shift the way we think about non-native species in the cases where they provide food resources for species of conservation concern (see Schlaepfer et al., 2011 for review). In laboratory experiments, *G. geographica* consume *D. polymorpha,* but when presented with a native gastropod the turtles consumed the *D. polymorpha* at slower rates (Serrouya et al., 1995). The potential negative effects of *Dreissena* species on *G. geographica* physiology needs to be further studied to understand whether shifts to these prey items can truly be considered positive or benign for map turtles.

The invasion of Zebra Mussels is one concern for the mollusk community diversity of the lower Susquehanna River; the Conowingo Hydroelectric Dam is another. Dam construction disturbs the environmental conditions to which native mollusks are adapted (McCartney, 2009). Rivers that have been impounded have lost or changed their mollusk faunas, almost without exception (Watters, 1999). In the United States and Canada, mollusk species richness following dam construction has decreased 37 % to 95 % (Williams et al., 1993). Many of these declines are in the lentic reservoirs that drastically change the original lotic environment. However, mollusk communities downstream of hydroelectric dams are impacted as well (Vaughn and Taylor, 1999; Babko and Kuzmina, 2009). Johnson and Brown (1997) studied a Pleurocerid snail, *Elimia semicarinata*, in Kentucky stream habitats that varied in current velocity and found adult density decreased with higher flow. North American Pleurocerid gastropods are highly endangered, and their ecology and conservation have not drawn as much interest from aquatic ecologists as have the ecology and conservation of unionid bivalves (Brown et al., 2008). *G. geographica* are known from both above and below the Conowingo hydroelectric dam, and both their diets and the impacts on their prey may be entirely different, especially for females who feed almost exclusively on Pleurocerid snails. Pleurocerid distribution is limited by relatively slow adult dispersal, and they have experienced dramatic reductions in their ranges because of impoundments (Neves et al., 1997). Future work should characterize the diets of the population in the reservoir above the dam to examine if those females there are reliant on Pleurcerid snails or if their diet is altered due to a shift in prey community by the transition of lotic to lentic habitat.

Very few studies have been able to demonstrate prey preference for turtles because data are needed on relative abundance of prey in the environment to compare to diet samples (Paramenter, 1980; Spencer, 1998; Alcalde et al., 2010). Future work in this population should include collection of prey community data. The data on how prey communities are distributed in the Susquehanna River will give insight into whether turtle distribution is based on prey availability. Furthermore, anthropogenic impacts to prey distributions will undoubtedly have population level effects on Northern Map Turtles. Monitoring the invasion of Zebra Mussels on the Lower Susquehanna River will likely happen because these mussels have both large ecological and economical impacts (see Strayer 2009 for review). Monitoring the diet of *G. geographica* on the Lower Susquehanna in conjunction with this invasion will allow for documentation of the potential dietary shift to this non-native prey.

