DISTRIBUTION AND STATUS OF THE BRAZOS WATER SNAKE

(NERODIA HARTERI HARTERI)

Dustin Lee McBride

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(NERODIA HARTERI HARTERI)

THESIS

Presented to the College of Graduate Studies
Tarleton State University
In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

By

DUSTIN LEE MCBRIDE

Stephenville, Texas
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Nerodia h. harteri (Brazos Water Snake) is a state threatened endemic Texas snake found along the upper Brazos River drainage in north-central Texas. A range-wide survey was conducted from 2006-2008 to determine the current distribution and relative abundance of *N. h. harteri*, identify potential habitat, and investigate habitat relationships of the snake. While the range of *N. h. harteri* and suitable habitat remain intact, the snake is now rare. Logistic regression analysis indicated the likelihood of finding the snake was positively related to both the amount of rock (>10 cm) at a site and surrounding a site. Reasons for the population decline remain unclear; however, results illustrate the importance of riffle habitat for the future conservation of this Texas snake.

INTRODUCTION

Nerodia h. harteri (Brazos Water Snake) is a relatively small natricine snake endemic to the upper Brazos River drainage in north-central Texas (Scott et al., 1989; Werler and Dixon, 2000). Initially discovered in the late 1930s along rocky stretches of the Brazos River in Palo Pinto County, *N. harteri* was formally described in 1941 (Trapido, 1941). In 1961, an allopatric population from the Concho and Colorado rivers in central Texas was described (Tinkle and Conant, 1961), thereby dividing *N. harteri* into two subspecies – *Nerodia h. harteri* from the upper Brazos River drainage, and *N. h. paucimaculata* (Concho Water Snake) from the upper Concho-Colorado River drainage. The taxonomy and systematics of these two populations is a source of contention, with some authors proposing an elevation of *N. h. paucimaculata* to specific status (Rose and Selcer, 1989; Densmore et al., 1992); however, recent biologists have retained the subspecific status for these two taxa (e.g., Werler and Dixon, 2000; Gibbons and Dorcas, 2004; Whiting et al., 2008). In accordance with recent literature and just completed population genetics results (M. R. J. Forstner, Texas State University – San Marcos, personal communication), the more conservative subspecific assignment of these taxa is retained herein.

Collectively, *N. harteri* is the only species of *Nerodia* endemic to a single state (Gibbons and Dorcas, 2004), and is one of just two snake species endemic to Texas (the other being the Trans-Pecos Black-headed Snake, *Tantilla cucullata*; Werler and Dixon, 2000). *Nerodia harteri* inhabits a limited portion of stream corridor and reservoir shoreline within the upper reaches of two river drainages (Scott et al., 1989), giving it one of the most restricted geographic ranges of any North American snake species. Despite being locally abundant in areas with suitable habitat (Trapido, 1941; Scott et al., 1989), the state of Texas placed both subspecies on the state list of endangered species in 1977 due to their limited distribution, specific habitat requirements, and perceived threats from future water development projects (Scott and Fitzgerald, 1985). In 1986, *N. h. paucimaculata* was listed as Threatened by the U.S. Fish and Wildlife Service (Stefferud, 1986), and was subsequently the focus of several in-depth ecological studies (e.g., Greene et al., 1994; Whiting et al., 1997; Greene et al., 1999; Whiting et al., 2008), while *N. h. harteri* has received little attention from the scientific community.

Knowledge specific to *N. h. harteri* is limited and has accumulated slowly since its formal description. Detailed bibliographies, species accounts, and literature reviews have been compiled by several authors (Dixon, 2000; Werler and Dixon, 2000; Ernst and Ernst, 2003; Gibbons and Dorcas, 2004). A concise literature review is provided here to highlight the available information pertaining to this subspecies. Following the original species description, brief distributional records (Tinkle and Knopf, 1964; Wade, 1968; Smith, 1983) and notes pertaining to reproduction and young (Conant, 1942; McCallion, 1944; Carl, 1981) were published. Worley (1970) described a single survey, Mecham (1983) reviewed current knowledge, and Seigel and Fitch (1984) summarized relative clutch mass data for over 100 populations of snakes, including *N. h. harteri*. The phylogenetic relationships of *N. h. harteri* have been discussed by several authors (Eberle, 1972; Kilpatrick and Zimmerman, 1973; Lawson, 1987; Rose and Selcer, 1989; Densmore et al., 1992), and two clearly defined taxa have been described. Scott et al. (1989) conducted the most comprehensive investigation of the ecology of *N. h. harteri* to date. Other authors have reported further on the status and distribution of the snake (Dorcas and Mendelson, 1991; Rossi and Rossi, 1999; Forstner et al., 2006), its parasites (McAllister and Upton, 1989; Upton et al., 1989; McAllister and Bursey, 2008), and captive maintenance (Rossi and Rossi, 2000).

Between 1979 and 1987, Scott et al. (1989) conducted extensive surveys for both *N. h. harteri* and *N. h. paucimaculata*. They found that the range of *N. h. harteri* encompassed approximately 700 km of the upper Brazos River drainage, and within this range the snake was found only to inhabit approximately 300 km of river corridor and portions of two reservoirs, Possum Kingdom Lake and Lake Granbury (Scott et al., 1989). The patchy distribution of *N. h. harteri* within even this very limited range is likely linked to the availability of suitable juvenile habitat (Scott et al., 1989). Scott et al. (1989) found that the most important habitat features for juveniles were the presence of medium (>10 cm) to large flat rocks on unshaded shoreline for cover and adjacent rocky shallows for foraging. Along the Brazos River and its tributaries these features are typically associated with riffles, and within Possum Kingdom Lake and Lake Granbury *N. h. harteri* is known to occupy shoreline with similar features (Scott et al., 1989). Adults utilize a much wider range of habitats than juveniles, such as deeper waters, and their distribution is believed to be limited by the distance they can travel from suitable juvenile habitat and their need for deeper, more secure rocky cover (Scott et al., 1989). Scott et al. (1989) conceded that *N. h. harteri* might lose some habitat due to future dams and development projects, but concluded that it was not likely to experience any threat that would jeopardize its long-term persistence. This conclusion was based on the assumption that no threat could likely affect the entire population because it was divided into at least five isolated segments (Scott et al., 1989). However, they believed that the barriers which isolate these populations also would inhibit recolonization should the population of any segment be extirpated (Scott et al., 1989).

Several herpetologists have recently noted the apparent extirpation of *N. h. harteri* from parts of its historic range (Rossi and Rossi, 1999; Forstner et al., 2006; C. T. McAllister, Hot Springs National Park, AR, personal communication). The causes of these declines are unknown, although potential threats include direct killing by humans, drought, habitat degradation, and reductions in prey availability (Maxwell, 1982; Rossi and Rossi, 1999; Bender et al., 2005; Forstner et al., 2006). At present *N. h. harteri* is classified as Threatened by the Texas Parks and Wildlife Department (Texas Parks and Wildlife Department, 2007a) and has a G2 (Imperiled) global status (i.e., at high risk of extinction; NatureServe, 2008). The IUCN lists *N. h. harteri* as Near Threatened due to its limited range, and states that it is close to qualifying as Vulnerable (Hammerson, 2007). The Texas Wildlife Action Plan identified research and monitoring for species of concern as a high priority for the Brazos River Basin, and identified *N. h. harteri* as a medium priority conservation need (Bender et al., 2005). Furthermore, surveying current populations and defining the extent of potential habitat were identified as priority conservation actions for *N. h. harteri* (Bender et al., 2005).

Given the apparent recent population declines, a systematic survey was needed to assess the current distribution and relative abundance of the snake. In addition, a better understanding was needed of the habitat characteristics of sites occupied by *N. h. harteri* as compared to unoccupied sites. The objectives of this study were to 1) determine the current distribution and relative abundance of *N. h. harteri*, 2) identify potential habitat, and 3) investigate the relationship between *N. h. harteri* and habitat quality and density.

MATERIALS AND METHODS

Study Area.—Surveys for *N. h. harteri* were conducted throughout the range of the snake, including stretches listed as uninhabited by Scott et al. (1989). The upstream limits were Deadman Creek (32°37.05′N, 99°37.60′W) in Jones County, and Paint Creek below Lake Stamford Dam (33°04.58′N, 99°33.40′W) in Haskell County, both tributaries to the Clear Fork of the Brazos River. Downstream, surveys extended along the Clear Fork from the mouth of Deadman Creek to the confluence with the Brazos River in Young County, and down the Brazos River to the FM (Farm-to-Market) 1118 bridge crossing (32°12.25′N, 97°36.33′W) near Brazos Point, Bosque County. Searches of tributaries adjacent to this range and not known to be occupied by *N. h. harteri* were also conducted opportunistically. Counties included within the study area were Jones, Shackelford, Haskell, Throckmorton, Stephens, Young, Palo Pinto, Parker, Hood, Somervell, Johnson, Bosque, and Hill.

The climate of north-central Texas is Subtropical-Subhumid and characterized by hot summers and relatively mild, dry winters (Larkin and Bomar, 1983). The average annual temperature of the region is 18.2°C, with a low monthly mean temperature of 6.8°C in January and a high of 28.7°C in July (National Oceanic and Atmospheric Administration, 2002). Precipitation is highly variable across the region and drought conditions are common and sometimes persistent (Stahle and Cleveland, 1988;

Woodhouse and Overpeck, 1998). Precipitation falls in a seasonally bimodal pattern, with the greatest amounts typically falling in the month of May, followed by September and October (National Oceanic and Atmospheric Administration, 2002). Mean annual precipitation within the study area ranges from 88.4 cm in the east (Glen Rose, Texas) to 72.3 cm in the west (Albany, Texas; National Oceanic and Atmospheric Administration, 2004).

The study area lies primarily within the Cross Timbers and Prairies ecoregion of Texas and extends westward into the Rolling Plains (Gould et al., 1960). The upland vegetation adjacent to the riparian corridor varies considerably throughout the study area. Beginning at the upstream limits in Jones County, the river corridor bisects the following vegetative and cover associations described by McMahan et al. (1984): Mesquite (*Prosopis glandulosa*)-Lotebush (*Ziziphus obtusifolia*) Shrub, Mesquite Brush, Post Oak (*Quercus stellata*) Parks/Woods, Live Oak (*Q. virginiana*)-Ashe Juniper (*Juniperus ashei*) Parks, Ashe Juniper Parks/Woods, Oak-Mesquite-Juniper Parks/Woods, and Silver Bluestem (*Bothriochloa saccharoides*)-Texas Wintergrass (*Nassella leucotricha*) Grassland. The riparian vegetation is dominated by pecan (*Carya illinoinensis*), cottonwood (*Populus deltoides*), black willow (*Salix nigra*), elm (*Ulmus* spp.), hackberry (*Celtis* spp.), ash (*Fraxinus* spp.), western soapberry (*Sapindus drummondii*), and bur oak (*Q. macrocarpa*). Mesquite and saltcedar (*Tamarix* spp.) become increasingly common riparian trees toward the west, particularly along the Clear Fork of the Brazos River and the Brazos River above Possum Kingdom Lake. Throughout most of the study area tall grasses line the low banks and islands within the stream channel, of which the most prominent species is switchgrass (*Panicum virgatum*). In some areas bermudagrass (*Cynodon dactylon*) has become established.

