SPATIAL ECOLOGY AND DEMOGRAPHICS OF A POPULATION OF *Sternotherus odoratus* (TESTUDINES: KINOSTERNIDAE) IN AN OZARK STREAM

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To Amber, who always knew I could do it.

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From 1969 through 2004, the turtle community of a 4.7 km section of the North Fork of the White River, Ozark County, Missouri was studied periodically. The Stinkpot, *Sternotherus odoratus*, was found in all years in low abundance. From 2005 through 2007, I continued this survey to determine the distribution and related parameters, movement patterns, population structure, and demographic parameters of *S. odoratus* within the research section.

Distribution was similar from 1969 through 2006, with expansion to the terminal station of the research section in 2007. Turtle distribution was positively correlated with dense submerged patches of mud and rooted vegetation. Movement between captures from 2004 to 2007 averaged 198 m for males and 102 m for females, with a range of 0 m to 740 m. There was no difference between male and female carapace lengths or weight. There was a significant difference in male and female plastron lengths with females being larger. Sex ratios were slightly female biased but not significantly so.

My study provides insight into the effects of land use change and habitat alteration on aquatic ecosystems. Continued habitat alteration, by affecting the behavior and abundance of species, may have consequences not only for *S. odoratus* but for the entire community.

CHAPTER 1
INTRODUCTION

Turtles date back in the fossil record 210 million years to the late Triassic, pre-dating the dinosaurs (Gaffney, 1990). Turtles have evolved several unique adaptations, the most characteristic being the shell that encases the body. Extant turtles, or chelonians, are long-lived organisms, and may have the longest life spans of any extant vertebrate (Ernst et al., 1994). Giant tortoises have been known to live 120 to 150 years, and the oldest known box turtle lived 123 years (Pritchard, 1967).

There are approximately 300 species of chelonians. Turtles can be found worldwide in terrestrial, aquatic, and marine habitats except at high latitudes or altitudes (Pough, 2004). Turtles, and river turtles in particular, can comprise a significant portion of the biomass of ecosystems they inhabit (Congdon et al., 1986; Moll and Moll, 2004). They serve as predators, frugivores, seed dispersers, and scavengers, as well as prey for crocodilians and some birds and mammals (Moll, 1990; Ernst et al., 1994; De Lima et al., 1997; Ford & Moll, 2004). These roles act as important linkages both within and between terrestrial and aquatic food webs (Moll and Moll, 2004). Turtles also play a vital role in nutrient cycling, maintenance of water quality, and energy flow (Moll and Moll, 2004). Moreover, turtle species with specialized diet or habitat requirements can serve as indicators of habitat quality (Ernst et al., 1994).

Despite their unique characteristics and the important impacts they have on their ecosystems, turtles remain largely understudied. Many turtle populations are believed to be in decline (Moll, 1986; Ernst et al., 1994; Buhlman and Gibbons, 1997; van Dijk et al., 2000), yet not enough is known about the natural and life histories of many species, nor have there been sufficient long-term population studies to support that claim (Congdon et al., 1993; Dodd and Franz, 1993; Moll and Moll, 2004). Chelonians face many threats to survival including collection for the pet trade, utilization as a food resource, and habitat loss and alteration (Ernst et al., 1994; Buhlman and Gibbons, 1997; van Dijk et al., 2000; Moll and Moll, 2004).

The Stinkpot, *Sternotherus odoratus* (Latreille)

The Stinkpot, *Sternotherus odoratus*, is a relatively small aquatic turtle found throughout North America from Maine to Florida, and west to Wisconsin and Texas (Ernst et al., 1994; Figure 1-1). Although it is considered to be a chiefly nocturnal species (Ernst, 1986), some studies have found peak activity periods to be bimodal. April to September activity periods in both Oklahoma and Pennsylvania have been reported between 0400 h to 1100 h and 1700 h to 2100 h (Mahmoud, 1969; Ernst, 1986). Peak activity for the rest of the year was between 1000 h and 1600 h (Mahmoud, 1969; Ernst, 1986).

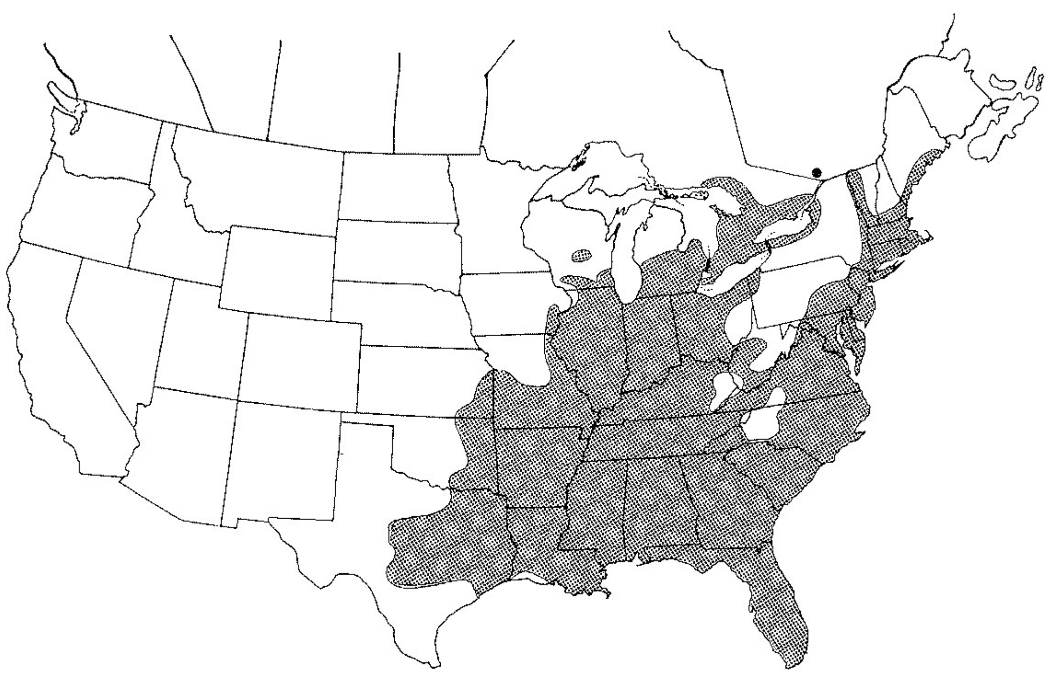


Figure 1-1. Distribution of the Stinkpot, *Sternotherus odoratus*. Reprinted from Ernst, C.H., J.E. Lovich, and R.W. Barbour. 1994. Turtles of the United States and Canada. Smithsonian Institution Press, Washington D.C. and London. P. 142. Used with permission of the author.

Sternotherus odoratus are omnivorous. Diet analyses reveal consumption of earthworms, leeches, clams, snails, crayfish, insects, minnows, tadpoles, algae, plants, seed, seed pods, fish eggs, and carrion (Lagler, 1943; Mahmoud, 1969; Ernst et al., 1994; Palmer and Braswell, 1995; Davis, 1996; Ford, 1999). Diets of Oklahoma Stinkpots consisted primarily of insects, snails, and aquatic vegetation (Mahmoud, 1969). Snails also represented a significant part of the diet of *S. odoratus* in Wisconsin (Vogt, 1981), Michigan (Lagler, 1943), and Florida (Bancroft et al., 1983).

Sternotherus odoratus serve as prey for numerous species. Eggs are eaten by snakes (*Lampropeltis, Cemophora*), raccoons (*Procyon lotor*), skunks (*Mephitis mephitis*), and herons (Ernst et al., 1994), and adults and juveniles are preyed upon by raccoons, foxes (*Vulpes vulpes*), American Alligators (*Alligator mississippiensis*), Common Snapping Turtles (*Chelydra serpentina*), Bald Eagles (*Haliaeetus leucocephalus*), Cottonmouths (*Agkistrodon piscivorous*), water snakes (*Nerodia sp.*), Largemouth Bass (*Micropterus salmoides*), and wading birds (Clark, 1982; Delaney and Abercrombie, 1986; Pritchard, 1989; Ernst et al., 1994; Mitchell, 1994; Palmer and Braswell, 1995).

Although many species of freshwater turtles exhibit pronounced sexual size dimorphism, sexual dimorphism in *S. odoratus* is not as pronounced. Tinkle (1961) reported that sexual dimorphism in *S. odoratus* body size is only seen in southern populations. This observation is supported by Bancroft et al. (1983) and Meshaka (1988) who found that females in Florida have longer carapace lengths (CL) than males. In contrast, Edmonds and Brooks (1996) found males in a population in Ontario to have significantly longer carapace lengths than females. They hypothesized that this dimorphism was a result of selection for larger male body size in response to combat related competition for mates (Edmonds and Brooks, 1996). Aside from body size, tails of mature males are thicker and longer than that of females, and males develop elevated scale patches on the inner hind legs (Risley, 1930).

Size at maturity varies with location and sex. In Michigan, Risley (1933) and Tinkle (1961) found that males reached maturity in three or four years at 60-70 mm carapace length (CL). Risley (1933) found that females matured between ages nine and eleven at 80 mm CL, while Tinkle (1961) found mature females between two and seven years old, also at 80 mm CL. Mitchell (1988) in Virginia reported seeing male secondary sex characteristics at two years and 51 mm CL, and females at 4 years and 66 mm CL. Mahmoud (1969) saw mature males at 65 mm CL between four and seven years of age and females matured between 65 mm and 85 mm CL at five to eight years of age in Oklahoma.

Sex ratios for populations vary widely, but generally follow the pattern of being male-biased in northern populations and female-biased in southern populations (Iverson and Meshaka, 2006). Mahmoud (1969) and Mitchell (1988) both found sex ratios not significantly different from 1:1 in Oklahoma and Virginia, respectively. An Ontario population consisted of 72% males (Edmonds and Brooks, 1996), and Dodd (1989) reported a sex ratio of 1:2.8 males to females in Alabama. A range of explanations have been proposed to account for the disparity in sex ratios, including differential mortality of nesting females (Edmonds and Brooks, 1996; Iverson and Meshaka, 2006), sampling bias as a result of trapping technique or behavioral differences (Dodd, 1989; Edmonds and Brooks, 1996; Iverson and Meshaka, 2006), and temperature-dependent sex determination of hatchlings (Edmonds and Brooks, 1996; Iverson and Meshaka, 2006).

S*ternotherus odoratus* can be long-lived. Ernst (1986) observed two individuals in his field study, a male and a female, who were known to be 27 and 28 years old at the date of last capture, and a specimen at the Philadelphia Zoo lived for 54 years, 9 months (Snider and Bowler, 1992).

Sternotherus odoratus can be found in most any body of freshwater, including ponds and lakes, rivers and streams, urban lakes, reservoirs, and other man-made impoundments, although Iverson and Meshaka (2006) report a preference for permanent bodies of water with little or no current. While *S. odoratus* has been found on rocky and gravelly substrates (Mahmoud, 1969; Ernst et al., 1994; Palmer and Braswell, 1995), this species is most commonly found in the soft-bottomed littoral zones of lentic systems with abundant submerged vegetation (Kingsbury, 1993).

Thermoregulatory basking in *S. odoratus* typically occurs while submerged in shallow water or floating at the surface, or while partially submerged atop lily pads or mats of algae or emergent vegetation (Ernst, 1986; Ernst et al., 1994; Iverson and Meshaka, 2006). Basking also occurs on logs, stumps, or trees overhanging the water, with some individuals climbing as high as three meters above the water's surface (Vogt, 1981; Ernst, 1986; Nickerson, 2000).