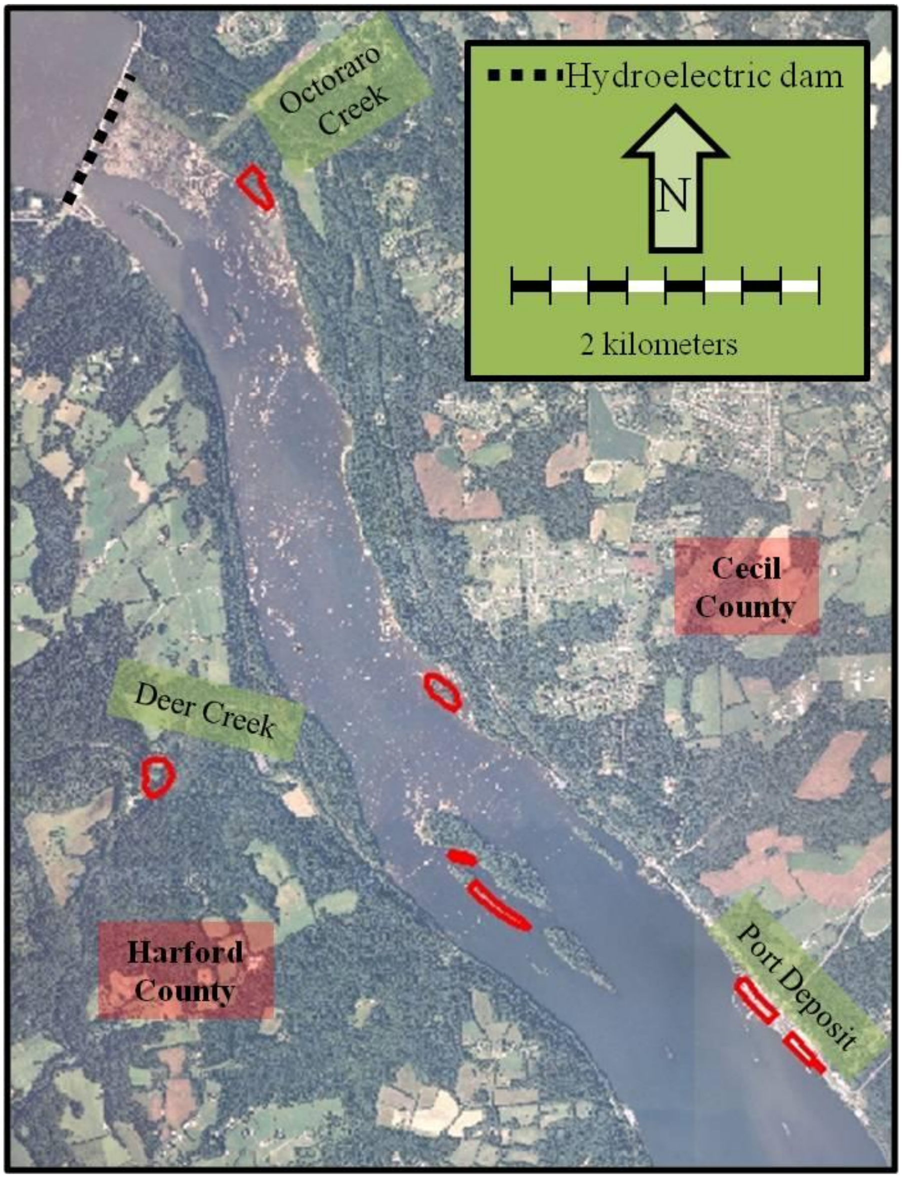
APPENDICES

Appendix A: Conservation and Management Recommendations

Detailed reproductive ecology data collection, nest site restoration, and monitoring. Northern map turtles were found nesting at a variety of sites in Harford and Cecil counties, especially (a) along islands adjacent to Susquehanna State Park, (b) along Octoraro Creek in Cecil County, (c) along deer creek in Harford County, and (d) in the town of Port Deposit (see Figure 1 for specific locations). All of these sites are heavily disturbed; specific impacts include predation by human-subsidized predators (e.g., raccoons), camping and campfires on the islands, and other recreational activities (specifically boating) which disturb turtles during the actual nesting process. Due to these disturbances, females appear at times to avoid prime nesting areas (open canopy, little vegetation) and instead dig nests in areas of heavy vegetation and canopy cover, which has the potential to alter hatchling sex ratios (Vogt and Bull, 1984).

Towson University (TU) has contracted with Exelon Corp. to gather more detailed data on the reproductive ecology of the population of Northern Map Turtles in the lower Susquehanna River in Maryland. The goals of that study are to (1) document the exact timing, duration, and behaviors of Northern Map Turtles during nesting; (2) determine nest success; and, (3) determine if habitat modifications of existing nesting areas can enhance nesting success and, consequently, population viability. Proposed nest site modifications include clearing foliage in some of the heavy canopy cover areas. However this will also make these sites more attractive to humans for campsites, so how well they will be used by nesting females in unknown. Therefore, I strongly suggest that discussions between Maryland Department of Natural Resources (MD-DNR), Exelon,

Figure 1. *Graptemys geographica* nest sites on the Lower Susquehanna River, MD. Nest area polygons in red.



Susquehanna State Park, and the Maryland National Resource Police (NRP) begin to determine how human use of these nesting sites can be discouraged.

Protection of nest sites. Data from the proposed TU/Exelon reproductive ecology study will greatly improve our understanding of the apparent threats of poor nest site quality and predation. However, proactively, the known nesting areas can and should be protected during the nesting season (1 May-15 July). A seasonal time-of-year restriction should prevent public use of the MD-DNR managed islands (Steel, Roberts, Wood, and unnamed island between Roberts and Wood) from 1 April-31 July. This time period will allow for protection of basking sites associated with these islands, as well as full access to areas turtles have not previously nested, presumably because of human disturbance (i.e., open sandy beach on Cecil County side of Roberts Island). Warning signs will need to be placed on the islands, which may require a regulation change in COMAR. If the islands are in the Chesapeake Bay Critical Area then these are already Habitat Protections Areas and will likely not need further regulation change (Scott Smith, pers. comm.), just increased enforcement. A meeting with representatives from DNR, NRP, Susquehanna State Park, and TU should be planned to establish how the time-of-year restriction could be enforced. Northern Map Turtles are also nesting on private lands in addition to state lands. Therefore, it will be worthwhile to pursue similar protection and improvement of nest sites on both Exelon managed properties (through current partnership with TU) and the town of Port Deposit (no contacts made at this time).

Northern Map Turtles are known to overwinter in the nest (Nagle et al., 2004), and I have confirmed this with one nest for the population in the Susquehanna River (unpublished data). The time-of-year restrictions suggested do not protect nests throughout the late summer, fall, and winter. Signage that asks island visitors to be careful and respectful of nesting habitat year round should be considered.

Predator control. Preliminary data on nesting has shown that subsidized mesopredators (e.g. raccoons) are heavily impacting the nest success of Northern Map Turtles on the Susquehanna River. In some areas (islands and Octoraro Creek site) there may be up to 100% nest failure from predation. In addition, one radio-equipped female was killed by a raccoon while attempting to nest on Roberts Island. This is of special concern as predation on adult turtles can greatly reduce population viability (e.g., Congdon et al., 1994; Heppel, 1998).