Field Surveys.—Surveys for *N. h. harteri* and potential juvenile habitat were conducted between September 2006 and October 2008. From September 2006 to September 2007, surveys were conducted along the lower half of the range of *N. h. harteri*, from Morris Sheppard Dam (Possum Kingdom Lake), Palo Pinto County, to the upper reaches of Lake Whitney, Johnson County. From October 2007 to October 2008 surveys were conducted along the upper half of the range, from Deadman Creek, Jones County, to Possum Kingdom Lake, Palo Pinto County, in addition to surveys along the lower portion of the range. Field work was concentrated during the spring (April-May) and fall (September-October), periods when *N. harteri* activity is highest and densities are greatest (Mueller, 1990; Greene, 1993). Flooding events during the spring of 2007 prevented surveys throughout most of April and May that year. During this period, smaller tributaries were searched opportunistically between flood pulses. Surveys along the Brazos River resumed when high flows receded in July 2007. Additionally, heavy rain events hampered survey efforts along most of the Clear Fork upstream from the confluence of Paint Creek in 2008.

A team of at least two people conducted surveys along the Brazos River and its tributaries using canoes. The shoreline, overhanging vegetation, and water were carefully searched for snakes, and the habitat was subjectively assessed for juvenile *N. h. harteri* suitability. Upon encountering potential habitat (i.e., shallow riffle areas), intensive timed searches were conducted on foot. This consisted of searching all cover that could harbor a snake within 3 m of the water's edge, including searching under all rocks (>10 cm), crevices, debris piles, and vegetation. Deadman Creek could not be surveyed by canoe due to lack of access and its small size; however, several road crossings of the creek were examined and extended searches were made at two of these.

Snakes were captured by hand, measured (snout-vent length [SVL], tail length, and mass), sexed, and released. Snout-vent and tail lengths were measured (±1.0 mm) by holding the snake along a metal tape until the body was fully relaxed but not over-stretched, and mass was measured (±0.5 g) by clipping a spring scale to the tail of the snake and holding it vertically in the air. Sex was determined by manually extruding the hemipenes, if present, or by visual inspection of the tail region; beginning in April 2008, blunt sexing probes were used to determine sex. The accuracy of sex determination in the field, particularly during the period before sexing probes were used, was examined by calculating the ratio of tail length to total length for all *N. h. harteri* with complete tails. Results were compared to ratios previously reported for *N. h. harteri* by Trapido (1941), Tinkle and Conant (1961), and Carl (1981), where they ranged from 0.244-0.291 for males and 0.220-0.258 for females. If the tail length to total length ratio fell within the overlap between the sexes (0.244-0.258), snakes (N = 7) were assumed to be sexed correctly. Four snakes (3 males and 1 female) were identified as being sexed incorrectly in the field. The sex ratio was tested against a null hypothesis of 1:1 using chi-square analysis. Relative age (juvenile or adult) of captured *N. h. harteri* was determined by the minimum SVL at sexual maturity (adult male: ≥380 mm, adult female: ≥460 mm) reported for *N. h. paucimaculata* (Greene et al., 1999). When snakes were found under rocks, the dimensions (thickness × longest axis × shortest axis; ±1.0 cm) of the rock were recorded. Comparisons were made between the sizes of rock utilized by adults and juveniles using a Student's *t*-test. Additional data collected included the coordinates where snakes were found, time of observation, air temperature at ground level, water temperature, a written description of the habitat, and any additional observations regarding the condition of the snake or the nature in which it was observed. Captured snakes were not marked during this study due to the unlikely nature of recapture given the large study area, and no snakes were collected. Photographs of captured snakes were taken in most cases.

Beginning in April 2008, blood or tissue samples were collected from 25 *N. h. harteri*. Blood was drawn (≤0.1 ml) from the ventral coccygeal vein of the tail (Willette-Frahm, 1995) using a 25-gauge tuberculin syringe, and was stored in 1.5 ml polypropylene tubes containing 0.5 ml of lysis buffer (Longmire et al., 1988). When blood collection was unsuccessful, a small (≤1.5 cm) portion of the tip of the tail was clipped and stored in 1.5 ml polypropylene tubes containing 0.5 ml of lysis buffer. All samples were accessioned into the MF Tissue Catalog at Texas State University – San Marcos, Department of Biology (Michael Forstner, Curator). Photographs were taken of each snake to document the morphological traits reported by Tinkle and Conant (1961), and consisted of the following images: dorsal head, ventral head, right and left side of head, ventral pre-cloaca, and ventral post-cloaca.

In addition to intensive searches at riffle areas, visual searches while traveling between sites in the canoe were used to document *N. h. harteri* presence. An attempt was made to capture or positively identify all snakes observed to species, and the total time spent on the entire trip was recorded. Commercial minnow traps were used opportunistically to sample for snakes along the river. Traps were set partially submerged along the shoreline and parallel to objects (e.g., rock piles) within shallow riffle habitat. Traps were checked approximately every 2-3 h, or in the morning if set overnight. The coordinates of traps, total time traps were set, and air and water temperatures were recorded.

The shorelines of Lake Granbury and Possum Kingdom Lake were surveyed by at least 2 people in a small motorized boat. Surveys consisted of subjectively assessing the shoreline for *N. h. harteri* suitability (e.g., a shallow, gently sloping lake bottom adjacent to rocky shoreline) and then slowly floating along suitable shorelines while looking for snakes. Areas were searched on foot when possible. Prior to conducting surveys along Lake Granbury and Possum Kingdom Lake, historic locations of *N. h. harteri* from Scott et al. (1989) were plotted on lake maps to ensure sampling at those sites. The entire shoreline of Lake Granbury was surveyed on 10-11 July 2007 and the locations of all potential habitat were plotted on a lake map. One canoe trip was made on 8 May 2007 to survey Strouds Creek, a small tributary to Lake Granbury at Thorp Spring, Texas, and adjacent lake habitat. To supplement visual searches, commercial minnow traps were placed along the shoreline of Lake Granbury in areas deemed potentially suitable on 8 May 2007, and 16-19 July 2007. Minnow traps were fitted with foam floats to prevent drowning of captured snakes, placed parallel to the shoreline, and tied to nearby vegetation, rocks, or debris. Engine failure on 17 July 2007 precluded traps from being checked until 19 July 2007 (2 nights) and halted trapping efforts in Lake Granbury. Surveys of Possum Kingdom Lake on 15-16 May 2008 were concentrated along the upper portion of the lake in areas where Scott et al. (1989) documented *N. h. harteri*, and minnow traps were not used.

Habitat Quantification and Delineation.—After searches for snakes were completed at each site along the river, the linear extent of the habitat (i.e., the riffle) was measured using a GPS unit, and the available rocky cover along both banks and any islands, if present, was quantified using a point intercept technique. This consisted of walking along the shoreline at its interface with the water and categorizing the rocky substrate located at the tip of the foot into one of three size classes (0: ≤99 mm; 1: 100-256 mm; 2: >256 mm) at an interval of every other step. This method provided an index of the amount of rocky habitat available to *N. h. harteri* at each site. These data were not collected when water levels were above normal because the majority of rock at a site became inundated.

The amount of rock in each of the three size classes was calculated for each site after field surveys were completed, and the linear extent of the habitat was plotted on a map of the river system. The amount of rock in size classes 1 and 2 (i.e., ≥10 cm) was summed to provide a measure of the abundance of rocky cover available to *N. h. harteri* at each site. Sites with shoreline composed entirely of substrate ≤99 mm (i.e., size class 0) were omitted since they lacked suitable juvenile cover. To provide a measure of the density of potential habitat surrounding a site, the number of riffles within 5 km of each site was summed. In addition, the amount of rock ≥10 cm was summed for all riffles within 5 km of each site. To identify the most important stretches of river for *N. h. harteri*, (i.e., those that contain the greatest amount of rocky habitat), the amount of rock ≥10 cm within each 5 km segment and the corresponding central riffle was summed. This created segments of river approximately 10 km in length that were centered on each site. The values of available habitat within each 10 km segment were divided into quartiles, ranked, and plotted on a map of the river system.

The efficacy of using aerial photography to remotely delimit potentially suitable juvenile *N. h. harteri* habitat (i.e., shallow riffles) was investigated using digital imagery with a 1-m resolution. Imagery of the entire study area was obtained from the Texas Natural Resources Information System (2008) and consisted of color-infrared digital orthophoto quarter quadrangles with imagery from 2004 provided by the National Agricultural Imagery Program (NAIP). The river corridor and lakeshore within the study area was examined for the presence of rock within 3 m of the water's edge at a spatial scale of 1:3,500. Viewing the imagery at a spatial scale beyond this point (i.e., at a finer scale), caused the image to become pixilated and increasingly difficult to interpret. All mapping and imagery analysis was completed with ArcView 9.2 software (Environmental Systems Research Institute, Redlands, CA, 2006).

Modeling.—Logistic regression analysis can be used to assess the relationship between a dependent binary response variable (e.g., presence or absence) and one or more explanatory independent variables (i.e., covariates) by applying maximum likelihood estimation after transforming the dependent variable into a logit variable (Hosmer and Lemeshow, 2000). In doing so, logistic regression estimates the odds of a certain event occurring. The logistic regression model has the form: $\pi(x) = e^{g(x)} / (1 + e^{g(x)})$, where $\pi(x)$ is the probability of a successful event (e.g., finding *N. h. harteri* at a site), and $g(x)$, the logit transformation function, is given by: $g(x) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n$, where β_0 is a constant and $\beta_1 \ldots \beta_n$ are the coefficients of the $x_1 \ldots x_n$ variables (Hosmer and Lemeshow, 2000). No assumptions are made about the distributions of the independent variables in logistic regression, and a linear relationship between the dependent and the independent variables is not assumed. Rather, logistic regression assumes a linear relationship between the independent variables and the logit of the dependent variable. Additional assumptions of the logistic regression model include absence of multicollinearity between independent variables, inclusion of all relevant variables and exclusion of all irrelevant variables, independent observations, independent variables measured without error, no outliers, and large sample size.

Logistic regression was used to test for a significant relationship between the logit of finding *N. h. harteri* at a site (i.e., a riffle) and the combination of habitat quality and density. Habitat quality was quantified using the abundance of rocky cover available to *N. h. harteri* at a site (i.e., the sum of rock in size classes 1 and 2). The density of potential habitat surrounding a site was measured by summing the amount of rocky cover available to *N. h. harteri* within 5 km up- and downstream of a site. Significance of the model was assessed using a full-reduced model likelihood ratio chi-square test. All statistical analyses were conducted using SPSS 16.0 software (Statistical Package for the Social Sciences, Inc., Chicago, IL, 2007), with $\alpha = 0.05$.