Several studies have examined movement of *S. odoratus*. Most studies reveal a pattern of a larger home range in males than females (Mahmoud, 1969; Ernst, 1986; Edmonds, 1998). Average distance traveled between captures by males and females ranges from 69 m and 51 m, respectively, in an Oklahoma stream (Mahmoud, 1969) to 2052 m and 828 m, respectively, in an Ontario lake (Edmonds, 1998).

Most research on *S. odoratus* has been carried out in closed bodies of water such as lakes or reservoirs, with several exceptions. Ernst (1986) sampled a small creek in Pennsylvania together with marsh, floodplain pool, and mill pond habitats. Mahmoud (1969) studied *S. odoratus* in a small stream (average depth and width, approximately 1 m and 3 m, respectively) in Oklahoma, and Meylan et al. (1992), studied the turtle community of Rainbow Run in Marion County, Florida, with an emphasis on two kinosternid turtles, the Loggerhead Musk Turtle, *Sternotherus minor*, and *S. odoratus*.

***Sternotherus odoratus* in Missouri**

Sternotherus odoratus is found statewide in Missouri except in the northern and northwestern third of the state (Johnson, 2000; Figure 1-2). The species is most commonly encountered in slow-moving sections of larger rivers and streams in the Ozarks, the sloughs and backwaters of the Bootheel, and rivers in the northeast part of the state (Johnson, 2000). Missouri's smallest turtle species, *S. odoratus* typically range in size from 51 mm to 115 mm carapace length (Johnson, 2000), with the Missouri record specimen measuring 117 mm carapace length (Powell et al., 1982).

Research on *S. odoratus* in Missouri has been restricted mainly to two studies (Davis, 1996; Ford, 1999) that investigated reproduction, diet, and demographics. Davis (1996) studied the effects of cold water effluent on *S. odoratus* diet and reproduction in a reservoir in southwest Missouri. Ford (2000) gathered data on foraging ecology and demographics of a population of *S. odoratus* in a lake created by the damming of a river, also in southwest Missouri. Ford (1999) found that there was seasonal and sexual variation in the diet of *S. odoratus* in Missouri, with females eating more grass seeds, *Heliosoma* snails, crayfish, mayflies, beetles, isopods, *Ludwigia* seeds, clams, and overall animal matter, and males consuming more nuts, water striders, and lepidopterans. Seed consumption in September was higher than for June-August, larger volume of vegetative material was consumed in July and August compared to June, and more crayfish, snails, clams, and insects were consumed in June.

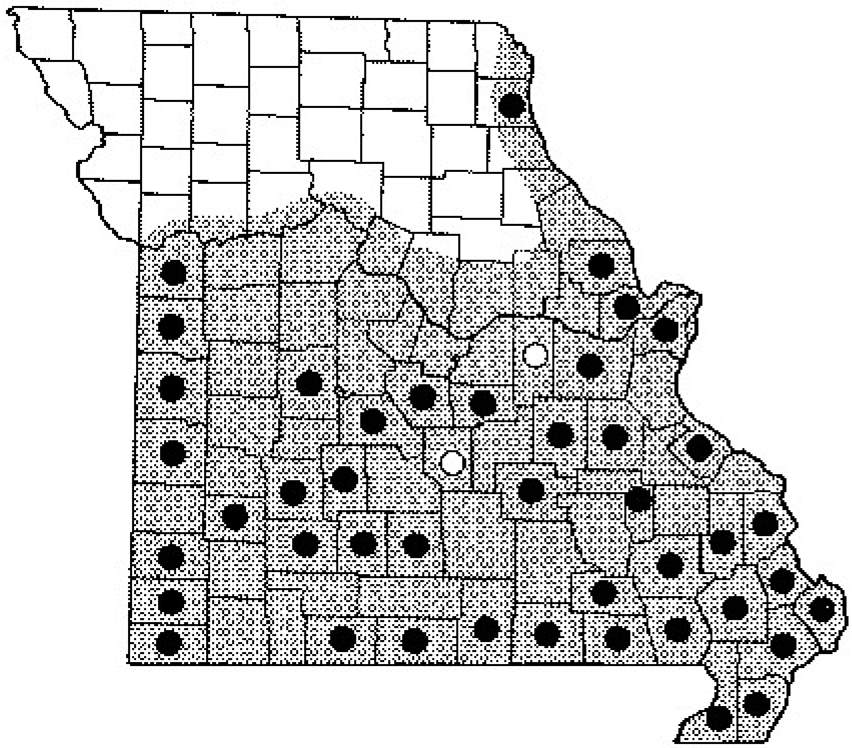


Figure 1-2. Distribution of *Sternotherus odoratus* in Missouri (Johnson, 2000). Range map for Sternotherus odoratus reproduced from "The Amphibians and Reptiles of Missouri." p. 182. Copyright 2000 by the Conservation Commission of the State of Missouri. Used with permission.

From 1969 through 1980, M. A. Nickerson conducted a mark-recapture study of the turtle community in a 4.7 km section of the North Fork of the White River (NFWR), Ozark County, Missouri (Pitt, 2005). Pitt's (2005) analyses revealed that *S. odoratus* was present in the research section, but in very low numbers. Pitt (2005) reassessed the turtle community of NFWR in 2004 with a focus on the Northern Map Turtle, *Graptemys geographica*, historically the most abundant turtle in this community (Nickerson, unpubl. data). She found that whereas the river and surrounding terrestrial habitat had undergone significant changes since Nickerson's surveys from 1969 through 1980, the number of *S. odoratus* captured was similar (Nickerson, unpub. data; Pitt, 2005).

Justification and Objectives

Although several ecological studies of *S. odoratus* have been conducted across its geographic range, little data exist on the life history of *S. odoratus* in one of its common habitats- the river ecosystem. Likewise, there has been only one published long-term study of a *S. odoratus* population (Ernst 1986). This study will add to the body of knowledge concerning *S. odoratus* by addressing these two crucial issues, as well provide additional data for future comparisons.

Objectives of my study were to map the historical and current distribution of *Sternotherus odoratus* in the 4.7 km study section of the North Fork of the White River; identify habitat variables positively and negatively associated with current *Sternotherus odoratus* distribution in NFWR; determine movement patterns of the NFWR *Sternotherus odoratus* population; assess population structure and demographics of *Sternotherus odoratus* in NFWR.

CHAPTER 2
SPATIAL ECOLOGY AND DEMOGRAPHICS OF A POPULATION OF *Sternotherus odoratus* (TESTUDINES: KINOSTERNIDAE) IN AN OZARK STREAM

Introduction

The Stinkpot, *Sternotherus odoratus* (Latreille), is a small aquatic turtle found statewide in Missouri except in the northern and northwestern third of the state (Johnson, 2000). Periodic surveys of the turtle assemblage of the North Fork of the White River, Ozark County, Missouri from 1969 through 1980 (Nickerson, unpubl. data) and in 2004 (Pitt, 2005) revealed the presence of a small but consistent number of *S. odoratus*. Pitt (2005) also found an increase in the likely habitat of *S. odoratus* within the research section. With this in mind, I conducted a mark-recapture study of *S. odoratus* in this same research section over the summers from 2005 through 2007, to compare current and historical distribution, determine microhabitat factors associated with current *S. odoratus* distribution, analyze movement patterns, and to assess population structure and demographics.

Materials and Methods

Study Site

The study area consists of a 4.7 km section of the North Fork of the White River (NFWR), Ozark County, Missouri. This stretch of river includes fast-flowing riffles, deep, calm pools, and long, straight, relatively shallow runs. Depths range from approximately 2.5 m (non-flood stage) to less than 50 cm (Nickerson and Mays, 1973).

The substrate is comprised of extensive chert-gravel beds, exposed limestone, sandstone, and dolomite bedrock, and numerous rocks and boulders, both submerged and emergent, ranging in size from approximately dinner plate size to the size of small automobiles (Nickerson and Mays, 1973). Patches of mud or sand can be found along the river banks where the current is slow or the banks are eroding. Water clarity is generally high, although siltation has increased significantly since construction of an upstream high-water bridge in 1995 (Missouri Department of Conservation (MDC), 2001). Still pools and slow moving stretches collect sediments and silt which can cloud the water for more than 20 minutes when disturbed (personal observation).

NFWR is primarily surrounded by oak-hickory forest with numerous shrubs and grasses (see Nickerson & Mays, 1973 for species list). The upstream end of the research section includes an extensively cleared private campground on the west bank and an MDC campsite and boat ramp access point on the east bank (Pitt, 2005). Clearing within the study section also occurs downstream at two canoe ranches/campgrounds, two private residences, and an MDC campground at the end of the study section (Pitt, 2005). More than 100 aquatic plant species occur in the NFWR drainage (Nickerson & Mays, 1973 for list) with the most common species in the study section being *Justicia americana*, Water Willow; *Ceratophyllum demersum*, Coontail; and *Myriophyllum heterophyllum* and *M. pinnatum*, Water Milfoil. Additionally, there are mosses and a species of long, fibrous algae from the genus *Cladophora*. The long, fibrous algae become very abundant mid- to late-summer and cling to submerged and emergent vegetation, rocks, and logs, forming extensive floating mats (Pitt, 2005). Other chelonian species found within the research section are the Northern Map Turtle, *Graptemys geographica*, the Red-Eared Slider, *Trachemys scripta*, the Spiny Softshell, *Apalone spinifera*, Common Snapping Turtle, *Chelydra serpentina,* and the River Cooter, *Pseudemys concinna*.

I followed the same methodology set forth in initial turtle surveys by Nickerson and Mays in 1969 (unpubl. data), Nickerson in 1980 (unpubl. data), and Pitt in 2004 (2005) who reassessed the turtle community with a focus on *G. geographica*. The 4.7 km section of river was divided into fifty-one 92 m-long stations (stations 0-50; Figure 2-1). The research section was surveyed every other day from mid-June to mid-August 2005 through 2007, between 0900 h and 1800 h,