Data collected by the proposed TU/Exelon reproductive ecology study will further our understanding of these impacts and better quantify nest success. A starting point to addressing nest predation would be to remove raccoons from islands prior to the nesting season for Map Turtles. However, without monitoring over multiple seasons there is no way to determine if this is an effective management strategy or if the islands will be re-colonized by these predators. Realistically, predator control is not a one-time solution. To be effective it will need to be an ongoing process and its validity as feasible management strategy will need to be determined.

Education and awareness. Through partnership with TU, MD-DNR should conduct education and outreach efforts with the public about Northern Map Turtle’s protected status. This can be done primarily from Susquehanna State Park through their nature center, public events, and campfire talks. A factsheet on the species to increase awareness has been prepared (by TMRD, currently being reviewed by Susquehanna State Park Staff) for dissemination from the park nature center and can be used elsewhere as deemed fit. Again, signs posted along areas where turtles bask and nest in/near Susquehanna State Park (i.e. the “beach” on Craig’s Corner Road by the pumping station) may elicit a more careful use of areas where Northern Map Turtles nest and bask. Patrons should be encouraged to support limiting public use of nesting areas and educated on the importance of basking behavior for this species (and human impacts on the behavior, see Moore and Seigel, 2006). Other areas to target for potential displays and awareness include fishing areas along Octoraro Creek and in the Town of Port Deposit.

Enforce collecting laws. Though many of the suggested management recommendations in this chapter focus on impacts on nesting, it should be stressed that nest and hatchling success is often extremely low in turtle populations and their life history strategy relies on high adult survival for population viability (Congdon et al., 1994; Klemens, 2000). It is well known that removal of adult turtles in high human-use areas can decimate a population (Garber and Burger, 1995). Fortunately, there is no current evidence of collection for Northern Map Turtles from the Susquehanna River. However, those in enforcement roles (NRP and Susquehanna State Park Rangers) should be aware of the species’ protected status in Maryland and enforce the associated laws when needed.

Artificial basking habitat. In addition to the known affects of recreation on basking behavior (Moore and Seigel, 2006), my data demonstrate that high flows from the dam hinder basking activity. A study in Ontario, Canada has shown that there are demographic effects (e.g. slower growth) from these types of impacts (Bennett et al., 2009). Mitigating for lost basking habitat may help reduce impacts. TU is currently collaborating with engineers and consultants from Exelon to begin to develop artificial basking platforms that can be used by turtles during periods of high water. Further research on what kinds of basking sites are most commonly used by map turtles will be used to guide the development of such artificial basking sites. If such development goes as planned, at least some artificial sites will be deployed in the spring and summer of 2012. These artificial platforms will then be monitored to determine their use by free-living turtles.

Flow regime change. A more extreme approach to minimizing impacts of fluctuations in stage and flow rates produced by the Conowingo Hydroelectric Dam would be to suggest and potentially require “re-operation” for restoring more natural flow regimes (see Richter and Thomas, 2007 for review and case studies on “re-operation”). Many previous case studies have specific goals for re-operation based on the particular impacts to biota of concern in that river system. In the Exelon Corp.’s Pre-Application Document (Exelon, 2009) there is no indication that there is consideration for changes in operation other than their required minimum flow rate. The current flow regime below Conowingo Dam was formally established with the signing of a settlement agreement in 1989 between the dam owners at the time and several federal and state resource agencies (FERC, 1989). The flow regime was determined through negotiation and based on several studies, including a habitat-based instream flow study and MDNR examination of benthic macroinvertebrate populations. None of these studies included impacts to Northern Map Turtles (see Conwingo Hydroelectric Project PAD (FERC no. 405) for established flow regime). This regime is based on minimum average flows and does not take into consideration the daily habitat changes based on peak flows during peak energy-use hours (see Chapter 1 discussion for description of changes in daily flow rate and stage).

It should be noted Exelon, is currently operating within federal regulations, are a source of “green energy”, and are willing to mitigate for lost Northern Map Turtle basking habitat. However, mitigation and a true “fix” may not be that same thing. If a group or agency wanted to promote restored natural flow on the Susquehanna River, data on this population of Northern Map Turtle’s reaction to “unnatural” flow rates would certainly support the exploration and implementation of more natural flow rates (e.g., more natural flooding in the spring and gradual shifts in flow and stage based on rainfall rather than cyclic energy needs). Required studies for Exelon’s relicensing are currently being completed on fish and macroinvertebrate communities by Normandeau Associates. Those data may further support changes in flow regimes. However, from previous meetings with representatives from FERC, MD-DNR, Normandeau, Exelon Corp., and TU, regime changes are considered a last resort and currently are not “on the table” as part of Exelon’s relicensing agreement. At this time it seems a single species may not be enough to change operations without strong legal and regulatory pressure. The economic impacts of “re-operation” need to be further assessed to understand the cost and benefit of potential natural flow operations.

Long term monitoring and rapid assessment. To assess long term viability and population status, TU and MD-DNR should collaborate to implement a yearly rapid assessment protocol based on line-distance sampling of basking map turtles. The details of the protocol should be tested in the spring and summer of 2011 and be available to MD-DNR to monitor this population into the future. This protocol can be used from year to year to get detection probabilities and abundance estimates (Buckland et al., 2001). Continued capture, marking, and collection of demographic data, will further allow for population projection, survivorship estimates, and overall understanding of population viability.