RESULTS

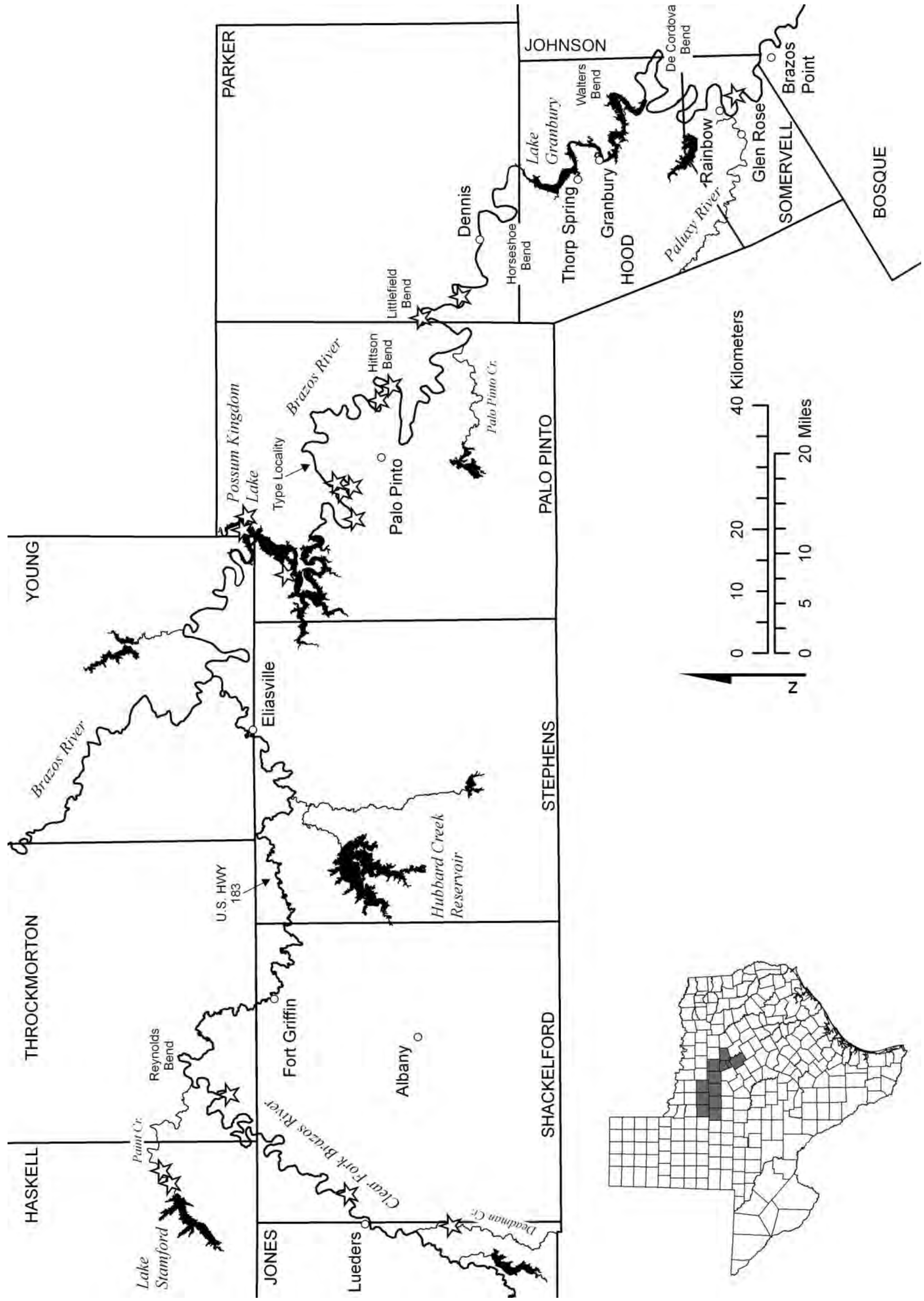
Field Surveys.—A total of 574 km (94%) of river corridor within the range of *N. h. harteri* was surveyed by canoe. Including resampling of river sections, 985 km were floated during 25 trips that spanned 57 days. Trips ranged from 4.13 h to 8 days in length. A total of 350.35 h (733.92 man-h) were spent searching for snakes while floating in a canoe, and 112.12 h (232.40 man-h) were spent intensively searching for snakes during 330 searches.

During this study 816 snakes and one Slender Glass Lizard (*Ophisaurus attenuatus*) were observed. Positively identified snakes (N = 755) comprised 14 different species (Table 1). The most common species encountered were *N. rhombifer* (Diamondback Water Snake; N = 421) and *N. erythrogaster transversa* (Blotched Water Snake; N = 253), which comprised 55.8% and 33.5% of all positively identified snakes, respectively. Forty-two (5.6%) *N. h. harteri* were observed (Fig. 1), and 38 were captured. Two were recaptures (determined by obvious scarring of the individuals and examination of photographs) and one individual escaped before measurements could be recorded; therefore, data were collected from 35 snakes. Of these, 11 (31%) were adult males, 6 (17%) were juvenile males, 9 (26%) were adult females, and 9 (26%) were juvenile females (Fig. 2). The overall sex ratio (χ^2_1 = 0.03, P = 0.87), and the sex ratio of juveniles (χ^2_1 = 0.60, P = 0.44) and adults (χ^2_1 = 0.20, P = 0.66) were not significantly

TABLE 1. Species and number of snakes observed along the upper Brazos River drainage, Texas, 2006-2008.

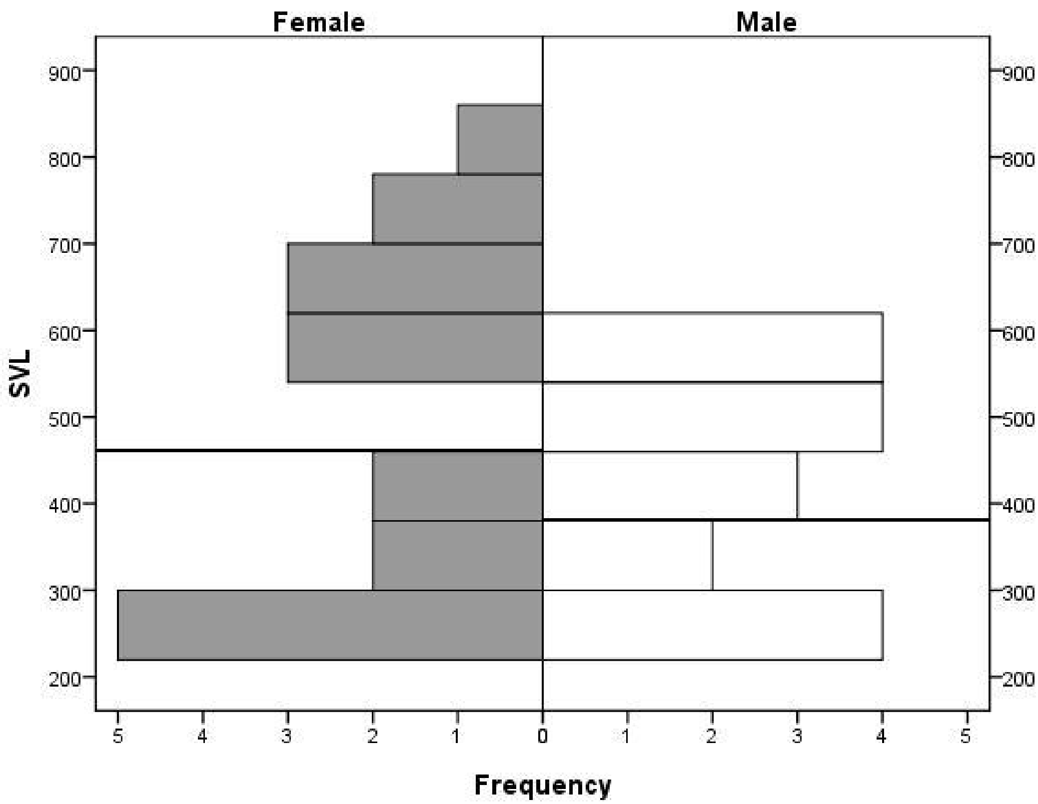
Species	No. observed	Percent (%)
Nerodia rhombifer	421	55.8
N. erythrogaster transversa	253	33.5
N. h. harteri	42	5.6
Thamnophis proximus	17	2.3
Pantherophis obsoletus	9	1.2
Coluber constrictor flaviventris	3	0.4
Agkistrodon contortrix laticinctus	2	0.3
A. piscivorus leucostoma	2	0.3
P. emoryi	1	0.1
Lampropeltis getula splendida	1	0.1
Opheodrys aestivus	1	0.1
Regina grahamii	1	0.1
Sonora semiannulata	1	0.1
T. marcianus	1	0.1
Total	755	100.0

FIGURE 1. Map of locations along the upper Brazos River drainage, Texas, where *N. h. harteri* were found, 2006-2008. Locations where snakes were found are indicated by stars. Some stars cover more than a single site.



HASKELL
THROCKMORTON
YOUNG
PARKER
JOHNSON
JONES
SHACKELFORD
STEPHENS
PALO PINTO
HOOD
SOMERVELL
BOSQUE
Lake Stamford
Paint Cr.
Reynolds Bend
Fort Griffin
Albany
Lueders
Clear Fork Brazos River
Deadman Cr.
U.S. HWY 183
Hubbard Creek Reservoir
Eliasville
Brazos River
Possum Kingdom Lake
Type Locality
Palo Pinto
Hittson Bend
Brazos River
Palo Pinto Cr.
Littlefield Bend
Dennis
Horseshoe Bend
Thorp Spring
Granbury
Lake Granbury
Walters Bend
De Cordova Bend
Rainbow
Glen Rose
Paluxy River
Brazos Point
0 10 20 40 Kilometers
0 5 10 20 Miles
N

FIGURE 2. Size class distribution by sex for *N. h. harteri* captured along the upper Brazos River drainage, Texas, 2006-2008. Solid horizontal lines represent the minimum SVL at sexually maturity reported for *N. h. paucimaculata* (Greene et al., 1999).


Female
Male
SVL
Frequency
900
800
700
600
500
400
300
200
5
4
3
2
1
0
1
2
3
4
5

different from parity. Captured *N. h. harteri* (*N* = 35) had a mean (±1 SE, range) SVL of 456.6 mm (±28.1, 245-805), tail length of 143.4 mm (±8.3, 73-235), and mass of 80.2 g (±12.7, 7.5-320). Two adult females had total lengths >902 mm, which is the total length of the largest known specimen of *N. h. harteri* (Werler and Dixon, 2000) prior to this study. The largest snake had a total length of 1040 mm, exceeding the previous record by 138 mm.