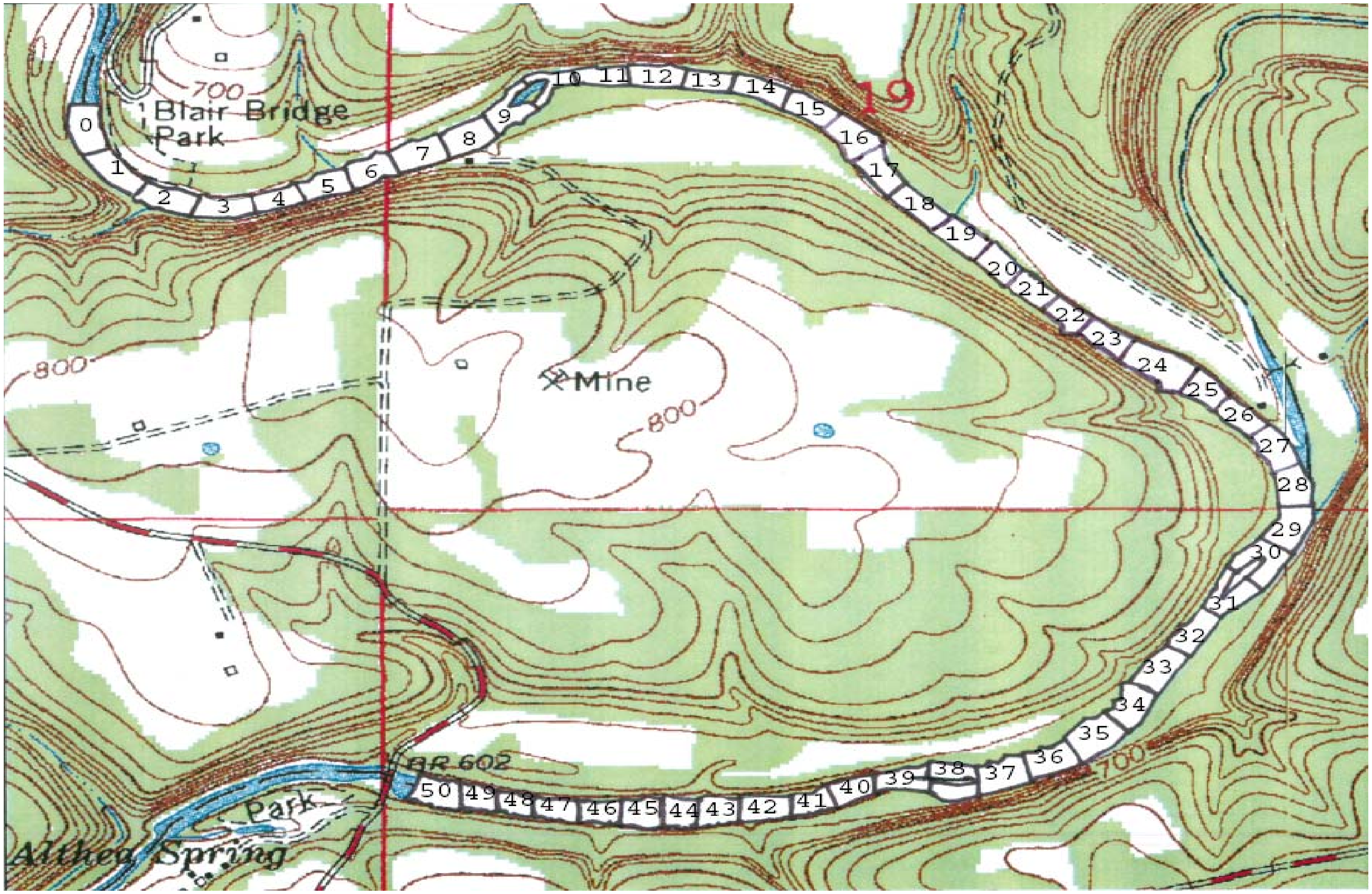


Figure 2-1. Stations 0-50 of the 4.7 km research section of the North Fork of the White River, Ozark County, Missouri. Whitewater riffles are located in or between stations 2-3, 9-10, 17, 29-30, and 38-39.

weather permitting. Summer rainfall in this region occurs most often in the form of brief but often intense thunderstorms (Nickerson and Mays, 1973). Nickerson and Mays (1973) reported that in 1969 water clarity was difficult to disrupt, and they were able to work the day after a heavy rainfall (e.g., 5 cm). On 1 July 2007, between 6 cm and 9 cm of rain fell at the study site (National Climatic Data Center, 2008), reducing underwater visibility to less than 50 cm for 5 days (personal observation).

Capture Methods

Surveys were conducted via snorkeling and hand capturing, paired with a novel capture technique (see below). Trapping with hoop or fyke nets is the common method of capturing *S. odoratus* (Plummer, 1979), and use of hoop traps was attempted in this study. Traps were set between 1800 h – 0900 h several times and yielded only captures of non-target species (e.g., crayfish). Trapping proved to be unsuitable for use in this study. NFWR is a popular river for recreation, receiving anywhere from 10 to ≥ 1000 recreational users/day in the summer. Theft or other disruption of traps, as well as removal of trapped turtles by recreational river users were concerns. Additionally, trap-related mortality was a concern, since traps would need to be placed where they would be fully submerged to avoid being seen by the public. Trap mortality of turtles is not uncommon (Barko et al., 2004), with one researcher having 41 *S. odoratus* drown in a trap within 24 hours (see Dodd, 1989).

In a pilot study, *S. odoratus* was primarily encountered basking atop mats of floating emergent vegetation consisting of *Myriophyllum sp.* and *Ceratophyllum demersum* which were too dense to move through, and which would release a cloud of silt if touched, reducing visibility to < 10 cm. Neither the silt substrate nor the vegetation mats were present in the research section during historical surveys.

The novel capture method involved one researcher sitting in the rear of an eight foot, flat-bottomed john boat with the other researcher standing in the water holding the front of the boat. The latter researcher would push the boat along the edge of the vegetation mats until stinkpots were sighted. The researcher holding the boat would then quickly push the boat forward onto and over the mat and the researcher in the boat would pick the turtles off the surface. The researcher pushing the boat through the water walked with his head submerged while wearing a facemask. The boat was pulled back upstream following the use of the novel technique and the area was surveyed while snorkeling in order to stay consistent with the other survey method. This method proved highly effective for both locating and capturing stinkpots in this study.

Marking Methods

Each captured turtle was numbered with nail polish (AM Cosmetics, Inc., North Arlington, NJ). The polish marks allowed for visual identification from a distance if the turtle was able to escape before recapture and minimized frequent, unnecessary recaptures and possibility of stress that may come with handling. A clear topcoat was also applied to assure the polish would not come off over the course of the season. Turtles that were large enough to be sexed in 2006 and 2007 were injected with a passive integrated transponder (PIT) tag (Destron-Fearing Corporation, So. St. Paul, MN) to identify recaptures in subsequent years. Tags were injected into the anterior inguinal region next to the bridge of the carapace following the protocol of Buhlmann and Tuberville (1998). The injection site was prepped by cleaning with 70% isopropyl alcohol. The hole was covered with New-Skin liquid bandage (Medtech Laboratories Inc., Jackson, WY).

Data Collection

Each turtle was weighed to the nearest 0.1 g using an Ohaus Scout Pro digital scale. I measured straight-line carapace length (SCL) to the nearest millimeter using calipers. I measured plastron length (PL) to the nearest millimeter using a tape measure. Turtles were sexed visually when possible based on secondary sexual characteristics. Mature male Stinkpots have longer and thicker tails than females, as well as scale patches on the inner hind legs (Ernst et al., 1994). Water depth, substrate type and depth, behavior, and distance from shore were recorded at the site of each capture, as well as GPS coordinates or station number.

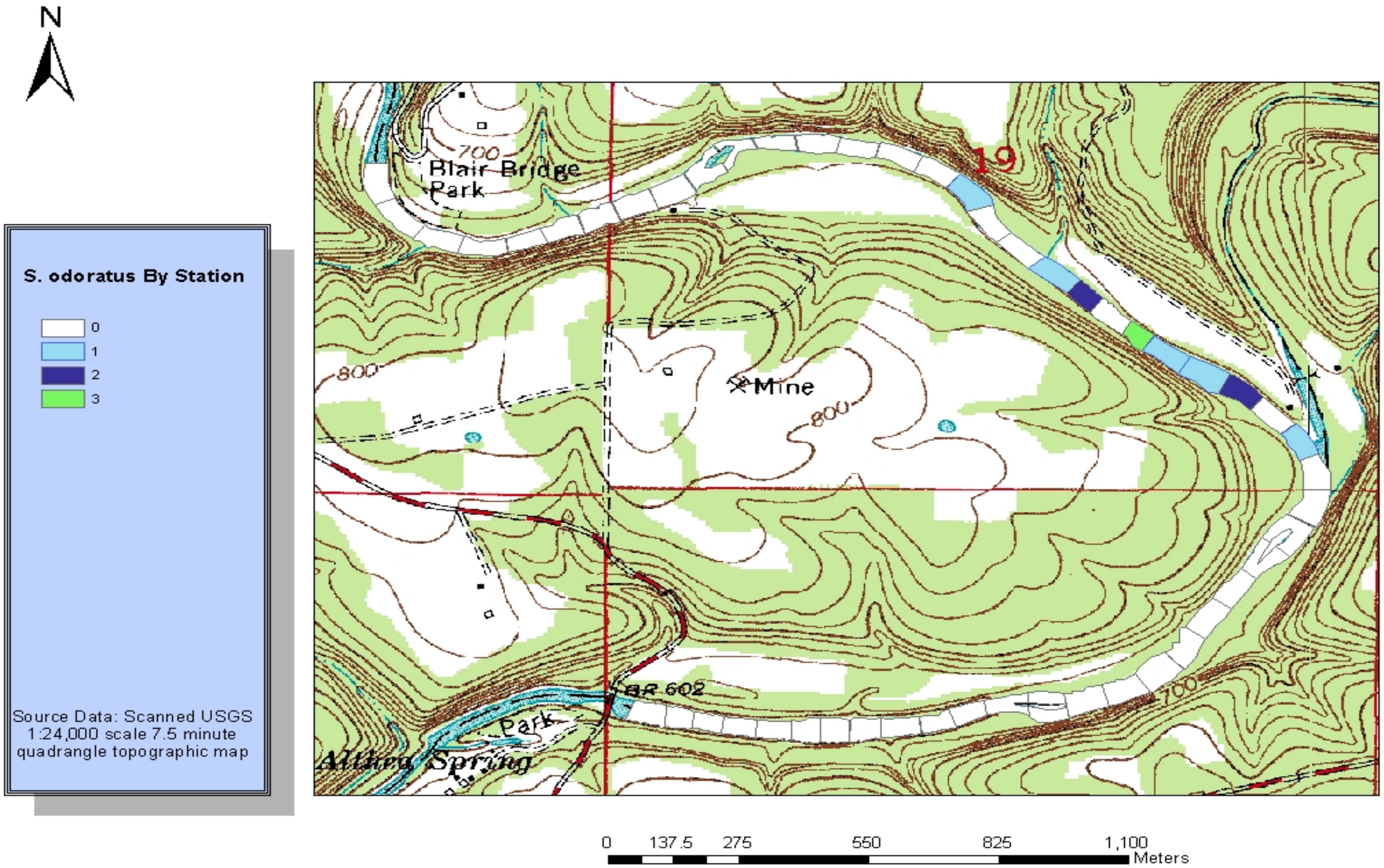
Data Analysis

GPS coordinates taken at capture sites were entered into ArcGIS 9.2 (ESRI). Distance between captures was determined using the “measure” tool. A geo-referenced map of the fifty-one 92 m study sections was created by tracing over a USGS 7.5 minute quadrangle topographical map in ArcGIS using the “edit” tool. Turtles from the historical and current data were placed in the stations in which they were captured. Chi-square (χ^2) goodness-of-fit tests were performed to determine if sex ratios differed from the expected value of 1:1. I performed Mann-Whitney Rank Sum tests to determine if there were any significant differences in CL, PL, or weight between sexes. Statistical analyses were performed at the $\alpha = 0.05$ level using SigmaStat 2.0 (Jandel Corporation 1995). Small sample sizes in 1969, 1970, 1980, and 2004 prevented more rigorous statistical comparisons.

Results

Distribution

Distribution of *S. odoratus* in the research section from 1969 through 2007, displayed as number of *S. odoratus* captured per station, is shown in Figures 2-2A-G. Distribution was similar for all years, with the exception of *S. odoratus* present at the downstream end (station 50) of the research section in 2007. No *Sternotherus odoratus* were encountered in any year in stations 3, 5-15, 17, or 30-49.



A

Figure 2-2. Distribution of *Sternotherus odoratus* within the 4.7 km study section of the North Fork of the White River, Ozark County, Missouri. A) 1969. B) 1970. C) 1980. D) 2004. E) 2005. F) 2006. G) 2007.