Appendix B: IACUC letter of permission to conduct research on Northern Map Turtles

Dear Ms Richards,

I am writing to inform you of the approval of the protocol IACUC # 04309 RS in title "Habitat use and diet of Maryland endangered Northern Map Turtles (Graptemys geographica) in an altered river system: Implications for conservation and management"

Thanks,

Best Regards,

Liliana

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Appendix C: Capture localities and morphometrics of *G. geographica* on the Susquehanna River. Recaptures highlighted in green.

Date	Time	East	North	Sex	Stage	Mark #	Method of Capture	Mass	CL	PL	SH	Gravid by Palp?	DNA?
9/24/2008	1330	403023	4385657	M	Adult	1	Snorkeling		111	97		N/A	N
9/24/2008	1350	402977	4385638	F	Adult	2	Snorkeling		264	227		N	N
5/15/2009	1210	402124	4385313	M	Adult	3	Basking Trap	165	115	99	38	N/A	Y
5/15/2009	1259	402124	4385313	F	Adult	5	Basking Trap	1900	250	205	82	N	Y
5/15/2009	1259	402124	4385313	M	Adult	4	Basking Trap	180	117	100	40	N/A	Y
5/16/2009	1421	402380	4385274	F	Adult	6	Basking Trap	1950	249	217	91	N	Y
5/16/2009	1444	402380	4385274	F	Adult	7	Basking Trap	1650	239	208	85	N	Y
5/16/2009	1557	402188	4385394	F	Adult	8	Basking Trap	1950	263	221	88	N	Y
5/20/2009	1355	402308	4385315	M	Adult	9	Basking Trap	170	113	99	39	N/A	Y
5/20/2009	1430	402199	4385396	F	Adult	11	Basking Trap	1550	227	202		N	Y
5/20/2009	1430	402199	4385396	F	Adult	10	Basking Trap	2100	258	253	89	N	Y
5/20/2009	1511	402308	4385315	M	Adult	14	Basking Trap	150	114	92	38	N/A	Y
5/20/2009	1515	402488	4385238	F	Adult	13	Basking Trap	1700	238	211	82	N	Y
5/20/2009	1530	402308	4385315	F	Adult	12	Basking Trap	2300	263	223	93	N	Y

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5/27/2009	1532	402383	4385276	F	Adult	15	Basking Trap	2100	271	227	93	N	Y
5/27/2009	1538	402189	4385401	F	Adult	16	Basking Trap	1750	258	216	84	Y	Y
5/27/2009	1605	402986	4385632	F	Adult	17	Basking Trap	2400	275	233	95	Y	Y
5/27/2009	1650	402487	4384235	M	Adult	14	Basking Trap					N/A	
5/27/2009	1719	402986	4385632	F	Adult	18	Basking Trap	1335	231	199	84	Y	Y
5/31/2009	1407	401720	4385932	M	Adult	19	Basking Trap	160	112	96	38	N/A	Y
5/31/2009	1407	401720	4385932	M	Adult	20	Basking Trap	140	107	91	37	N/A	Y
5/31/2009	1448	401720	4385932	F	Adult	21	Basking Trap	2050	256	215	91	Y	Y
5/31/2009	1550	402327	4385303	F	Adult	22	Basking Trap	2150	257	223	91	N	Y
6/3/2009	1013	402161	4385645	F	Adult	24	Hand	1850	243	203	88	Y	Y
6/3/2009	1100	404380	4384217	F	Adult	23	Hand	1950	265	229	90	N	Y
6/3/2009	1142	404446	4384111	F	Adult	13	Hand					Y	
6/7/2009	1804	402184	4385390	F	Adult	6	Basking Trap					Y	
6/8/2009	1415	402192	4385392	F	Adult	25	Basking Trap	2200	264	226	88	Y	Y
6/8/2009	1428	402192	4385392	F	Adult	22	Basking Trap					Y	
6/9/2009	1515	402307	4385324	M	Adult	26	Basking Trap	260	137	119	44	N/A	Y
6/10/2009	1309	402307	4385324	F	Adult	27	Basking Trap	1300	226	196	79	N	Y

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6/10/2009	1341	402307	4385324	F	Adult	10	Basking Trap					N/A	
6/10/2009	1418	402195	4385403	F	Adult	28	Basking Trap	1950	247	218	89	N	Y
6/10/2009	1450	402307	4385324	F	Adult	29	Basking Trap	1450	233	197	79	N	Y
6/10/2009	1450	402307	4385324	F	Adult	6						Y	
6/12/2009	923	405115	4383126	F	Adult	17						N	
6/12/2009	1617	402190	4385404	F	Adult	30	Basking Trap	1850	260	212	86	N	Y
6/19/2009	1624	403290	4385403	UNK	Juvenile	31	Dip net	50	73	64	28	N/A	Y
6/23/2009	1820	402330	4385299	M	Adult	32	Basking Trap	200	118	102	39	N/A	Y
6/24/2009	1058	402196	4385390	F	Adult	33	Basking Trap	2300	263	215	92	N	Y
6/24/2009	1157	402196	4385390	F	Adult	34	Basking Trap	1950	259.5	220	89	Y	Y
6/24/2009	1750	402196	4385390	F	Adult	35	Basking Trap	1950	254	211	90	N	Y
6/25/2009	1031	402986	4385632	F	Adult	36	Basking Trap	2000	253	218	90	Maybe?	Y
6/25/2009	1045	402321	4385303	F	Immature	37	Basking Trap	320	134	123	48	N	Y
6/25/2009	1104	404081	4384470	Hatch	Hatchling		Dip net	10	31	28	15	N	N
6/25/2009	1520	402321	4385303	F	Immature	38	Basking Trap	170	106	94	42	N	Y
6/27/2009	1331			UNK	Juvenile	31	Dip net					N/A	
6/27/2009	1635	402324	4385300	M	Adult	39	Basking trap	210	119	100	39	N/A	Y