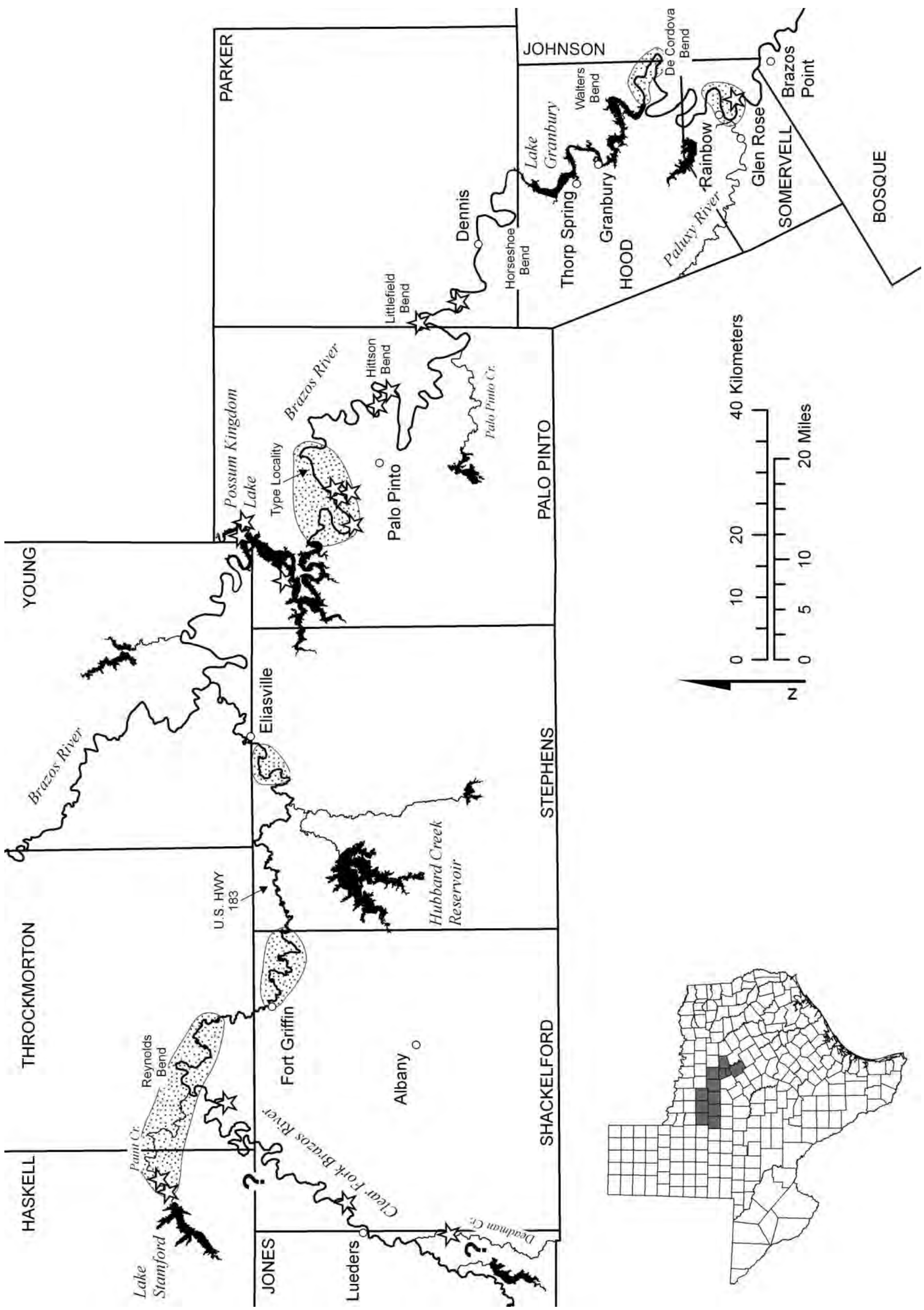
Twenty-five *N. h. harteri* (9 adults, 16 juveniles) were found during 15 intensive searches, and 17 (adults) were found while visually searching from a boat. A great amount of survey effort was necessary to find *N. h. harteri* during this study. Along the river corridor, catch-per-unit-effort (CPUE) was 1 *N. h. harteri*/9.30 man-h and 1 *N. h. harteri*/91.74 man-h for intensive searching and observing from a canoe, respectively. In Possum Kingdom Lake, nine *N. h. harteri* were observed in 47.80 man-h, resulting in CPUE of 1 *N. h. harteri*/5.31 man-h. Survey times were not recorded during searches of Lake Granbury; therefore, survey effort could not be calculated. Additionally, no *N. h. harteri* were captured using minnow traps, and because of their limited use in this study, these data were excluded. Overall, CPUE during this study was 1 *N. h. harteri*/24.15 man-h.

During intensive searches, 17 *N. h. harteri* were found under rock (3 adults, 14 juveniles), 7 (5 adults, 2 juveniles) were found in the water, and 1 (adult) was basking on a rock shelf. All *N. h. harteri* observed from a boat (*N* = 17) were adults swimming in the water, except for one adult found partially exposed in a rock pile along the shoreline. The mean (±1 SE, range) dimensions of rock (thickness × longest axis × shortest axis) that adults and juveniles were found under were 11.3 cm (±2.3, 7-15) × 86.7 cm (±16.3, 61-117) × 65.3cm (±9.8, 46-78), and 8.2 cm (±0.7, 4-14) × 55.6 cm (±7.6, 30-127) × 36.5 cm (±4.1, 15-60), respectively. No significant difference was detected in thickness (t_{15} = 1.65, P = 0.12) or longest axis (t_{15} = 1.71, P = 0.11) of rocks that adult and juvenile *N. h. harteri* were found under; however, adults were found under rocks that had a significantly longer shortest axis (t_{15} = 2.91, P = 0.01). This result is likely an artifact of larger snakes needing larger cover objects.

Habitat Quantification and Delineation.—Six sections of river within the range of *N. h. harteri* contained the most rocky habitat (i.e., these stretches had counts for rock ≥10 cm that were in the highest two quartiles; Fig. 3). All sections identified encompassed localities where *N. h. harteri* have been previously documented except for one, immediately west of Eliasville, Texas. Habitat data could not be collected along approximately 46 km of the Clear Fork of the Brazos River, beginning in northwestern Shackelford County downstream to the confluence of Paint Creek, due to high water following heavy rain events during each of two surveys along this stretch of river. Additionally, habitat data were not collected along Deadman Creek due to a lack of access.

Using aerial imagery to delimit juvenile *N. h. harteri* habitat was unsuccessful for a number of reasons. Aerial photographs from Possum Kingdom Lake down to the upper reaches of Lake Whitney were taken on 04 August 2004, and photographs of the upper portion of the range of *N. h. harteri* were taken on 14-18 October 2004. Initial

FIGURE 3. Map of sections of river along the upper Brazos River drainage, Texas, which contained the greatest amount of rocky habitat, 2006-2008. Locations where *N. h. harteri* were found during this study are indicated by stars. Some stars may cover more than a single site. Habitat data were not collected along Deadman Creek and approximately 46 km of the Clear Fork of the Brazos River, indicated by the "?".


HASKELL
THROCKMORTON
YOUNG
PARKER
JOHNSON
JONES
SHACKELFORD
STEPHENS
PALO PINTO
HOOD
SOMERVELL
BOSQUE
Lake Stamford
Paint Cr.
Reynolds Bend
Clear Fork Brazos River
Deadman Cr.
Lueders
Fort Griffin
Albany
U.S. HWY 183
Hubbard Creek Reservoir
Brazos River
Eliasville
Possum Kingdom Lake
Type Locality
Palo Pinto
Brazos River
Hittson Bend
Palo Pinto Cr.
Littlefield Bend
Horseshoe Bend
Dennis
Thorp Spring
Granbury
Lake Granbury
Walters Bend
De Cordova Bend
Paluxy River
Rainbow
Glen Rose
Brazos Point
40 Kilometers
20
10
0
20 Miles
10
5
0
N

examination of the imagery indicated that water levels were above normal throughout most of the study area at the time the photographs were taken. Examination of streamflow data collected from U.S. Geological Survey hydrologic stations (U.S. Geological Survey, 2008) within the study area confirmed this observation (Table 2). Another problem with this method was the resolution of the imagery; despite having a 1-m resolution, unvegetated rocky shoreline along the river was virtually indistinguishable from sand or any other bare substrate. Furthermore, calculation of the area of rock within 3 m of water would encompass only 3 pixels at this resolution. Finally, NAIP imagery is obtained during the growing season (spring and summer months) for “leaf on” conditions (Texas Natural Resources Information System, 2008). This prevents the majority of shoreline from being visible. If remote delineation of *N. h. harteri* habitat is to be effective, these issues need to be addressed. Suitable imagery for this task should have a sub-meter resolution, and aerial photographs should be taken during the non-growing season during “leaf off” conditions, when streamflow is at, or below, normal.

Modeling.—Using logistic regression analysis, a significant linear relationship was detected between the logit of finding *N. h. harteri* at a riffle and the combination of the amount of rock ≥10 cm at a site (i.e., habitat quality), and the total amount of rock ≥10 cm surrounding that site (i.e., habitat density; $\chi^2_2 = 18.046$, $P < 0.001$). The logit of finding *N. h. harteri* increased as both habitat quality at a site and habitat density surrounding a site increased (Table 3). The regression equation took the form: $g(x) = -5.318 + 0.020(\text{habitat quality}) + 0.016(\text{habitat density})$. The likelihood of finding *N. h.*

TABLE 2. Comparison of streamflow recorded 4 August 2004 to historic streamflow for 4 August from U.S. Geological Survey hydrologic stations along the upper Brazos River, Texas. Discharge >75th percentile is above normal. Data obtained from U.S. Geological Survey (2008).

Station no.	Location	Mean daily discharge 4 Aug 2004 (m^3/sec)	Historic median daily discharge (m^3/sec)	75th percentile (m^3/sec)
8088610[a]	Brazos River near Graford, TX	75.32	9.43	16.23
8089000	Brazos River near Palo Pinto, TX	90.90	11.47	30.02
8090800	Brazos River near Dennis, TX	151.78	11.38	20.25
8091000	Brazos River near Glen Rose, TX	37.38	10.48	29.73

[a]<30 yr of recorded data.

TABLE 3. Results from logistic regression analysis used to model the likelihood of finding *N. h. harteri* along the upper Brazos River drainage, Texas, 2006-2008.