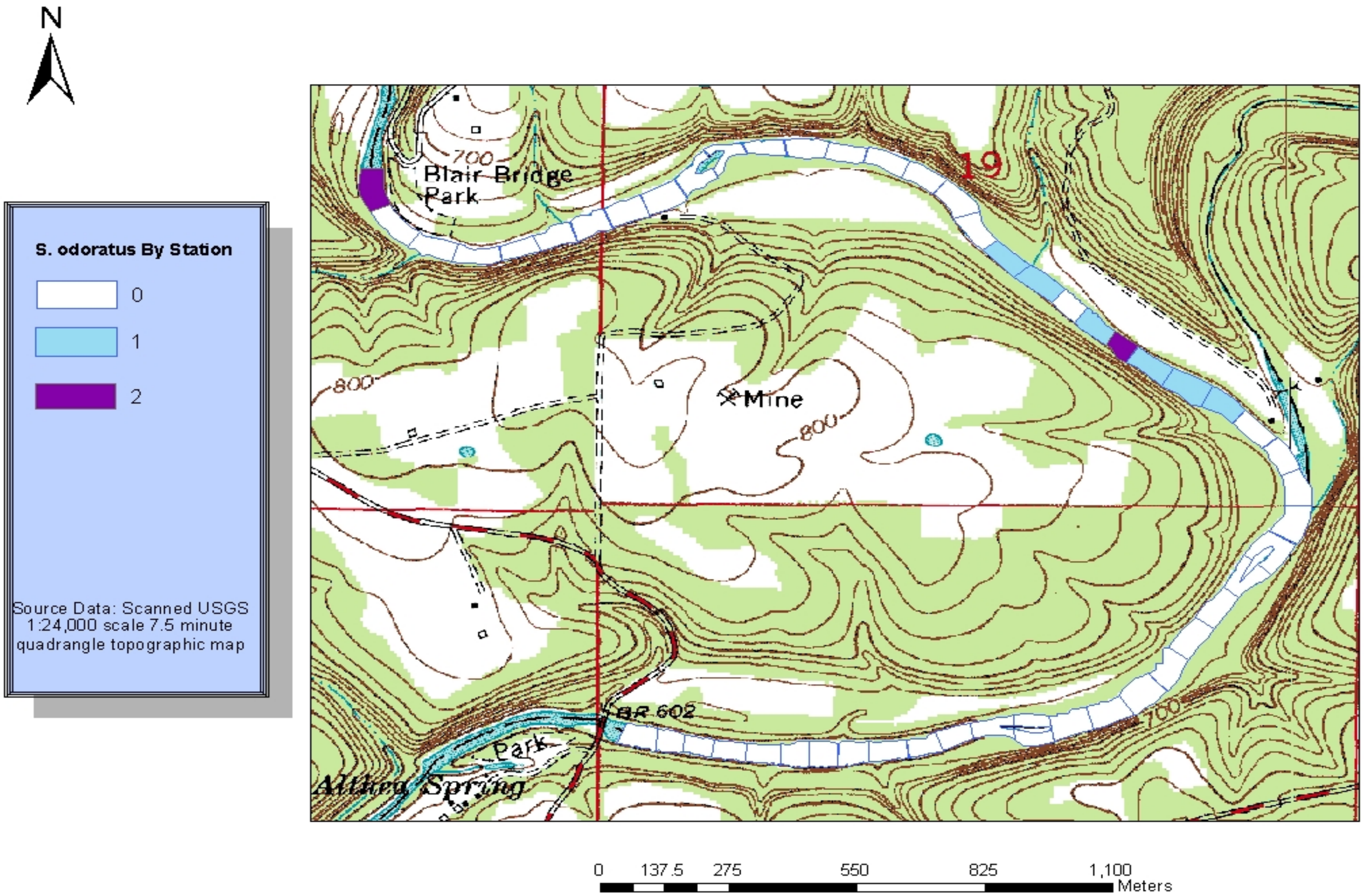


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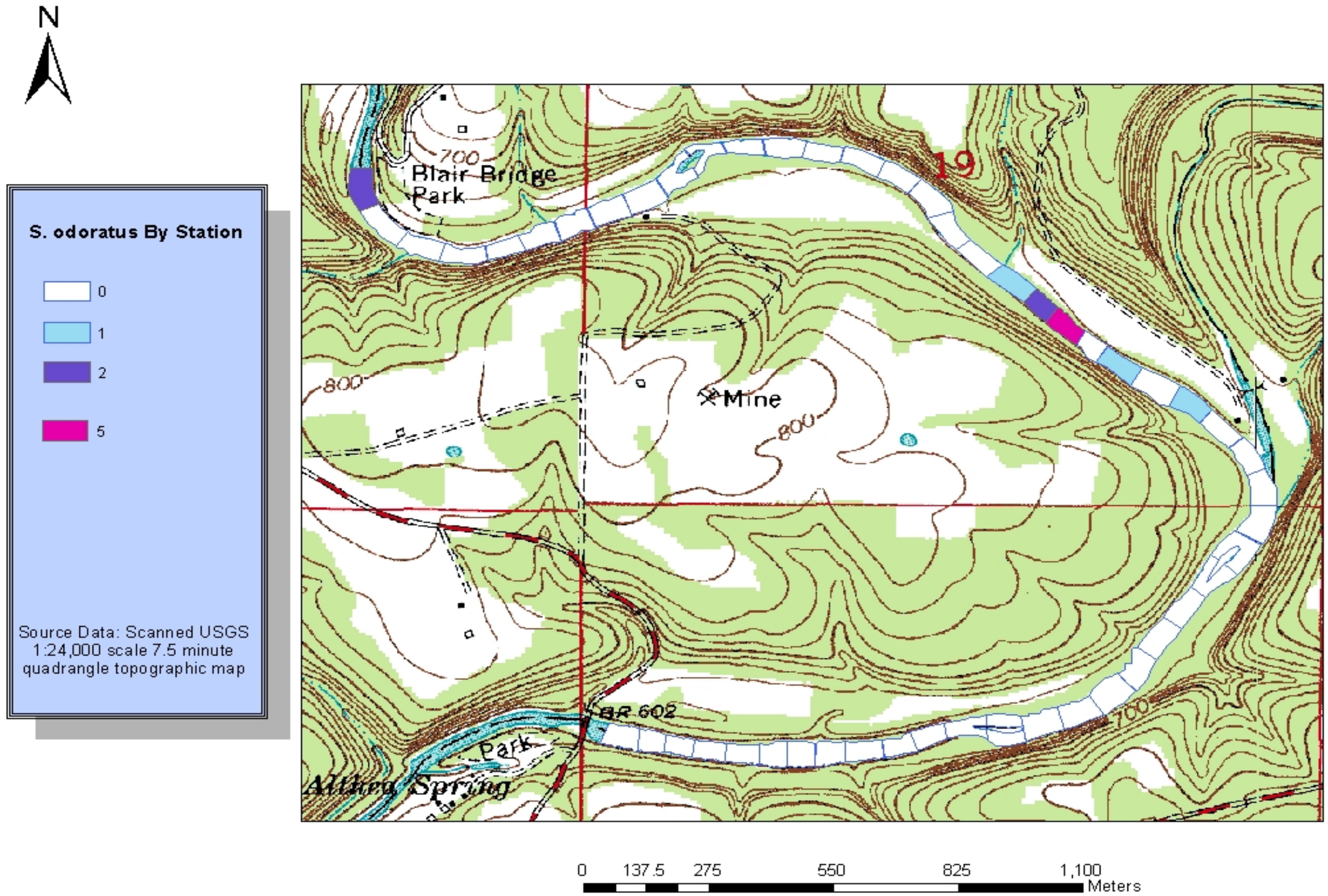
Figure 2-2. Continued



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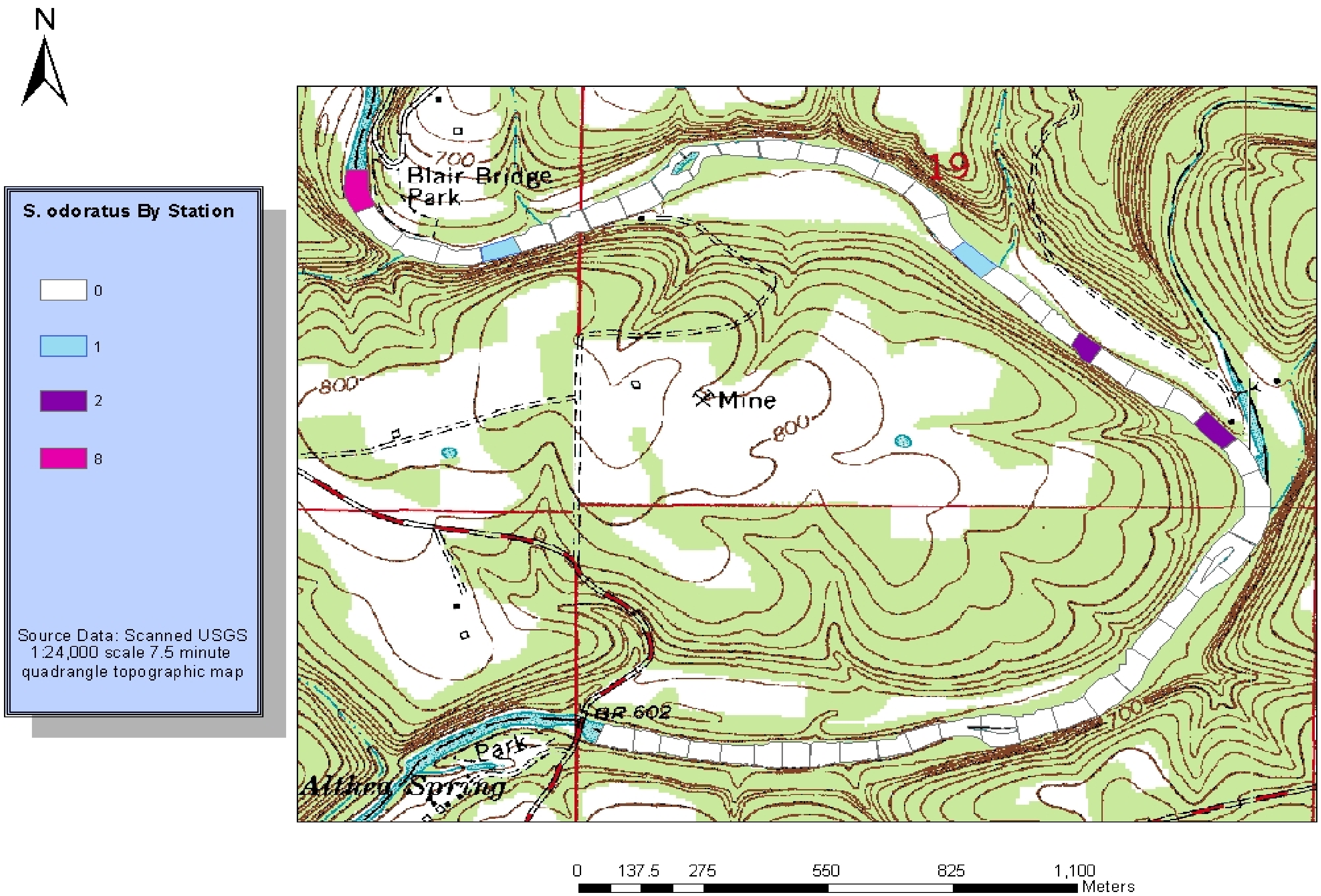