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6/27/2009	1635	402324	4385300	M	Adult	40	Basking Trap	240	124	106	42	N/A	Y
6/27/2009	1552	404029	4384517	Hatch	Hatchling	Plastron R-anal	Dip net	15	35	31	15	N/A	N
7/1/2009	1552	404016	4384512	Hatch	Hatchling	Plastron R-anal	Dip net	15	39	35	17	N/A	N
7/1/2009	1451	402187	4385406	F	Adult	35	Basking Trap					Y	
7/1/2009	1603	405122	4383141	F	Adult	41	Basking Trap	1200	212	193	83	N	Y
7/1/2009	1541	404025	4384521	Hatch	Hatchling	Plastron R-anal	Dip net	<10	35	32	15	N/A	N
7/1/2009	1542	404025	4384521	Hatch	Hatchling	Plastron R-anal	Dip net	<10	35	29	16	N/A	N
7/1/2009	1543	404025	4384521	UNK	Hatchling							N/A	
7/10/2009	1154	402132	4385470	F	Adult	42	Snorkeling	1800	241	204	86	N	Y
7/10/2009	1710	405119	4383130	F	Adult	43	Basking Trap	1600	239	204	85	N	Y
7/28/2009	1150	402022	4385188	M	Adult	44	Hand	70	78.5	66	29	N/A	Y
8/13/2009	1540	404041	4384502	M	Adult	45	Basking Trap	70	80	66	29	N/A	Y
8/25/2009	1541	401942	4385158	M	Adult	46	Basking Trap	190	118	96	38	N/A	Y
8/26/2009	1522	401942	4385158	F	Adult	7	Basking Trap					N	N
8/26/2009	1522	401942	4385158	F	Immature	47	Basking Trap	290	136	123.5	48	N	Y
8/26/2009	1522	401942	4385158	M	Adult	48	Basking Trap	220	122	102.5	40	N/A	Y

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8/26/2009	1630	401942	4385158	M	Adult	49	Basking Trap	180	119	99	42	N/A	Y
8/26/2009	1630	401942	4385158	M	Adult	50	Basking Trap	110	96	81	33	N/A	Y
8/28/2009	1420	402977	4385638	M	Adult	51	Hoop trap	110	100	84	33.5	N/A	Y
9/1/2009	1155	401865	4385118	M	Adult	53	Snorkeling	200	124	102	38	N/A	Y
9/5/2009	1130	402699	4385849	M	Adult	54	Snorkeling	180	112.5	95	38	N/A	Y
10/25/2009	1450	402966	4385651	M	Adult	58	Dip net	135	102	82.5	33	N/A	Y
11/8/2009	1222	402917	4385701	M	Adult	59	Hand	150	104	85.5	36	N/A	Y
11/15/2009	1435	402120	4385421	F	Adult	55	Hand	1600	230.5	205.5	84	N	Y
11/15/2009	1321	402687	4385172	M	Adult	56	Hand	190	115.5	98	38	N/A	Y
11/15/2009	1423	402585	4384933	M	Adult	57	Dip net	170	113	94	37	N/A	Y
11/16/2009	1327	402539	4385022	M	Adult	52	Hand	170	112	94	37	N/A	Y
11/21/2009	1146	403034	4385571	M	Adult	60	Hand	105	93	78	33	N/A	Y
11/21/2009	1158	402569	4385236	M	Adult	61	Dip net	155	108	91.5	35.5	N/A	Y
11/21/2009	1341	402404	4385236	M	Adult	56	Dip net					N/A	
11/22/2009	1455	402545	4385215	F	Immature	62	Dip net		109	109	45	N	Y
4/4/2010	1303	402261	4385199	M	Adult	63	Hand	205	122	100	40.5	N/A	Y
4/4/2010	1545	402212	4385384	M	Adult	64	Hand	100	95	80.5	32.5	N/A	Y
4/4/2010	1600	402321	4385307	M	Adult	65	Hand	100	91	79	33.5	N/A	Y
4/5/2010	1355	402261	4385152	M	Adult	66	Hand	165	101.5	90	36.5	N/A	Y
4/7/2010	1433	402326	4385312	F	Adult	67	Basking Trap	2100	251	208.5	88	N	Y
4/7/2010	1439	402305	4385343	M	Adult	68	Hand	270	139.5	115	43	N/A	Y
4/7/2010	1511	402189	4385391	F	Adult	69	Basking Trap	1600	237	200	80	N	Y
4/7/2010	1511	402189	4385391	F	Adult	70	Basking Trap	1600	233	199	85	N	Y