							95% CI for e^{β}	
Variable	*d.f.*	β	SE	Wald χ^2	*P*	e^{β}	Lower	Upper
Constant	1	-5.318	1.080	24.250	<0.001	0.005	-	-
Habitat quality[a]	1	0.020	0.010	4.487	0.034	1.021	1.002	1.040
Habitat density[b]	1	0.016	0.005	10.617	0.001	1.016	1.006	1.026

[a]Amount of rock ≥10 cm at a site.
[b]Amount of rock ≥10 cm within 5 km up- and downstream from a site.

harteri at a site increased by 2.1% with every additional rock ≥10 cm recorded at a site, holding habitat density constant. Likewise, the likelihood of finding *N. h. harteri* at a site increased by 1.6% with every additional rock ≥10 cm recorded within 5 km up- and downstream of a site, holding habitat quality constant.

DISCUSSION

Current Status.—From the time of its discovery and initial description (Trapido, 1941) through the mid-1980s (Scott et al., 1989), *N. h. harteri* was the common and abundant snake in areas with suitable habitat throughout its range. Concern was expressed in 1999 regarding an apparent rapid disappearance of the snake from the section of river known historically to support the largest population (Rossi and Rossi, 1999). Results from this study indicate that while the range of *N. h. harteri* remains intact (Fig. 1), the population density has declined significantly and *N. h. harteri* is now a rare snake throughout its range. Compared to surveys conducted during the 1980s (N. J. Scott, Jr., U.S. Geological Survey, retired, unpublished data), these snakes were found at fewer sites and in drastically reduced numbers. To illustrate the magnitude of the current decline the following example is offered. During a single survey at the type locality of *N. h. harteri* (11 km north of Palo Pinto, Texas) in May 1984, 36 individuals were found in about 3 man-h of effort (N. J. Scott, Jr., unpublished data). During this study more than 11 man-h were spent searching this location and no *N. h. harteri* were found. The most productive sites in this study yielded only four individuals during a single survey.

Scott et al. (1989) observed that the majority of *N. h. harteri* at sites were <1 yr old. The overall paucity of juveniles found during this study was alarming and indicates a contracting population. Life history studies of *N. h. paucimaculata* (Mueller, 1990;

Greene et al., 1999; Whiting et al., 2008) suggest that *N. h. harteri* is an early-maturing, short-lived snake that exhibits relatively high fecundity to offset low annual survivorship. Female *N. h. paucimaculata* give birth to their first clutch at 24-25 or 36-37 months (Werler and Dixon, 2000). Clutch sizes range from 4-29 young (mean = 11) and are positively correlated with female SVL (Greene et al., 1999). Clutch sizes reported for *N. h. harteri* range from 4-23 young (Conant, 1942; McCallion, 1944; Carl, 1981). Annual survival for adult and juvenile *N. h. paucimaculata* is about 0.23 and 0.14, respectively (Whiting et al., 2008), and approximately 1 in 100 (0.012-0.018) snakes are estimated to survive to age five (Mueller, 1990; Whiting, 1993). Given this life history strategy, a high juvenile to adult ratio is expected for a relatively stable or expanding population.

Potential Causes of Decline.—Six factors have been associated with the worldwide decline of amphibians and reptiles: habitat loss and degradation, introduced invasive species, environmental pollution, disease and parasitism, unsustainable use, and global climate change (Gibbons and Stangel, 1999). While this study was not able to provide direct evidence to explain the recent decline of *N. h. harteri*, anecdotal evidence has allowed for speculation on a number of potential factors.

Dams and water development projects have been the primary factor responsible for the degradation and loss of *N. h. harteri* habitat (Scott et al., 1989). Several low-head dams along the Clear Fork of the Brazos River and two major impoundments along the Brazos River, Possum Kingdom Lake and Lake Granbury, lie within the range of *N. h. harteri*. Aside from inundation of river habitat upstream from these dams, the negative effects from a modified flow regime must be considered. Analysis of streamflow data

(U.S. Geological Survey, 2008) recorded at the type locality of *N. h. harteri* clearly demonstrates how impoundment of the upper Brazos River drainage has dramatically altered the natural flow regime of the system (Fig. 4). Prior to the completion of Possum Kingdom Lake in 1941, streamflow mimicked the bimodal pattern of precipitation, with a late spring peak followed by a smaller peak in the fall. Following impoundment, the magnitude of spring and fall streamflow has been reduced and there is now a single peak in early summer followed by a gradual reduction in flow through the fall. Summer flow is dramatically higher and winter flow is slightly greater. Additionally, the magnitude of extreme high and low flow events has been reduced following impoundment (Table 4) and the variability of streamflow has increased dramatically (Fig. 5), with the median annual number of reversals (i.e., the number of days in which the direction of flow rate reverses) more than doubling from 71.5 to 147 for pre- and post-impoundment conditions, respectively. Suitable rocky riffles still exist below Possum Kingdom Lake, and while the Brazos River has not experienced sedimentation of riffle habitats like that observed along the Colorado River (Fig. 4 in Scott et al., 1989), the reduction of extreme high flow events has likely reduced flushing and scouring of the river channel and threatens juvenile *N. h. harteri* habitat. Furthermore, the attenuation of extreme events may affect the riparian vegetation by promoting the establishment of invasive species such as saltcedar over native plants. As discussed below, this can also lead to degradation of riffle habitat. Finally, the constant variability of flow caused by frequent hydroelectric releases, particularly during the summer months, may directly affect *N. h. harteri*. These usually short periods of increased flow cause riffle habitat to become inundated. The

FIGURE 4. Median monthly streamflow at the type locality of *N. h. harteri*, 11 km north of Palo Pinto, Texas, before and after impoundment of the Brazos River upstream by Morris Sheppard Dam in 1941. Data were recorded from U.S. Geological Survey hydrologic station 8089000 (U.S. Geological Survey, 2008).

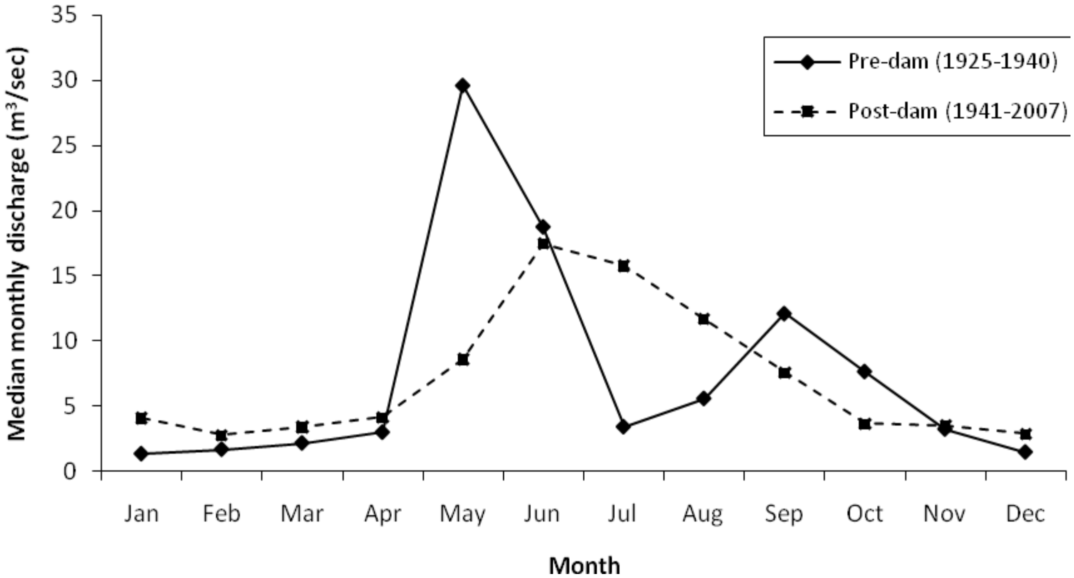
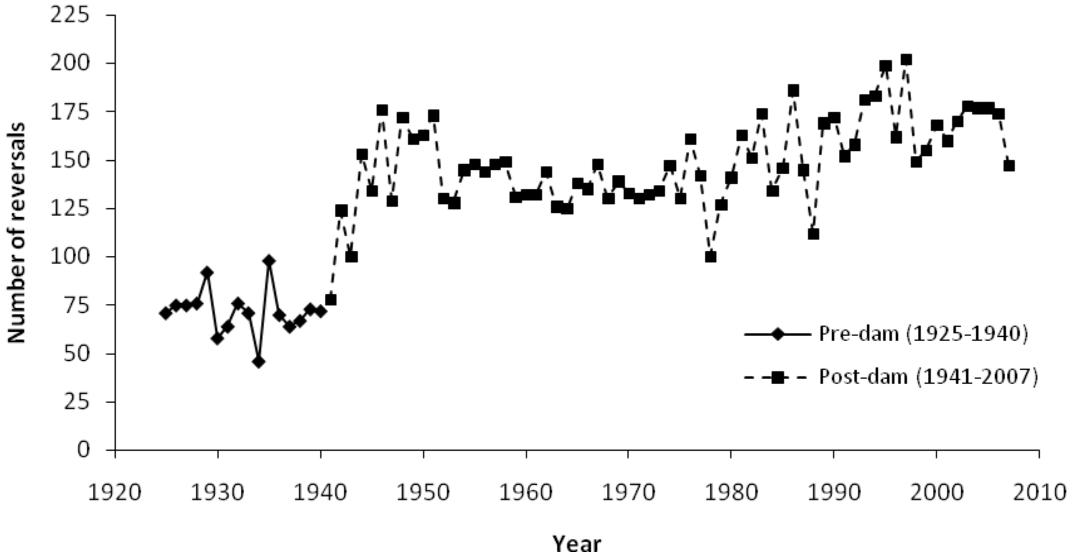

35
30
25
20
15
10
5
0
Median monthly discharge (m³/sec)
Pre-dam (1925-1940)
Post-dam (1941-2007)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

TABLE 4. Comparison of extreme flow events at the type locality of *N. h. harteri*, 11 km north of Palo Pinto, Texas, before and after impoundment of the Brazos River upstream by Morris Sheppard Dam in 1941. Data were recorded from U.S. Geological Survey hydrologic station 8089000 (U.S. Geological Survey, 2008).

Low flow events	Median (m^3/sec)		High flow events	Median (m^3/sec)	
	Pre-dam	Post-dam		Pre-dam	Post-dam
1-day minimum	0.000	0.623	1-day maximum	872.2	368.1
3-day minimum	0.000	0.670	3-day maximum	683.4	262.6
7-day minimum	0.001	0.777	7-day maximum	444.0	166.7
30-day minimum	0.111	1.518	30-day maximum	149.2	88.3
90-day minimum	1.793	3.288	90-day maximum	75.6	46.9

FIGURE 5. Number of days the rate of change of streamflow switched direction at the type locality of *N. h. harteri*, 11 km north of Palo Pinto, Texas, before and after impoundment of the Brazos River upstream by Morris Sheppard Dam in 1941. Data were recorded from U.S. Geological Survey hydrologic station 8089000 (U.S. Geological Survey, 2008).