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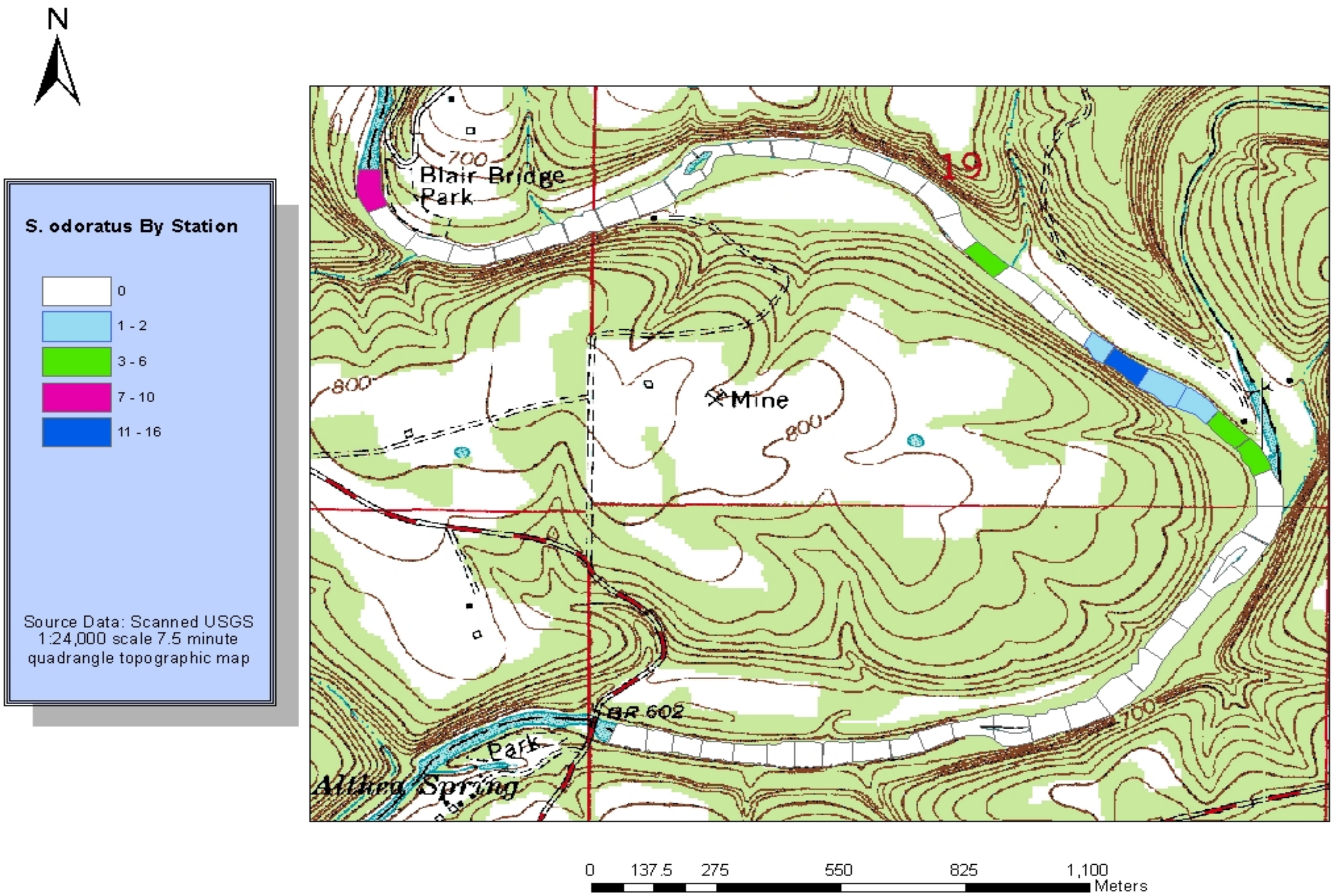

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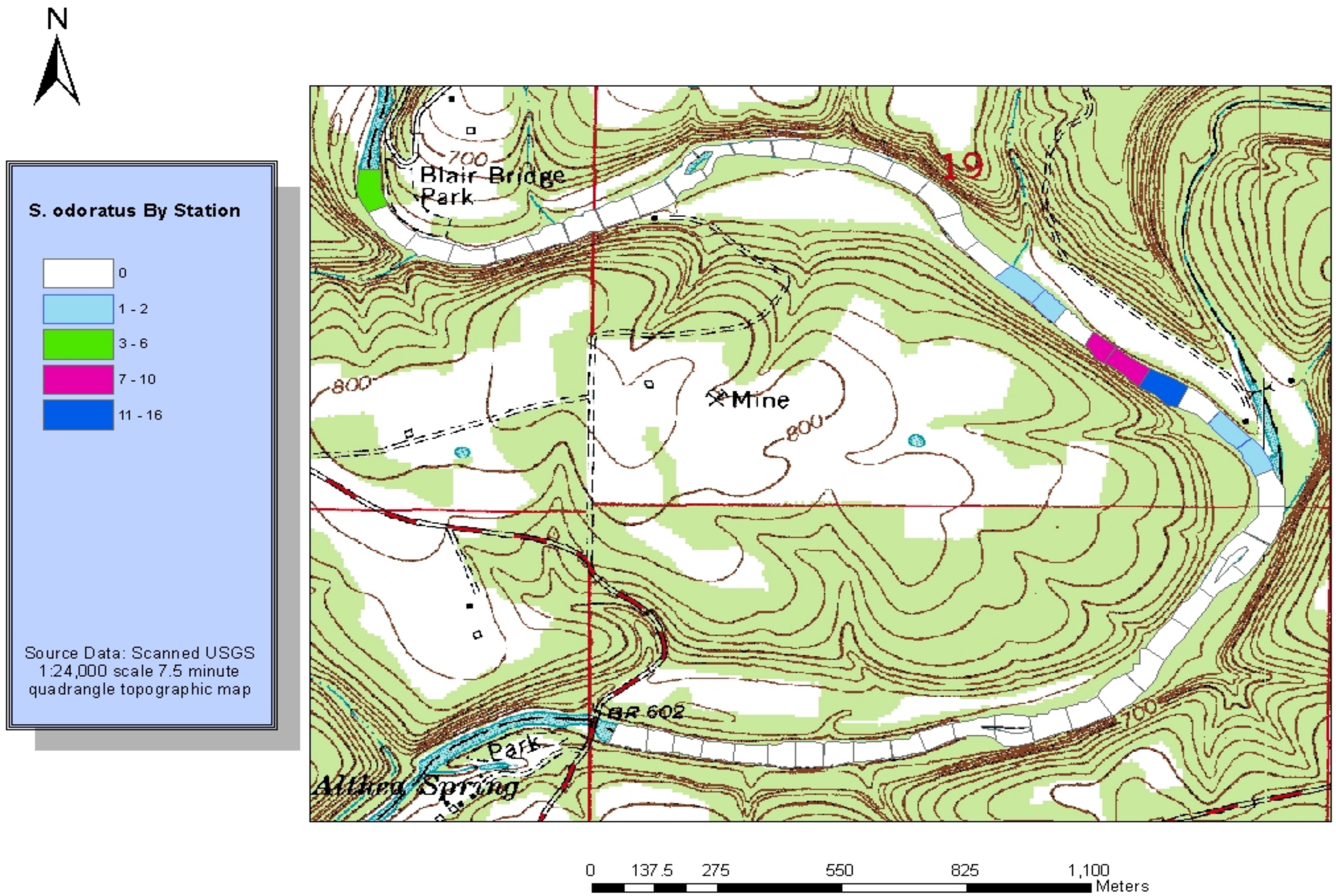

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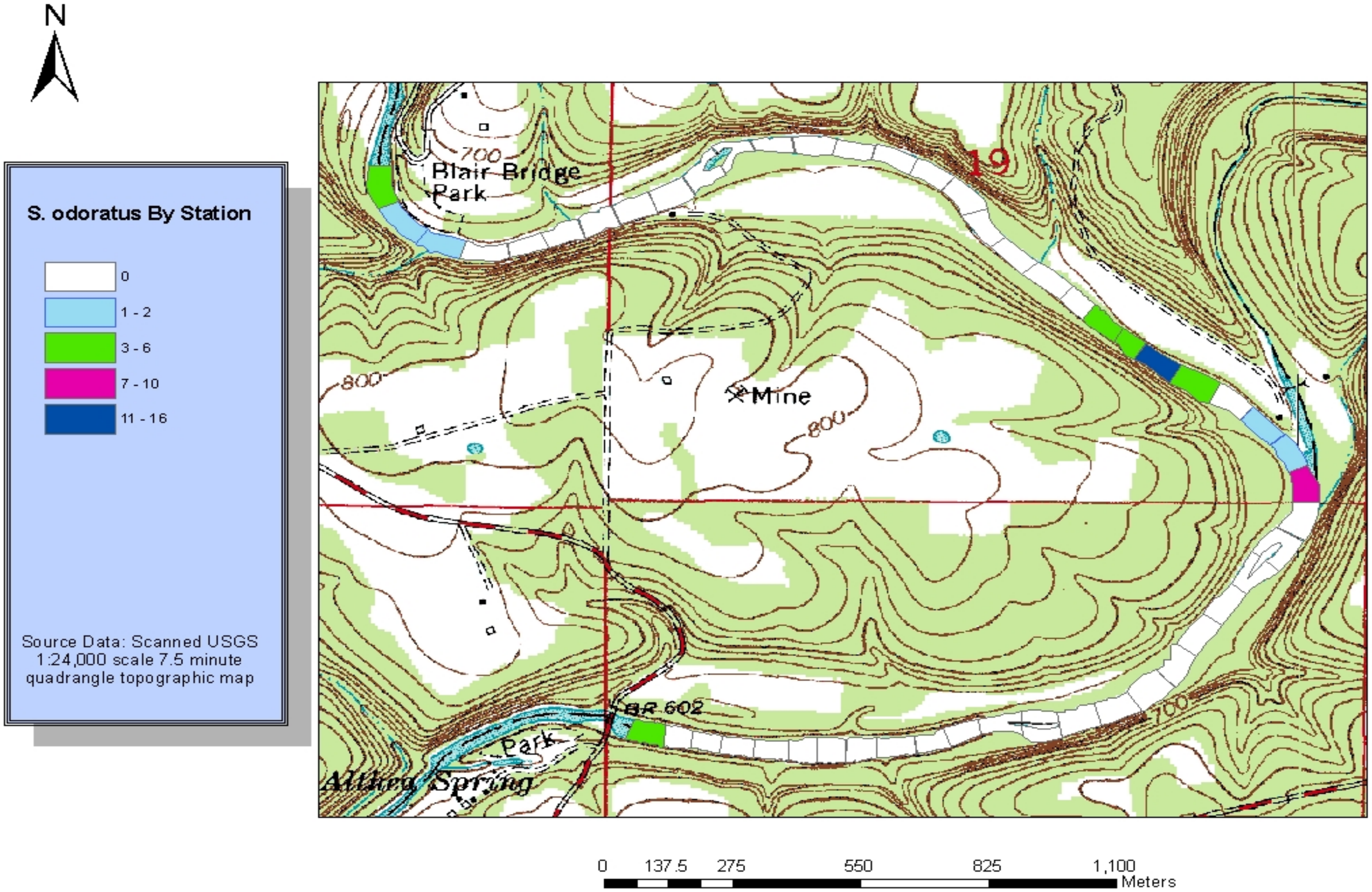
Figure 2-2. Continued



G

Figure 2-2. Continued

Habitat

Mean water depths at capture sites from 2005 through 2007 were 74.8 cm, 77.9 cm, 62.4 cm, and 76.0 cm for males, females, juveniles, and all pooled, respectively. From 1969 through 1980 *Sternotherus odoratus* were most often observed basking on logs (13/28 observations) or walking on the river bottom (12/28 observations). From 2004 through 2007, *S. odoratus* were most often observed basking on emergent vegetation or algal mats (Table 2-1). *Sternotherus odoratus* was found on all substrate types, but was only found over sand, rock, or gravel if there was also dense vegetation present.

Table 2-1. Behavior of *Sternotherus odoratus* at site of capture, North Fork of the White River, Ozark County, Missouri.