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4/16/2010	1443	402135	4385305	F	Immature	71	Basking Trap	540	165	143	69	N	Y
5/1/2010	1256	402198	4385395	F	Immature	72	Basking Trap	350	142	127	50.5	N	Y
5/1/2010	1256	402198	4385395	M	Adult	73	Basking Trap	150	109.5	90		N/A	Y
5/3/2010	1436	402198	4385395	F	Adult	74	Basking Trap	1850	248.5	203	89	N	Y
5/3/2010	1436	402198	4385395	F	Adult	75	Basking Trap	1650	248	207	81	N	Y
5/6/2010	1231	402186	4385391	F	Adult	10	Hand	1950	251	213	89	N	
5/20/2010	1220	402048	4385410	F	Adult	30	Basking Trap	1900	242.5	209	87	Y	
5/25/2010	1633	404468	4384084	F	Juvenile	76	Snorkeling	110	95	84	33	N/A	Y
5/28/2010	1410	403945	4384610	F	Adult	78	Hand	1900	239	210	88.5	Y	Y
5/28/2010	1410	403936	4384629	F	Adult	77	Hand	1500	221	193.5	84.5	N	Y
6/4/2010	1635	399660	4386316	F	Adult	79	Hand	1650	245	212.5	95	N	Y
6/7/2010	1100	401519	4386975	F	Adult	80	Hand	2625	269.5	221	98	Y	Y
6/10/2010	1230	400562	4390263	F	Adult	81	Hand	1950	242.5	206	89	Y	Y
6/15/2010	1646	400037	4386488	Hatch	Hatchling		Hand					N/A	N
6/17/2010	1337	400077	4386558	F	Adult	83	Hand	1625	236	206	86.5	Y	Y
6/17/2010	1346	400057	4386558	F	Adult	29	Hand	1500	233	192	80	Y	
6/18/2010	818	401887	4385012	UNK	Juvenile	82	Hand	40	65	62	36	N/A	Y
7/15/2010	1755	401940	4385158	F	Adult	84	Basking Trap	2050	257	215.5	93	N	Y
7/15/2010	1747	402704	4385822	M	Adult	85	Basking Trap	95	92	75.5	31	N/A	Y
8/19/2010	1025	402660	4384849	M	Adult	86	Basking Trap	145	104	89	35	N/A	Y

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9/15/2010	1403	402690	4385393	M	Adult	87	Basking Trap	185	121	99	37	N/A	Y
9/15/2010	1417	402967	4385637	M	Adult	88	Dip net	95	90	82.5	32	N/A	Y
9/17/2010	1209	402066	4385530	M	Adult	89	Dip net	100	94	80	32.5	N/A	Y
9/18/2010	1305			UNK	Juvenile	90	Hand					N/A	N
9/24/2010	1212	402528	4385049	F	Adult	91	Basking Trap	1100	200.5	178.5	73	N	Y
9/24/2010	1254	402528	4385049	M	Adult	92	Basking Trap	165	116	94.5	36.5	N/A	Y
10/8/2010	1230	402184	4385393	M	Adult	89	Dip net					N/A	
10/8/2010	1534	402312	4385313	M	Adult	97	Basking Trap	235	127	103	41	N/A	Y
10/8/2010	1433	402312	4385313	M	Adult	94	Basking Trap	205	119.5	101	40	N/A	Y
10/8/2010	1450	402312	4385313	M	Adult	95	Basking Trap	180	110.5	86	39	N/A	Y
10/8/2010	1455	402184	4385393	M	Adult	96	Basking Trap	80	82	68.5	30	N/A	Y
10/10/2010	1348	402312	4385315	M	Adult	93	Basking Trap	165	111	94.5	37.5	N/A	Y
10/10/2010	1350	402312	4385313	M	Adult	50	Basking Trap					N/A	
10/10/2010	1350	402312	4385313	M	Adult	98	Basking Trap	155	106.5	91	37	N/A	Y
10/10/2010	1435	402552	4385002	M	Adult	99	Basking Trap	185	122	99	37.5	N/A	Y
10/10/2010	1435	402552	4385002	M	Adult	100	Basking Trap	205	118	98	38.5	N/A	Y
10/10/2010	1447	402184	4385393	M	Adult	101	Basking Trap	130	103.5	88	34.5	N/A	Y