225
200
175
150
125
100
75
50
25
0
Number of reversals
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year
Pre-dam (1925-1940)
Post-dam (1941-2007)

timing of these releases is likely very detrimental to birthing on a riffle (J. R. Dixon, Texas A&M University, personal communication). These short bursts of high water may reduce foraging opportunities for neonates and increase the risks of predation by forcing snakes to frequently move out from under rocks when the river rises.

Invasive species, particularly saltcedar and the red imported fire ant (*Solenopsis invicta*), potentially threaten *N. h. harteri* populations and habitat. Saltcedar becomes increasingly common along the stream channel above Possum Kingdom Lake. This invasive shrub consumes large quantities of water, competes with native plants, increases sediment deposition within the stream channel, and ultimately results in contraction of the stream channel (Blackburn et al., 1982; Brotherson and Field, 1987). These effects can quickly reduce a rocky riffle to a slow, sediment filled channel, and threatens juvenile *N. h. harteri* habitat. Negative impacts of *S. invicta*, both direct and indirect (e.g., reduced survival, behavioral changes, and changes in habitat use), have been reported for several species of herpetofauna (reviewed in Allen et al., 2004), including snakes. These ants are common in Texas, and were observed at several potentially suitable riffles where they were found under nearly every rock turned. No snakes of any species were found in this situation, and a snake seeking refuge in these areas would likely be exposed to significant risks of injury or mortality from ants. No direct evidence exists to indicate that *S. invicta* negatively impacts *N. h. harteri*; however, these ants are recognized as a threat to *N. h. paucimaculata* (Forstner et al., 2006) and can likewise be considered a threat to *N. h. harteri*.

Another factor potentially affecting *N. h. harteri* populations are the rather recent outbreaks of toxic *Prymnesium parvum* (golden algae) blooms within the Brazos River drainage. Toxins produced during blooms are not known to directly affect lung-respiring organisms; however, ichthyotoxins released by *P. parvum* disrupt the functioning of gills in fish, mollusks, arthropods, and gill-breathing amphibians (Paster, 1973), and can result in extensive mortalities (James and De La Cruz, 1989; Rhodes and Hubbs, 1992). Within the Brazos River drainage, confirmed fish kills by *P. parvum* blooms were first reported in 1988 and have subsequently continued to be documented throughout the range of *N. h. harteri* (Texas Parks and Wildlife Department, 2007b). While the prevalence of *P. parvum* in Texas is poorly understood, its effect on fish populations may pose a significant threat to *N. h. harteri*. The diet of *N. h. harteri*, inferred from the feeding ecology of *N. h. paucimaculata* (Greene et al., 1994), is almost entirely piscivorus with minnows (Cyprinidae) constituting the largest component. A reduction in prey availability, particularly during crucial feeding periods (e.g., after spring emergence or after parturition in the fall), may reduce survivorship. The actual effects of *P. parvum* blooms on *N. h. harteri* prey are not well known; however, the coincidence of massive fish kills within the range of *N. h. harteri* and the observed decline of the snake is apparent.

Rossi and Rossi (1999) found many juvenile *N. erythrogaster transversa* in areas where *N. h. harteri* were previously found and suggested that competition between syntopic snake species for food and hiding places may be a significant factor affecting *N. h. harteri* populations. According to the competitive exclusion principle (Gause, 1934;

Hardin, 1960), species competing for the same resources cannot coexist indefinitely in a stable environment. *Nerodia h. harteri* fills a unique niche (i.e., shallow riffle habitats) not typically exploited by *N. rhombifer* and *N. e. transversa* (Werler and Dixon, 2000), except perhaps for a short period when snakes are young. During this study, juvenile *N. rhombifer* and *N. e. transversa* were found under rocks in apparently suitable habitat lacking *N. h. harteri*. Additionally, juveniles of all three snakes were found occupying the same riffles, and on occasion *N. h. harteri* were found under the same rock as a congener. Large *N. rhombifer* and *N. e. transversa* were not found in shallow riffles during this study, but adults of all three snakes were found together in deeper waters. These areas however, were typically occupied only by *N. rhombifer* and *N. e. transversa*. Scott et al. (1989) reported similar findings. Niche partitioning and ontogenetic shifts in prey, habitat preferences, and activity patterns likely relax direct competition between these syntopic snakes (see Gibbons and Dorcas, 2004). While competition may have had an important influence in the present distribution of these three snake species (Tinkle and Conant, 1961), it is unlikely that it has had a major role in the reduction of *N. h. harteri* presently observed.

A final potential factor warranting discussion is direct anthropogenic impacts on *N. h. harteri*. Of particular concern are the combined pressures from increasing human densities and recreational use of the Brazos River system. During this study recreational use was observed to be highest along the Brazos River below Possum Kingdom Lake; however, evidence of extensive recreational use was also observed along the more remote stretches of the Clear Fork along the western extent of the range of *N. h. harteri*. Juvenile

N. h. harteri habitat consists of low lying, rocky shorelines adjacent to shallow waters, and this habitat is ideal for human recreation. During this study, many people were observed utilizing these areas. Additionally, anglers often turn rocks along the riverbank in search of fishing bait. These circumstances have undoubtedly led to the unexpected discovery of snakes and their likely demise. Turtles and one *N. e. transversa* were found shot by small caliber firearms during this study. Turtles were also found snagged on trot-lines, and one dead *N. rhombifer* was found entangled in a limb-line overhanging the river. Furthermore, extensive efforts were made searching for *N. h. harteri* at one of the historically most productive sites without success; coincidentally, this is also the site of a very popular campground. While this evidence is largely anecdotal and speculative, the notion of direct anthropogenic impacts on *N. h. harteri* is shared by other experienced herpetologists (J. R. Dixon, personal communication; M. R. J. Forstner, personal communication).

Distribution and Habitat.—This study provided a detailed account of the distribution of *N. h. harteri* throughout the range of the snake (Fig. 1). At the most upstream extent of the range, Scott et al. (1989) noted an apparently isolated population along Deadman Creek, a small tributary to the Clear Fork of the Brazos River east of Lake Fort Phantom Hill, Jones County. A single individual was found 7 km upstream from the confluence with the Clear Fork, and approximately 3.5 km downstream from the locality reported by Scott et al. (1989). In accordance with Scott et al. (1989), habitat exists from the mouth of the creek upstream approximately 16 km. At all sites examined upstream from this point, the creek was slow flowing, choked by heavy vegetation, and unsuitable for *N. h. harteri*.

Along Paint Creek, Smith (1983) reported *N. h. harteri* from just below Lake Stamford Dam in Haskell County. Scott et al. (1989) found the snake approximately 2 km below the dam and assumed populations to be present along the entirety of the creek below Lake Stamford. Subsequent to the study by Scott et al. (1989) a dam was built on Paint Creek near where they reported finding *N. h. harteri*. The dam allows water to pass during normal flows, but inundates the stream channel and surrounding area upstream during high flows. As a result, the upstream habitat has been reduced to a muddy flat and is unsuitable for *N. h. harteri*. Surveys during this study began at the dam on Paint Creek, approximately 2 km below Lake Stamford, and proceeded downstream to the creek's confluence with the Clear Fork. One *N. h. harteri* was found <1 km downstream from where Scott et al. (1989) reported finding the snake, and six additional snakes were found <4.5 km downstream (Fig. 1). No additional *N. h. harteri* were observed along Paint Creek beyond this point despite the presence of suitable habitat.

Below the confluence of Deadman Creek, the Clear Fork of the Brazos River is impounded approximately 11 km downstream by an old dam and grist mill at the small town of Lueders, Jones County, and is unsuitable for *N. h. harteri*. Previous investigators have documented *N. h. harteri* from below the dam at Lueders (Scott et al., 1989; Forstner et al., 2006; F. L. Rose, Texas State University – San Marcos, personal communication); however, none were found during this study. From Lueders downstream to the confluence of Paint Creek in Throckmorton County, *N. h. harteri* have not been documented prior to this survey, but were assumed to be present (Scott et al., 1989). One individual was found 8.8 km downstream from the dam at Lueders and another was found 10.9 km upstream from the confluence of Paint Creek (Fig. 1). Approximately 17 km downstream from Lueders, river habitat is impounded by a low-head dam, and water is backed up for several kilometers upstream and is unsuitable for *N. h. harteri*.

Nerodia h. harteri have previously been documented along the Clear Fork near the mouth of Paint Creek, downstream at Reynolds Bend, Throckmorton County, and at Fort Griffin, Shackelford County (Tinkle and Knoph, 1964; Scott et al., 1989). During this study *N. h. harteri* were not found at any of these locations, or along the remainder of the Clear Fork below the Paint Creek confluence. Habitat was present along the Clear Fork from the dam at Lueders downstream to the Shackelford/Stephens county line. This finding is similar to Scott et al. (1989) who reported suitable habitat from Lueders downstream to Fort Griffin. Except for a stretch of river near the mouth of Paint Creek, rocky habitat was never abundant along the Clear Fork and was often separated by long stretches of deep, slow moving water. Downstream from the Shackelford-Stephens county line, rocky habitat is rare and the river becomes impounded by a series of six low-head dams from below the U.S. Highway 183 crossing in Stephens County, downstream to Eliasville, Young County. These dams create still backwaters for several kilometers upstream, and only short sections of river flow at normal levels downstream before becoming impounded again. Below Eliasville habitat is lacking overall, except for an isolated rocky riffle at the confluence of the Clear Fork and the Brazos River.

The Brazos River below the confluence of the Clear Fork is impounded by Possum Kingdom Lake and unsuitable for *N. h. harteri*. Porter (1969) reported the snake in the still waters of Possum Kingdom Lake, and Scott et al. (1989) found it along approximately 17 km of the upper end of the lake. Eight *N. h. harteri* (not including a recapture) were found at three sites previously reported by Scott et al. (1989; Fig. 1). All sites where *N. h. harteri* were found had similar habitat characteristics that included a gently sloping, rocky lake bottom adjacent to rocky shoreline, and were in relatively calm waters protected from wave action. These findings are similar to those reported by Scott et al. (1989), and by Whiting et al. (1997), who investigated the spatial ecology of *N. h. paucimaculata* at E. V. Spence Reservoir in Coke County, Texas.