	Number of Observations	
Behavior	2004-2007	1969-1970
Basking on vegetation or algal mat	133	2
Basking on log	6	13
Swimming	2	1
On bottom	7	12
Total	148	28

Movement

Most recaptured turtles were found either within their original capture station or the adjacent station (Table 2-2). The mean distance traveled by recaptured females was 102 m (n=17) and by males 198 m (n=10). One female had no measurable change in movement after 348 days. The longest movement recorded was by a male that traveled downstream approximately 780 m in 401 days. This included a movement of 440 m in 49 days. The longest movement by a female was 525 m downstream in 380 days. No turtle was captured on the opposite side of the river from the side where it was originally captured. Most movement was in the direction of upstream to downstream.

Table 2-2. Distance traveled by recaptured *Sternotherus odoratus* from the North Fork of the White River, Ozark County, Missouri, 2004-2007.

Turtle ID	Sex	Station	Distance Traveled (m)	Days Between Capture
1	Female	50	10	34
2	Female	29	<5	25
3	Female	29	40	25
4	Male	24	6	7
5	Female	24	14	15
6	Female	23	16	1
7	Male	23	10	6
8	Male	23→28	530	18
9	Male	22→23	72	356
10	Female	22→23	80	328
11	Female	22	10	19
11	Female	22	-	1
12	Male	19→24	340	352
12	Male	24→29	440	49
13	Female	18→24	470	720
14	Unknown	0.5	-	1
15	Female	24	-	6
16	Male	23	70	26
17	Female	23→21	100	772
18	Female	27→24	300	15
19	Male	20.5→23.5	270	333
20	Female	23	-	348
21	Female	23→21.75	100	731
22	Female	23→22	50	374
23	Female	24→28	525	380
24	Female	24	-	7
25	Female	24→23	100	12
26	Male	24→22	180	31
27	Male	24	45	368
28	Male	0.5	20	408

Population Structure and Demographics

A total of 112 different turtles was captured from 2004 through 2007 with 28 turtles recaptured a total of 35 times. Mean CL, PL and weight from 2005-2007 are reported in Table 2-3. There were no statistically significant differences between male and female carapace lengths or weight in any year (Table 2-4, 2-5). There were statistically significant differences in male versus female plastron length in 2007 and for the years pooled (Table 2-6). Sex ratios did not differ from the expected ratio of 1:1 (Table 2-7). Size class distributions by carapace length for each year are shown in Figures 2-3A-G.

Table 2-3. Mean carapace length (CL), plastron length (PL) and weight (WT) of *Sternotherus odoratus* in the North Fork of the White River, Ozark County, Missouri, 2005 - 2007.

Year	Sex	Mean CL (mm)	Mean PL (mm)	Mean WT (g)
2005	M	97	71	162.4
	F	89	69	139.3
2006	M	103	70	180.5
	F	97	75	164.2
2007	M	91	62	131.3
	F	95	74	172.2
All Years	M	96	67	155.2
	F	94	73	159.5

Table 2-4. Test for difference in male versus female carapace length of *Sternotherus odoratus* in the North Fork of the White River, Ozark County, Missouri, 2005-2007.

Year	Statistic	P
2005	T = 201.0	0.312
2006	T = 262.0	0.597
2007	T = 181.5	0.569
All Years	T = 1454.0	0.860

Table 2-5. Test for difference in male versus female weight of *Sternotherus odoratus* in the North Fork of the White River, Ozark County, Missouri, 2005-2007.

Year	Statistic	P
2005	T = 200.0	0.332
2006	T = 258.0	0.928
2007	T = 153.0	0.107
All Years	T = 1392.0	0.685

Table 2-6. Test for difference in male versus female plastron length of *Sternotherus odoratus* in the North Fork of the White River, Ozark County, Missouri, 2005-2007.

Year	Statistic	P
2005	T = 182.5	0.804
2006	T = 207.0	0.131
2007	T = 142.0	0.034*
All Years	T = 1253.5	0.035*

* Denotes significance at the α=0.05 level.

Table 2-7. Sex ratios and chi-square statistics for *Sternotherus odoratus*, North Fork of the White River, Ozark County, Missouri, 2005-2007.

Year	Ratio males:females	Chi-square	P-value (2-tailed)
2005	1:1.82	2.065	0.151
2006	1:1.27	0.265	0.607
2007	1:1.38	0.516	0.472
All Years	1:1.43	2.306	0.129

Yates' correction factor for continuity was applied to all cases to compensate for small sample sizes.

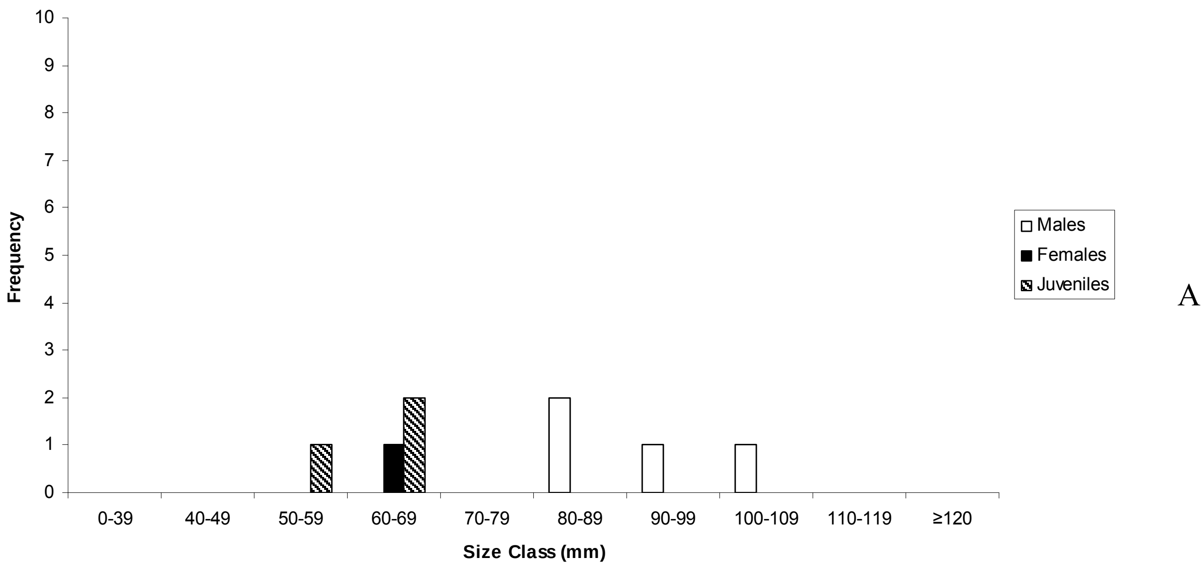
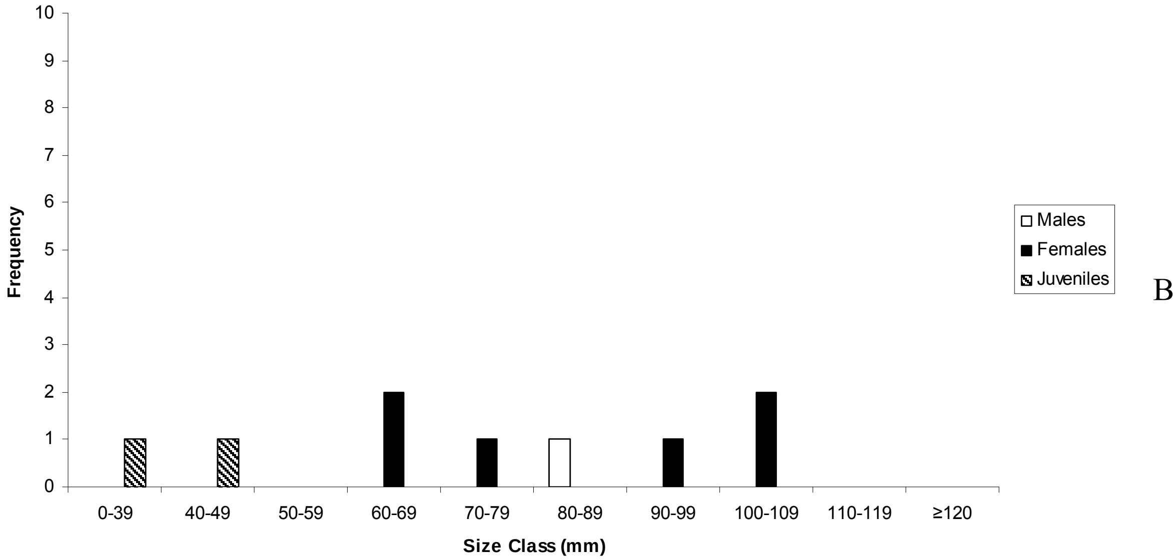


Figure 2-3. Size class distribution by carapace length for *Sternotherus odoratus* captured in the 4.7 km research section of the North Fork of the White River, Ozark county Missouri. A) 1969. B) 1970. C) 1980. D) 2004. E) 2005. F) 2006. G) 2007.



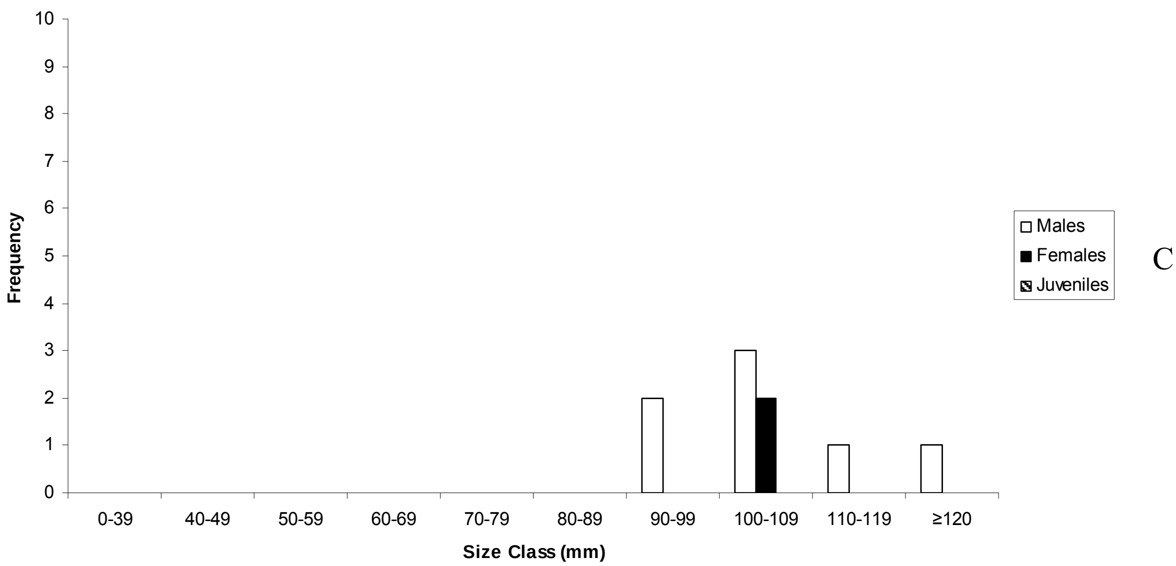
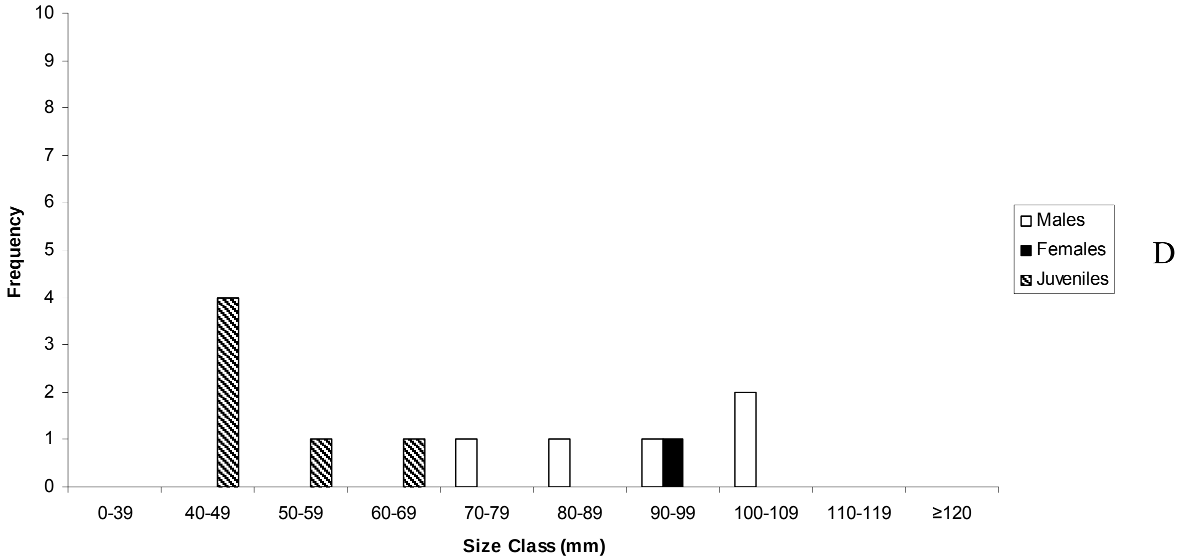