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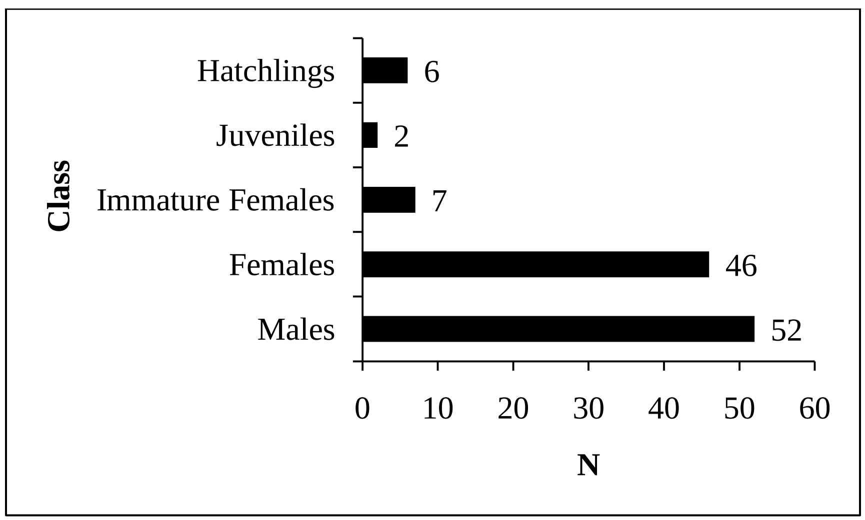
10/10/2010	1547	402310	4385315	M	Adult	4	Basking Trap	180	117.5	95	40	N/A	
10/17/2010	1434	402447	4385227	F	Adult	102	Hand	1450	224	193.5	82.5	N	Y
10/17/2010	1452	403073	4385484	M	Adult	45	Hand	100	91.5	75	31	N/A	
10/24/2010	1530	403024	4385641	F	Adult	104	Dip net	1600	230	230	83	N	Y
10/24/2010	1720	402524	4385032	M	Adult	103	Hand	205	116	98	38.5	N/A	Y
10/31/2010	1244	402526	4385032	M	Adult	106	Hand	160	109.5	88	37	N/A	Y
10/31/2010	1332	402517	4385163	F	Immature	105	Hand	500	157	144	57.5	N	Y
11/7/2010	1303	402132	4385158	M	Adult	107	Hand	220	125	101	41.5	N/A	Y
		402679	4385163										
11/10/2010	1332	402310	4385315	M	Adult	109	Hand	235	123.5	102	42.5	N/A	Y

Summary of captures by age and reproductive class. Adult sex ratio not different than 1:1 ($\chi^2 = 0.367$, df = 1, P = 0.545).



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Education

Master of Science, Biology GPA 4.0
Towson University, Towson, MD August 2008-May 2011

Coursework: Conservation Biology, Professional Aspects of Biology, Herpetology, Independent Study in Population Biology, Data Analysis and Interpretation, Landscape Ecology, Advanced Data Exploration and Presentation, Graduate Seminar in Evolution, Community Analysis and Bioassessment

Bachelor of Science, General Biology
Chemistry Minor GPA 3.78
Grand Canyon University, Phoenix, AZ August 2002-May 2006

Relevant Coursework: General Biology (two semesters), Sonoran Sketchbook, Science Communication (two semesters), Basic Physiology, Fundamentals of Ecology, Evolutionary Biology, Vertebrate Zoology (two semesters), Cell Biology, Genetics, Comparative Invertebrate Zoology, Developmental Biology

Research

Towson University Master of Science Thesis 2008-2011
Spatial ecology and diet of Maryland endangered Northern Map Turtles (*Graptemys geographica*) in an altered river system: Implications for conservation and management

- ♦ Conducted under two year Maryland Department of Natural Resources State Wildlife Grant

Grand Canyon University Honors Program 2005-2006
Senior Thesis- Nest site fidelity of the Sonoran Desert Tortoise (*Gopherus agassizii*)

Colusa High School Environmental Sciences Academy 2002
Senior Project- Post wildfire seed bank and erosion analysis, Mendocino National Forest, California

Presentations

(P = Poster, T = Talk)
National Aquarium Professional Development Presentation (T) 2011

- ♦ Spatial ecology of Northern Map Turtles in an altered river system: Implications for conservation and management

MD/DE Chapter of The Wildlife Society Regional Meeting – Laurel, Maryland (P) 2010

- ♦ Diet of Northern Map Turtles (*Graptemys geographica*): Relationship to Sexual Dimorphism and Potential Impacts of an Altered River System in Maryland, **Best Student Poster**

Northeastern Partners for Amphibian and Reptile Conservation Annual Meeting
– Acadia N.P, ME (P) 2010
- Diet of Northern Map Turtles (*Graptemys geographica*): Relationship to Sexual Dimorphism and Potential Impacts of an Altered River System in Maryland

Susquehanna State Park Camp Fire Program (T) 2010
- Rollin' on the river: Conservation research of Maryland's Northern Map Turtle

MD/DE Chapter of The Wildlife Society Regional Meeting – Hockessin, DE (P) 2010
- The effects of landscape composition and configuration on the occurrence of amphibians in Maryland and Delaware

Mid-Atlantic Turtle Tortoise Society Meeting (T) 2010
- Conservation research of Maryland's Northern Map Turtle

Ecological Society of America Annual Meeting – Albuquerque, NM (P) 2009
- Habitat use of Northern Map Turtles (*Graptemys geographica*) in an altered system, the Susquehanna River, Maryland (USA)

Susquehanna State Park Camp Fire Program (T) 2009
- Rollin' on the river: The Northern Map Turtle of the Susquehanna

MD/DE Chapter of The Wildlife Society Regional Meeting – Hancock, Maryland (P) 2009
- Habitat use of Northern Map Turtles (*Graptemys geographica*) in an altered system, the Susquehanna River of Maryland.