Between Morris Sheppard Dam, Palo Pinto County, and Lake Granbury, Hood County, *N. h. harteri* have been reported from several locations (e.g., Trapido, 1941; Tinkle and Conant, 1961; Scott et al., 1989; Dorcas and Mendelson, 1991). Nineteen *N. h. harteri* were found at eight locations along this stretch of river (Fig. 1), and of these, four locations have not been previously reported. Scott et al. (1989) observed a 100 km hiatus in the distribution of *N. h. harteri* from Hittson Bend, downstream to Lake Granbury, and attributed it to a lack of cover and the sandy nature of the river along this section. Furthermore, they assumed populations within this stretch of river to be sparse and ephemeral (Scott et al., 1989). In agreement with Scott et al. (1989), the riverbed below Hittson Bend becomes increasingly sandy and habitat was less abundant compared to upstream; however, some habitat does occur, such as at Littlefield Bend where *N. h. harteri* were found in this study and by others (Wade, 1968; Dorcas and Mendelson, 1991). Downstream from Littlefield Bend, habitat becomes increasingly rare. The Brazos River reaches Lake Granbury at Horseshoe Bend, approximately 12 km downstream from the FM 1189 crossing near Dennis, Parker County.

Scott et al. (1989) documented *N. h. harteri* at only one location within Lake Granbury (U.S. Highway 377 bridge near Granbury, TX), and this has been the only report of the snake's presence since the lake's impoundment in 1969. Prior to impoundment, Wade (1968) found *N. h. harteri* near Walters Bend, approximately 4.8 km upstream from De Cordova Dam. *Nerodia h. harteri* were not observed within Lake Granbury during this study; however, it is important to note that surveys of the lake were conducted primarily in July 2007, and the combined effects of high lake levels from spring flooding and reduced activity of *N. harteri* during hot summer months (Greene et al. 1993) likely reduced the chances of detecting the snake. Furthermore, the shoreline around Lake Granbury has been modified extensively by human development and very little habitat was observed. If populations are present within the lake, they are likely isolated and small.

Below Lake Granbury, Wade (1968) documented *N. h. harteri* along De Cordova Bend approximately 4.5 km below the dam, and at the U.S. Highway 67 bridge east of Glen Rose, Somervell County. Scott et al. (1989) found *N. h. harteri* at the FM 200 crossing east of Rainbow, Somervell County, and at the FM 1118 bridge east of Brazos Point, Bosque County. While no *N. h. harteri* were found at these locations during this study, three snakes were found at a new locality east of Glen Rose, Texas, 10.5 km downstream from the U.S. Highway 67 crossing (Fig. 1). In agreement with Scott et al.

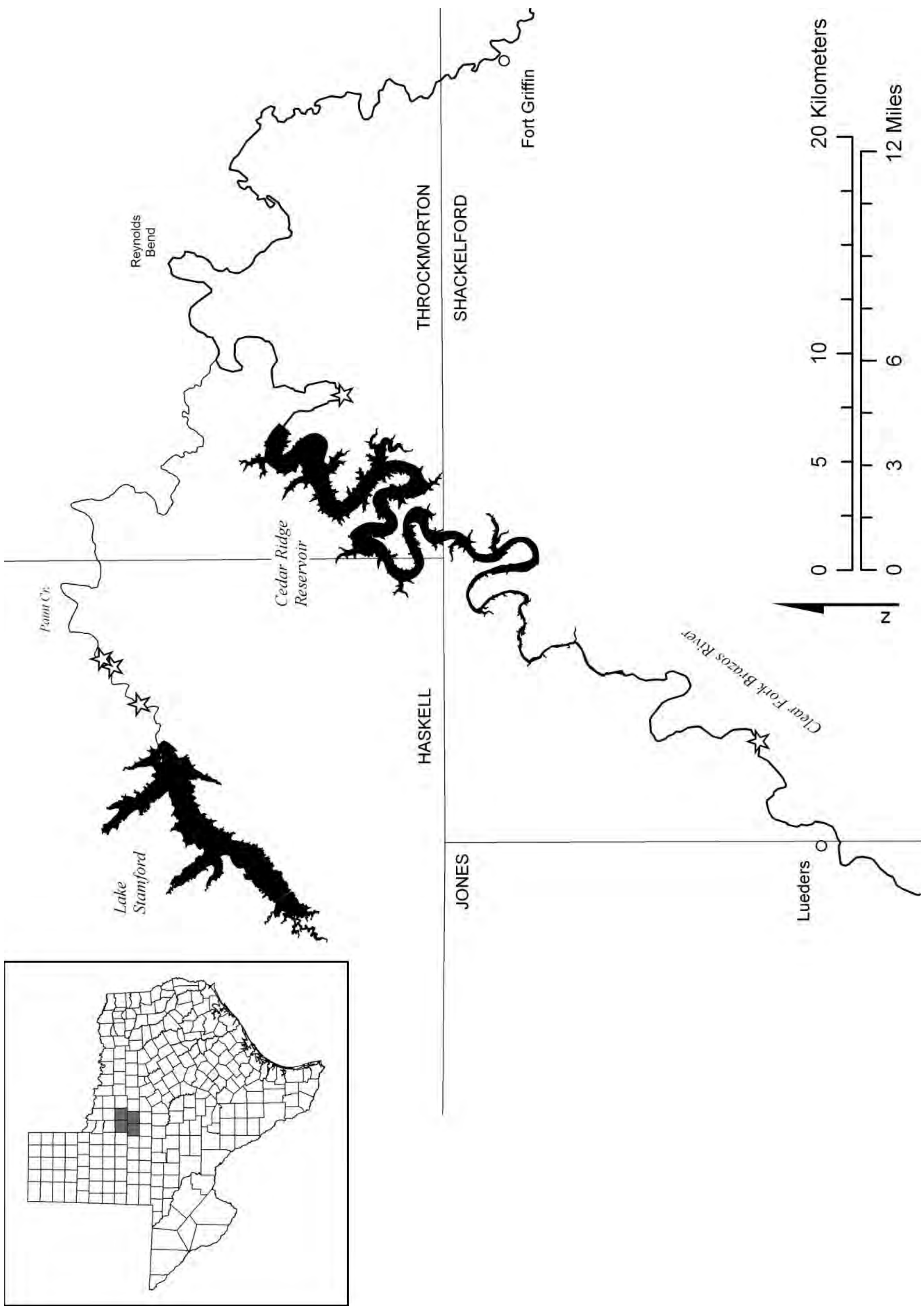
(1989), the river below De Cordova Dam is suitable downstream to the FM 1118 bridge. A short distance below this point the river becomes inundated by Lake Whitney. *Nerodia h. harteri* have not been documented from Lake Whitney or any point downstream.

Modeling.—The objective of this study was not only to assess the current status of *N. h. harteri*, but also to investigate habitat relationships of the snake. Logistic regression analysis indicated that the abundance of rock ≥10 cm along the shoreline, both at a riffle and in proximity to a riffle, were significantly related to the likelihood of finding *N. h. harteri* at a site. The scope and design of this study did not allow for the use of presence-absence data to estimate occupancy and detection probabilities as described by MacKenzie et al. (2006). The low probability of detection, based on studies of *N. h. paucimaculata* (≤0.2; J. M. Mueller, Tarleton State University, personal communication), and the perceived low occupancy (probably <0.1) suggest that ≥7 surveys at each site would be necessary to estimate occupancy (MacKenzie et al., 2006). This was not feasible in this study. These findings suggest that *N. h. harteri* are more likely to be found in areas with higher amounts of rocky shoreline, and this fits the current understanding of the needs of juveniles.

An attempt was made to incorporate human recreational use of the river system into the logistic regression model by calculating the shortest distance of public access points (i.e., road crossings, campgrounds, public use areas) for each site. When added to the model, analysis indicated that the covariate was not useful (Wald $\chi^2_1 = 0.269$, $P = 0.604$) in explaining where *N. h. harteri* were found during this study. Several access points exist above Possum Kingdom Lake, in areas that are far less densely populated compared to below the lake. To accurately model the impact of human use along the river, the chosen variable needs to incorporate not only access points along the river, but also the surrounding human density. This was not possible during this study.

Future.—Historically, *N. h. harteri* were found to be remarkably abundant in rocky areas throughout the range of the snake (Trapido, 1941; Scott et al., 1989); however, narrow habitat requirements and a limited distribution make it exceptionally vulnerable to environmental disturbances (Scott et al., 1989). *Nerodia h. harteri* has experienced a drastic reduction in population size since the 1980s and the reasons for this contraction are not well understood. Several potential factors have been addressed, although supporting evidence is largely anecdotal. Anthropogenic factors, particularly dam construction, appear to have had the greatest effect on reducing *N. h. harteri* habitat (Scott et al., 1989). In response to projected increasing water demands for the City of Abilene and irrigated agriculture in Throckmorton County, the 2007 State Water Plan (Texas Water Development Board, 2007) recommended that Cedar Ridge Reservoir, a proposed impoundment project along the Clear Fork of the Brazos River in southwestern Throckmorton County (Fig. 6), be designated as a unique reservoir site by the Texas legislature to ensure availability of the site for future water supply development. If constructed, Cedar Ridge Reservoir will inundate approximately 55 km of river habitat. Although *N. h. harteri* have not been documented along this stretch of river, snakes were found both up- and downstream from the proposed impoundment during this study (Fig. 6), and populations are likely present. In addition to inundating occupied river habitat, Cedar Ridge Reservoir will likely significantly alter the flow regime below the dam and

FIGURE 6. Map of proposed site for Cedar Ridge Reservoir along the upper Brazos River drainage, Texas. Locations where *N. h. harteri* were found during this study are indicated by stars.


Lake Stamford
Paint Cr.
Cedar Ridge Reservoir
Reynolds Bend
THROCKMORTON
SHACKELFORD
HASKELL
JONES
Fort Griffin
Lueders
Clear Fork Brazos River
N
0
5
10
20 Kilometers
0
3
6
12 Miles

curtail genetic exchange between populations separated by the dam. If completed, the median monthly streamflow downstream of the reservoir is estimated to be reduced by ≥85% from July-October (Brazos G Regional Water Planning Group, 2006). The ability of *N. h. harteri* to persist in a reservoir environments (Scott et al., 1989; this study) will partially mitigate the direct effects of flooding river habitat. However, in an investigation of the population dynamics of *N. h. paucimaculata,* Whiting et al. (2008) noted that while the snake can persist in lakes, they tend to occur in relatively low densities. Surveys during this study indicated that habitat is limited along the section of river to be inundated by the reservoir project, and the population of *N. h. harteri* was probably never great in numbers even before the recent decline. In light of this, the proposed impoundment could potentially increase available habitat so long as appropriate measures are taken to ensure adequate distribution of gently sloping, rocky shorelines along the entire vertical gradient of the reservoir. Doing so will ensure that habitat is present across the range of lake surface elevations (Whiting et al., 1997). Once established, protection of these rocky shorelines from development or improvement will also be critical. Furthermore, the potential effects of a modified flow regime deserve careful consideration and provisions should be implemented to assure adequate streamflow for the maintenance of riffle habitat downstream from the proposed reservoir.