Figure 2-3. Continued



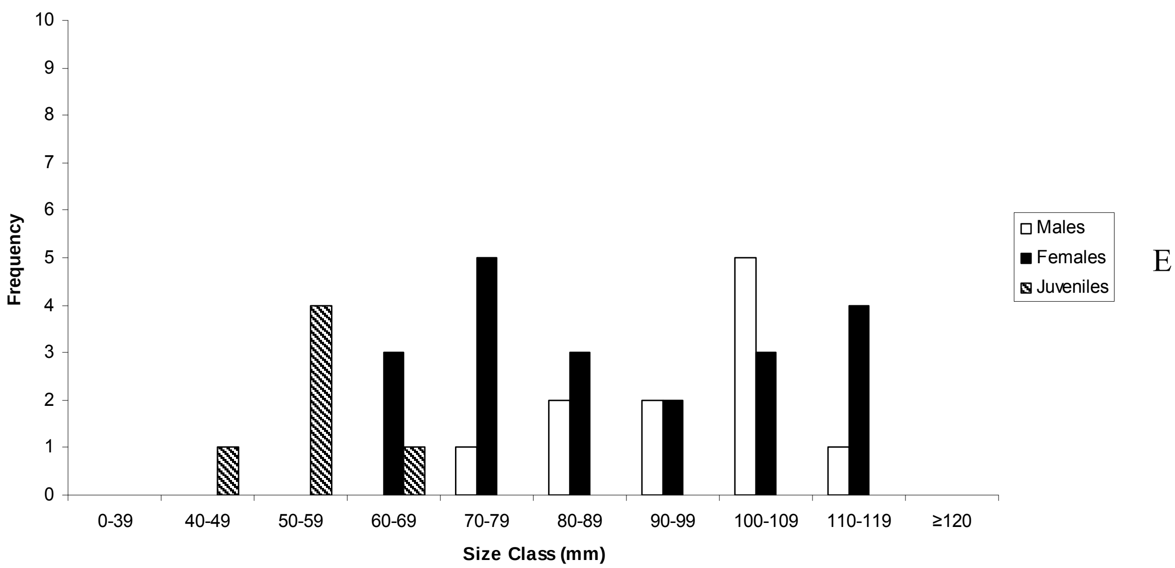
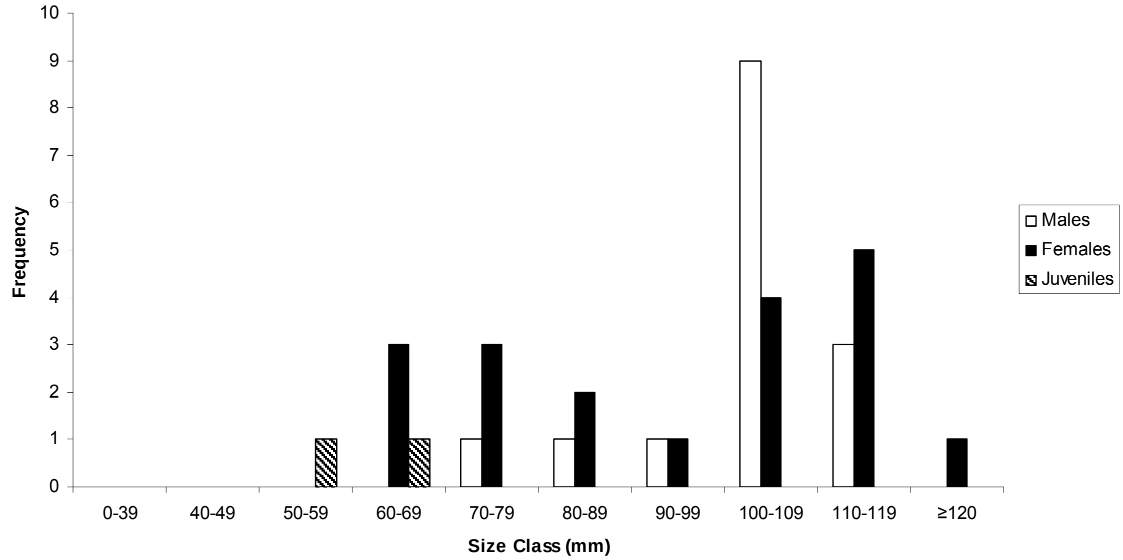
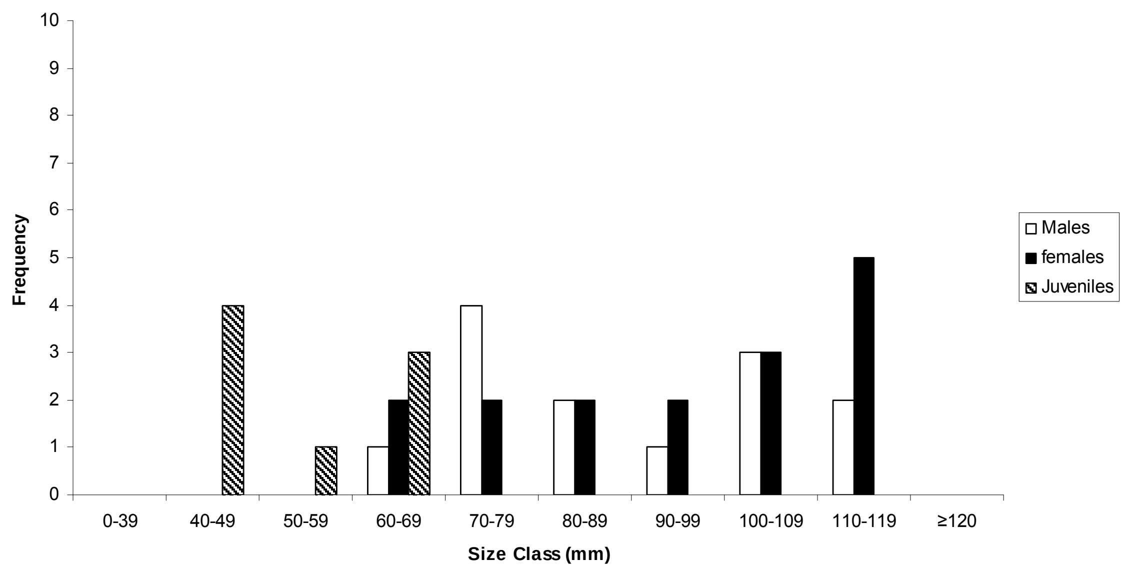


Figure 2-3. Continued



F



G

Figure 2-3. Continued

Discussion

Distribution and Habitat

The distribution of *S. odoratus* in the research section has remained virtually unchanged since 1969, with the primary difference being the presence of the species in the farthest downstream station (station 50) of the section in 2007. *Sternotherus odoratus* is found in three distinct areas: the west stream margins of stations 0-3 and 50, and the east stream margin from station 18-29. These three areas are separated by long stretches of river with gravel and bedrock substrates as well as by whitewater riffles, which both probably serve as barriers to movement of *S. odoratus*. No individual was observed to move between these areas in either a single season or between years. This observation, together with the presence of potential barriers to movement, indicates that there are probably three subpopulations of *S. odoratus* within the research section. In addition to being the only areas of the research section that contain thick muddy substrates, they are the only areas that also contain dense stands of rooted underwater vegetation. These stands were considerably smaller or absent in 1969-1970, 1980 (Nickerson, personal comm.), and 2004 (personal observation) than from 2005-2007. There are several likely explanations for the observed increase in vegetation. A flood event occurred just prior to the field season in 2004 that registered a daily mean discharge of over 15,000 cubic feet per second (cfs) (United States Geological Survey (USGS), 2008). This flood may have scoured submerged vegetation from the stream bed as well as displaced turtles downstream, both of which returned to the research section in 2005 in the absence of any subsequent flood events. Nutrient loading is another likely cause of the increase in both aquatic vegetation and earlier and larger seasonal blooms of long fibrous algae. The research section of NFWR flows through a narrow valley, and atop bluffs on both sides of the river are cow pastures. In addition, much residential development has occurred on the river upstream of the research section, and NFWR is heavily used in the summer for canoeing, kayaking, and tubing. All of these activities could be adding significant levels of nitrogen and phosphorus to the river, resulting in increased growth of aquatic vegetation. Water quality testing upstream of, in, and downstream of the research section in summer 2007 revealed levels of total and fecal coliform bacteria that exceed those recommended for full body contact (Pitt, personal comm.). These high coliform counts indicate that human or animal waste is entering the river, and most likely causing an increase in nutrient levels. This could explain the increase in aquatic vegetation. More vegetation, and thus potential habitat, is probably why more *S. odoratus* were found in 2005-2007 than in historical surveys.

While Ernst et al. (1994) report finding an individual in a gravel-bottomed stream in Arkansas, no *S. odoratus* were observed in open water on rock or gravel substrates in NFWR. Several individuals were captured on emergent mats of *Myriophyllum sp.* and *Ceratophyllum demersum* that were rooted in and growing over rock and gravel. These areas were in close proximity to (~10 m) areas with mud substrate. These data indicate that presence of rooted vegetation, as opposed to soft-bottom substrates, are more important to the distribution of *S. odoratus* in NFWR. Taking into account the preferred microhabitat of *S. odoratus* from this study as well as that reported in the literature (i.e., soft bottom, emergent vegetation) and the area of that habitat in the research section, I estimate that *S. odoratus* could inhabit approximately 1.5 hectares, or 6% of the total area of the research section. This figure is arrived at by multiplying the approximate distance vegetation mats extend out from the banks (11 m) times the length of the number of stations occupied by vegetation mats in 2007 (1380 m) It is possible that *S. odoratus* utilizes the rock and gravel-bottomed sections of river not included in this estimate, particularly during nighttime hours when surveys were not conducted, but they were not observed doing so in this or previous studies of NFWR. Future studies of the NFWR should include nocturnal sampling to determine if *S. odoratus* uses these widely available habitats.