Desert Tortoise Council 31st Annual Meeting and Symposium – Tucson, Arizona (T) 2006
- Nest Site Fidelity of *Gopherus agassizii* in the Sonoran Desert, Arizona

Experience

Towson University, *Teaching Assistant* 2011
- Assisted lecture, laboratory, and field demonstration for Biology 467/567: Herpetology

Towson University, *Research Assistant* 2011
- Importance of freshwater wetlands for maintenance of amphibian and reptile biodiversity at Canaveral National Seashore, Florida
- Nesting and basking ecology of Northern Map Turtles in the Susquehanna River: Impacts of human disturbance and effectiveness of mitigation measures

Towson University College for Kids, *Instructor* 2010
- Taught students entering 4^{th} and 5^{th} grade in an indoor/outdoor education setting
- Developed curriculum under the course tile "Exciting Ecology"

Towson University, *Teaching Assistant* 2009-2010
- Taught Undergraduate Majors Biology 202: Ecology and Evolution laboratories
- Project Wild and Wild Aquatic certification

Harford Glen Center for Conservation Research, *Teaching Assistant* 2009

- Assisted with primary research conducted by 4th-8th grade students

Towson University, *Teaching Assistant* 2008

- Taught Biology 115: non-majors biology laboratories
- Project Learning Tree facilitator certification

Illinois Natural History Survey, *Herpetological Technician* 2008

- Habitat use and movement ecology of two state listed turtle species (*Emydoidea blandingii* and *Clemmys guttata*) within three county forest preserves

Jungle Bay Resort and Spa, *Special Projects Coordinator* 2008

- Helped to coordinate initiatives to improve environmental integrity, as well as assisted in supporting eco-friendly systems already in place
- Assisted with natural history education and interpretation
- Assisted in the marketing, image, and perception of Jungle Bay
- Assisted with the coordination of weddings, yoga retreats, meetings and other group activities
- Assisted in Yoga instruction and other wellness programs

Arrowhead Ranch Outdoor Science School, *Director and Naturalist* 2007

- Developing curriculum, training staff and running teaching programs for 5th-8th grade Biology, Ecology and Natural History in an outdoor education setting

Arrowhead Ranch Outdoor Science School, *Assistant Director and Naturalist* 2006-2007

- Teaching 5th-8th graders Biology, Ecology and Natural History in an outdoor education setting

Chicago Botanic Gardens Conservation and Land Management, *Intern* 2006

Bureau of Land Management Carlsbad Field Office

- Sand Dune Lizard (*Sceloporus arenicolus*) and Lesser Prairie Chicken population surveys
- Worked with Texas A&M graduate students on population dynamics and reproductive ecology of the Sand Dune Lizard
- Sacramento Mountain Salamander (*Aneides hardii*) population surveys

Arizona Game and Fish Department Non-Game Branch, *Intern* 2005-2006

- Desert Tortoise (*Gopherus agassizii*) Project
  Population sampling, reproductive ecology and disease monitoring
- Assisted University of Arizona graduate student with comparing strategies for monitoring Sonoran Desert Tortoises
- Certification to work with Chiricahua Leopard Frogs (*Rana Chiricahuensis*) as well as other Ranids
- Desert Tortoise Council Handling Workshop certification

Volunteer Experience

North American Amphibian Monitoring Program, *Route Volunteer* 2011

- Amphibian call surveys

Susquehannock Wildlife Society, *Education Consultant* 2011

- Assisting new non-profit with environmental education and outreach initiatives

Fisher College of Math and Science Curriculum Committee, *Student Member* 2010-2011

- Reviewed graduate and undergraduate course and program proposals, representing the graduate student perspective

Harford Glen Center for Conservation Research, *Herpetological Expert* 2010

- Shared and taught techniques for reptile and amphibian searching and monitoring to 4^{th}-8^{th} grade students conducting a "BioBlitz"

Awards and Honors

Towson University Research Assistantship, $9,600 2011

- 33% National Park Service Grant, 66% Exelon Corp. Map Turtle Grant

Maryland Department of Natural Resources State Wildlife Grant, $8667 2009-2010
Towson University Graduate Student Association, Department Representative 2009-2010
Towson University Summer Research Support, $3000/year 2009 and 2010
Towson University Teaching assistantship, $11,000/year 2008-2010
Grand Canyon University Magna Cum Laude Honors 2006
Grand Canyon University Honors Program Graduate 2006
Grand Canyon University Deans list 2003-2006
Associated Students of Grand Canyon University, Vice President 2005-2006
Associated Students of Grand Canyon University, Marketing Coordinator 2004-2005
National Dean's List 2003-2006
½ Tuition Academic Scholarship, $6,000/year 2002-2006
Robert C. Byrd Scholarship, $1,500/year 2002-2006
Anthony & Mary Steidlmayer Scholarship, $1,000/year 2002-2006
½ Tuition Athletic Scholarship, $6,000/year 2002-2004

Professional Organizations

Ecological Society of America 2009-present
Turtle Survival Alliance 2009-present
Society for the Study of Amphibians and Reptiles 2008-present
Partners in Amphibian and Reptile Conservation 2008-present
Pacific Crest Trail Association 2007-2010
Association of Environmental and Outdoor Educators 2006-2008
National Turtle and Tortoise Society 2005-2006

- Gave educational Library Presentations: taught children about the biology and conservation of turtles and tortoises

Desert Tortoise Council 2005-2006