In contrast to Carr (1952) and Ernst et al. (1994) who reported that aerial basking (basking on objects out of the water) was uncommon in *S. odoratus*, Nickerson (2000) found that North Fork individuals in 1969 and 1970 were most often observed basking aerially on logs or trees (15 observations), while aquatic basking was observed only three times. From 2004 to 2007, there were only six observations of aerial basking, while observations of partially submerged basking on mats of aquatic vegetation totaled 133. Over the period of Nickerson's sampling, sycamores, willows, and other large trees were observed at the stream banks extending out over the river providing ample basking sites for turtles, as well as refugia in the exposed underwater root masses. These conditions no longer exist in the research section. Between surveys in 1980 and 2004, several massive floods occurred in the NFWR. Flooding in February and November of 1985 registered daily mean discharge of 32,000 cfs and 45,000 cfs, respectively (peak flow: 108,000 cfs and 133,000 cfs, respectively) at the downstream USGS monitoring station (USGS, 2008). Floods in September and November of 1993 registered daily mean discharge of 25,100 cubic feet per second (cfs) and 32,600 cfs, respectively (peak flow: 52,500 cfs and 71,200 cfs, respectively) (USGS, 2008). The non-flood discharge of NFWR is less than 2500 cfs (Nickerson et al., 2007). Flooding in NFWR between 3700 cfs and 5100 cfs in 1970 is known to have removed a massive sycamore tree from the research section (Nickerson et al., 2007). The floods of 1985 and 1993 likely washed out many more trees and may have led to the observed change in *S. odoratus* basking behavior. In addition, Pitt (2005) noted the general lack of basking sites in 2004 compared to historical studies. *G. geographica*, by far the most abundant chelonian species in the research section, may be out-competing *S. odoratus* for a limited number of woody or rocky basking sites. Basking plays an important thermoregulatory role in digestion and egg development, as well as aids in parasite removal. Boyer (1965) found that turtles basking on partially submerged substrates (such as vegetation or algal mats) were able to raise body temperature above that of the air or the water. *Sternotherus odoratus* in the NFWR may be able to thermoregulate effectively in this way, but apparently are unable to receive the benefit of parasite removal, demonstrated by the prevalence of leech infestation on captured turtles.

Movement

Movement of *S. odoratus* observed in this study is similar to patterns observed in other systems. Mahmoud (1969) found that the average distance traveled between captures was 66 m and 38 m for males and females, respectively, in less than 100 days, and 69 m and 51 m for males and females, respectively, in greater than 100 days. Ernst (1986) reported average movements of 117 m and 90 m for males and females, respectively. The average distance traveled between captures for males and females in this study, 198 m and 102 m, respectively, follow the same pattern of longer distances traveled by males. Iverson and Meshaka (2006), analyzing data from several studies, speculated that local conditions, rather than geography, dictate movement of *S. odoratus*. This seems to be the case in NFWR. Both males and females were recorded traveling distances greater than 500 m, as well as not traveling any measurable distance. All recorded movements occurred within and may have been confined to the preferred microhabitat: submerged patches of rooted vegetation. A small-scale experiment intended as a pilot study was conducted during this survey to examine barriers to movement in *S. odoratus.* Four adults were displaced to the opposite bank of the river from where they were initially captured, a distance of approximately 50 m. Between the initial capture site and release site was a 1.5 m - 2.5 m deep channel with a gravel/bedrock substrate. To find the preferred habitat, turtles would need to cross the river or travel approximately 300 m downstream on the same side of the river. Displacement occurred in August 2006, and the turtles were not recaptured in 2007. Both the initial capture sites and the release sites, including preferred and non-preferred microhabitat, were surveyed. While definitive results were not obtained from this side experiment, similar experiments could be done in rivers like the North Fork using radio telemetry to track the released turtles to answer this question.

Population Structure and Demographics

Small sample sizes combined with few recaptures during each sampling period prevented the determination of any reliable population estimates for *S. odoratus* in the research section. The sex ratios for 2005-2007 were all female-biased, but none were significantly different from the expected ratio of 1:1 (Table 2-7). Ford (1999) also reported a slightly female-biased population in Missouri, and female-biased populations have also been reported for Michigan (Risley, 1933), Illinois, (Tinkle, 1961), Alabama (Dodd, 1989, Prassak et al., 1992), Louisiana (Rayburn et al., 1989), and Florida (Meshaka, 1988, Aresco, 2005). Risely's (1933) high proportion of females in the population was attributed to sampling bias (Gibbons, 1970 in Bury, 1979). Likewise Dodd (1989) stated that sampling over a wider area or over different portions of the reproductive season may have yielded a different sex ratio in Alabama. Females in the NFWR may have been captured more often than males because of increased activity related to nesting in the early-to-mid summer when sampling primarily occurred. Males would likely be encountered more often in the fall due to their search for mates.

An examination of size class based on CL reveals that all size classes are fairly well represented and evenly distributed. The exceptions to this are the hatchling size class (under 40 mm CL) in all years and the distribution for the year 1980. Hatchlings were likely missed in sampling due to their small size and cryptic nature. Hatchlings are most likely inhabiting the shallowest areas of the river that are not amenable to sampling via snorkeling. In addition, eggs in Missouri are laid from June through August, and take two to three months to hatch (Johnson, 2000). Eggs may not have hatched during the field season that may explain the absence of hatchlings in samples. The 1980 data stand out in that only the largest size classes are represented (over 90 mm CL). While sampling for all other years occurred in the early to mid-summer, 1980 sampling occurred late-summer to fall. Larger size classes may have been more conspicuous during this time of year due to movements related to the fall mating season. Juveniles were captured in every year except 1980, suggesting that there is recruitment. The most striking detail that comes from the size class distribution graphs is the large increase in the number of turtles captured between 2004 and 2005-2007. As discussed above, 2005 saw an increase in the area of mats of emergent vegetation, as well as an increase in the amount of time the mats were present. In 2004, mats of vegetation or algae did not appear until early August, whereas from 2005-2007, these mats were present from the start of the field season in early June. The newly available habitat may have drawn *S. odoratus* from other parts of the river. In addition, drought conditions in the area may have caused *S. odoratus* to migrate into the study section from nearby cow ponds, creeks or backwaters. It is also possible that in 2004, more *S. odoratus* were present in the research section but highly cryptic, spending daytime hours buried in mud or hiding in muskrat or otter dens when the protection of dense submerged vegetation was not available. When the vegetation was present from 2005-2007, these turtles may have become more apparent by basking and feeding in the relative safety of the vegetation mats.

It was not surprising that dimorphism was not found between male and female carapace length, as dimorphism has been rarely reported in the species. The significant difference in plastron length may confer fitness benefits to males with small plastrons. Ford (1999) also found female *S. odoratus* in Missouri with larger plastron lengths than males, while the carapace lengths were similar. The biological significance of this, cited by Ford in Gibbons and Lovich (1990), is that males with smaller plastrons may have a copulatory advantage through greater flexibility. Since greater plastron lengths in females were not observed in each year, further investigation of this phenomenon in NFWR is warranted.

Male *S. odoratus* in the NFWR reach sexual maturity when CL ranges between 61 mm and 70 mm. The smallest male that could be identified based on secondary sexual characteristics was 70 mm. This individual was initially captured in 2006 with a CL of 61 mm and sex could not be determined. It was recaptured 408 days later and was clearly a male based on secondary sex characteristics. Its age could not be determined accurately because of obscured plastral annuli, but the size at maturity is similar to that found by Mahmoud (1969) for males in Oklahoma (65 mm CL). Females in the NFWR were sexable between 57 mm CL and 65 mm CL. Most studies have found that female *S. odoratus* mature at larger sizes and greater ages than males (Risley, 1933; Tinkle, 1961; Mitchell, 1988; Edmonds, 1998). The findings on size at maturity in this study could be an artifact of small sample size, so future studies should involve some histological examination of specimens to more accurately determine the age and size at maturity of *S. odoratus* in the NFWR.

Conclusions

It is clear that while there currently are more *S. odoratus* within the 4.6 km research section than were found in historical studies, the number is still small, even without accurate population estimates. The increase in number of turtles captured in recent years corresponds to the increase in available habitat. While significant habitat alteration has occurred in and around the research section in the form of development, land clearing, siltation, and basking site removal, distribution of *S. odoratus* within the research section has changed little in the last 38 years, with the species confined to three distinct areas.

This study provides insight into the effects of land use change and habitat alteration on aquatic ecosystems. The NFWR has changed from a relatively pristine, remote river where few people were encountered during sampling periods in 1969 and 1970, to a heavily used recreation destination in 2007. Continued habitat alteration, by affecting the behavior and abundance of species, may have consequences not only for *S. odoratus* but for the entire community. These data can inform future studies by providing a long-term perspective on a turtle species, as well as baseline data against which future surveys can be compared.

CHAPTER 3
CONCLUSIONS

Pitt (2005) and Nickerson et al. (1984) documented dramatic changes in the NFWR watershed between 1969 and 2004, including large-scale land and riparian zone clearing, development, the removal of basking sites, nutrient loading, and increased recreational use. These factors appear to be benefiting the *Sternotherus odoratus* populations of the North Fork through an increase in mud, sedimentation, and growth of submerged aquatic vegetation.

Many other ecologically generalized chelonians have been shown not only to tolerate but flourish in polluted or degraded habitats. Moll's (1977) study on the polluted Illinois River revealed that Common Snapping Turtles, Spiny Softshells, False Map Turtles, and sliders were thriving while Yellow Mud Turtles, Blanding's Turtles, and Smooth Softshells were greatly reduced or absent. Likewise, Moll and Moll (2004) note that several species, such as the Malayan Box Turtle, and the Black Pond Turtle have been more successful in impacted habitats than in more natural habitats (Moll and Khan bin Momin Khan, 1990 in Moll and Moll, 2004).

Presumably, if generalists tend to benefit from degraded conditions, specialists likely would not. Pitt (2005) documented a decline in *G. geographica*, a mollusk specialist, within the NFWR research section between 1969 and 1980, as well as a failure to rebound from the 1980 level by 2004. She attributed as least part of this failure to degraded habitat conditions. In addition, the generalist *Trachemys scripta elegans* became established in the research section over this time period, and Pitt (2005) determined that its distribution had expanded between 1980 and 2004.

My study should not prove to be the end of research in NFWR, as additional questions arose over the course of my research. While I did not encounter *S. odoratus* on rock or gravel substrates in open water, I suggest that future studies in NFWR vary sampling both seasonally and temporally (nocturnal and diurnal) to determine variation in habitat use. Radio telemetry could also be employed to determine nocturnal habitat use. I suggest that the phenomenon of NFWR *S. odoratus* males having smaller PL's than females should be confirmed, as this phenomenon was not found to occur in 2005 or 2006. Likewise, I suggest that the age and size at maturity of NFWR *S. odoratus* should be confirmed, as findings in my study were based on just a few individuals. This could be accomplished by x-raying individuals in the lab for presence of ova or follicles, or by harvesting some individuals for histological examination. Finally, while my study has shown that the increase in *S. odoratus* abundance is correlated with an increase in rooted underwater vegetation, I suggest that the causative factors contributing to the increase in *S. odoratus* abundance be examined. Manipulative experiments involving vegetation and substrate, as well as examination of reproductive rate, recruitment, and migration from outside the study section could point to the factors causing the increase in *S. odoratus* abundance.

My study provides further evidence of how generalist species can increase in abundance when habitats become degraded. Studies such as this, while important in a broad ecological context, will also add to the knowledge of Urban Ecology, a growing field with increasing importance as growing human populations expand into less populated, relatively undisturbed areas.

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BIOGRAPHICAL SKETCH

Joseph J. Tavano was born in 1978 in Hyannis, Massachusetts. He grew up in the town of Harwich, Massachusettes, on Cape Cod, where he graduated from Harwich High School in 1996. He earned a B.A. in biology from the University of Vermont in 2005. He began graduate school at the University of Florida in 2006, working toward an M.S. in interdisciplinary ecology. Upon graduating, Mr. Tavano plans to pursue a career in teaching or as a Wildlife Biologist.