Nerodia h. harteri can obtain high local population densities within the river system (Trapido, 1941; Scott et al., 1989) and can persist in unnatural lake environments (Scott et al., 1989; this study). In the absence of long term population trend data for *N. h.*

harteri, it is difficult to assess whether the observed recent decline is within the natural range of variability for the population (Gibbons et al., 2000). Nonetheless, small population size (Pimm et al., 1988), small geographic range (Gaston, 1994), and specialized habitat requirements (Brown, 1995) have been hypothesized to increase a species vulnerability to extinction. Furthermore, Pimm et al. (1988) predicted that risk of extinction is greater at low population densities for species that are small-bodied, fast-growing, and short-lived, compared to those that are large-bodied, slow-growing, and long-lived. *Nerodia h. harteri* is restricted to one of the smallest geographic ranges of any North American snake, and is a highly aquatic, riffle dependent snake, whose life history is characterized by a relatively short life span, quick maturation, and high fecundity. Given the recent population decline and current scarcity of *N. h. harteri*, high recreational use of the Brazos River system, and proposed water development projects within its range, this snake may now be more vulnerable than *N. h. paucimaculata*, which has recently been proposed for removal from the list of species protected by the Endangered Species Act.

This study investigated the current status and distribution of *N. h. harteri* throughout its range and modeled the relationship between the abundance of rocky habitat and the likelihood of finding the snake. Results suggest that *N. h. harteri* is now a rare snake and the presence of riffle habitat is crucial for its continued persistence. Education and public awareness will be key in mitigating direct human impacts on *N. h. harteri* populations and habitat. In light of ever increasing human densities and demands for water and the climatic uncertainties of global climate change, the assurance of adequate instream flows and maintenance of the river channel will be critical for the conservation of this Texas endemic snake. Given the rate at which this snake has declined, future conservation efforts need to be implemented in a timely manner, and consideration of a captive breeding program and potential reintroductions may be warranted. Future research should focus on assessment of local population dynamics, as well as the feasibility of reintroduction efforts. Other research should include an accurate survey of Lake Granbury, an assessment of the flow regime necessary for maintenance of riffle habitat, and the prevalence of fish kills caused by the microalga *P. parvum* within the upper Brazos River drainage and the response of forage fish populations. Finally, if construction of Cedar Ridge Reservoir is approved, there will be a unique opportunity to investigate the response of *N. h. harteri* to a major impoundment project.

REFERENCES CITED

Allen, C. R., D. M. Epperson, and A. S. Garmestani. 2004. Red imported fire ant impacts on wildlife: a decade of research. American Midland Naturalsit 152:88-103.

Bender, S., S. Shelton, K. C. Bender, and A. Kalmbach. 2005. Texas wildlife action plan 2005-2010: Texas comprehensive wildlife conservation strategy. Texas Parks and Wildlife Department, Austin.

Blackburn, W. H., R. W. Knight, and J. L. Schuster. 1982. Saltcedar influence on sedimentation in the Brazos River. Journal of Soil and Water Conservation 37:298-301.

Brazos G Regional Water Planning Group. 2006. 2006 Brazos G Regional Water Plan. Texas Water Development Board, Austin.

Brotherson, J. D., and D. Field. 1987. *Tamarix*: impacts of a successful weed. Rangelands 9:110-112.

Brown, J. H. 1995. Macroecology. University of Chicago Press, Chicago, Illinois.

Carl, G. 1981. Reproduction in the captive Brazos Water Snake, *Nerodia harteri*. Texas Journal of Science 33:77-78.

Conant, R. 1942. Notes on the young of three recently described snakes, with comments upon their relationships. Bulletin of the Chicago Academy of Sciences 6:193-200.

Densmore, L. D., III, F. L. Rose, and S. J. Kain. 1992. Mitochondrial DNA evolution and speciation in water snakes (Genus *Nerodia*) with special reference to *Nerodia harteri*. Herpetologica 48:60-68.

Dixon, J. R. 2000. Amphibians and Reptiles of Texas: with Keys, Taxonomic Synopses, Bibliography, and Distribution Maps. Second edition. Texas A&M University Press, College Station.

Dorcas, M. E., and J. R. Mendelson, III. 1991. Distributional notes on *Nerodia harteri harteri* in Parker and Palo Pinto counties, Texas. Herpetological Review 22:117-118.

Eberle, W. G., 1972. Comparative chromosomal morphology of the New World natricine snake genera *Natrix* and *Regina*. Herpetologica 28:98-105.

Ernst, C. H., and E. M. Ernst. 2003. Snakes of the United States and Canada. Smithsonian Institution Press, Washington D.C.

Forstner, M. R. J., S. M. Reilly, and J. R. Dixon. 2006. Persistence and distribution of *Nerodia harteri* in Texas river systems. Unpublished Report, U.S. Fish and Wildlife Service, Austin, TX.

Gaston, K. J. 1994. Rarity. Chapman and Hall, London.

Gause, G. F. 1934. The Struggle for Existence. Williams and Wilkins, Baltimore, MD.

Gibbons, J. W., and M. E. Dorcas. 2004. North American Water Snakes: A Natural History. University of Oklahoma Press, Norman.

Gibbons, J. W., and P. W. Stangel, coordinators. 1999. Conserving Amphibians and Reptiles in the New Millennium. Proceedings of the Partners in Amphibian and Reptile Conservation (PARC) Conference. PARC 2-4 June 1999, Atlanta, GA. Savannah River Ecology Laboratory, Herp Outreach Publicaiton #2. Aiken, SC.

Gibbons, J. W., D. E. Scott, T. J. Ryan, K. A. Buhlmann, T. D. Tuberville, B. S. Metts, J. L. Greene, T. Mills, Y. Leiden, S. Poppy, and C. T. Winne. 2000. The global decline of reptiles, déjà vu amphibians. BioScience 50:653-666.

Gould, F. W., G. O. Hoffman, and C. A. Rechenthin. 1960. Vegetational areas of Texas. Texas A&M University, Texas Agricultural Experiment Station L-492, College Station.

Greene, B. D. 1993. Life history and ecology of the Concho Water Snake, *Nerodia harteri paucimaculata*. Unpublished Ph D. dissertation, Texas A&M University, College Station.

Greene, B. D., J. R. Dixon, J. M. Mueller, M. J. Whiting, and O. W. Thornton, Jr. 1994. Feeding ecology of the Concho Water Snake, *Nerodia harteri paucimaculata*. Journal of Herpetology 28:165-172.

Greene, B. D., J. R. Dixon, and M. J. Whiting, J. M. Mueller. 1999. Reproductive ecology of the Concho Water Snake, *Nerodia harteri paucimaculata*. Copeia 1999:701-709.

Hammerson, G. A. 2007. *Nerodia harteri*. In: IUCN 2008. 2008 IUCN Red List of Threatened Species. <www.iucnredlist.org>. Accessed 21 January 2009.

Hardin, G. 1960. The competitive exclusion principle. Science 131:1292-1297.

Hosmer, D. W., and S. Lemeshow. 2000. Applied Logistic Regression. Second edition. John Wiely and Sons Inc., New York, NY.

James, T., and A. De La Cruz. 1989. *Prymnesium parvum* Carter (Chrysophyceae) as a suspect of mass mortalities of fish and shellfish communities in western Texas. Texas Journal of Science 41:429-430.

Kilpatrick, C. W., and E. G. Zimmerman. 1973. Karyology of North American natricine snakes (family Colubridae) of the genera *Natrix* and *Regina*. Canadian Journal of Genetics and Cytology 15:355-361.

Larkin, T. J., and G. W. Bomar. 1983. Climatic atlas of Texas. Texas Department of Water Resources (now Texas Water Development Board) Report LP-192, Austin.

Lawson, R. 1987. Molecular studies of thamnophiine snakes: 1. The phylogeny of the genus *Nerodia*. Journal of Herpetology 21:140-157.

Longmire, J. L., A. K. Lewis, N. C. Brown, J. M. Buckingham, L. M. Clark, MD. Jones, L. J. Meincke, J. Meyne, R. L. Ratliff, F. A. Ray, R. P. Wagner, and R. K. Moyzis. 1988. Isolation and molecular characterization of a highly polymorphic centromeric tandem repeat in the family Falconidae. Genomics 2:14-24.

Mackenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence. Academic Press, Burlington, MA.

Maxwell, T. C. 1982. Status and distribution of *Nerodia harteri harteri*. Unpublished Report, Endangered Species, U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

McAllister, C. T., and C. R. Bursey. 2008. First report of *Ochetosoma aniarum* (Digena: Ochetosomatidae) from the Brazos Water Snake, *Nerodia harteri* (Serpentes:

Colubridae), in Texas, with a summary of definitive hosts of this parasite. Texas Journal of Science 60:63-68.

McAllister, C. T., and S. J. Upton. 1989. Coccidian parasites (Apicomplexa: Eimeriidae) of *Nerodia* spp. (Serpentes: Colubridae), with a description of a new species of *Eimeria*. Journal of Progozoology 36:271-274.

McCallion, J. 1944. Notes on *Natrix harteri* in captivity. Copeia 1944:63.

McMahan, C. A., R. G. Frye, and K. L. Brown. 1984. The Vegetation Types of Texas, Including Cropland. Texas Parks and Wildlife Department, Austin.

Mecham, J. S. 1983. *Nerodia harteri* (Trapido) Harter's Water Snake. Catalogue of American Amphibians and Reptiles 330:1-2.

Mueller, J. M. 1990. Population dynamics of the Concho Water Snake. Unpublished thesis, Texas A&M University, College Station.

NatureServe. 2008. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.0. NatureServe, Arlington, Virginia. <http://www.natureserve.org/explorer>. Accessed 26 August 2008.

National Oceanic and Atmospheric Administration. 2002. Climatography of the United States No. 85: Divisional normals and standard deviations of temperature, precipitation, and heating and cooling degree days 1971-2000 (and previous normals periods). NOAA National Climatic Data Center, Asheville, NC.

National Oceanic and Atmospheric Administration. 2004. Climatography of the United States No. 20: Texas monthly station climate summaries, 1971-2000. NOAA National Climatic Data Center, Asheville, NC.

Paster, Z. K. 1973. Pharmacology and mode of action in prymnesin. In: D. F. Martin and G. M. Padilla (eds.). Cell biology: A Series of Monographs, Marine Pharmacognosy, Action of Marine Biotoxins at the Cellular Level, pp. 241-263. Academic Press, New York, NY.

Pimm, S. L., H. L. Jones, and J. Diamond. 1988. On the risk of extinction. The American Naturalist 132:757-785.

Porter, S. T. An ecological survey of the herpetofauna of Palo Pinto County, Texas. Unpublished thesis, North Texas State University, Denton.

Rhodes, K., and C. Hubbs. 1992. Recovery of Pecos River fishes from a red tide fish kill. The Southwestern Naturalist 37:178-187.

Rose, F. L., and K. W. Selcer. 1989. Genetic divergence of the allopatric populations of *Nerodia harteri*. Journal of Herpetology 23:261-267.

Rossi, J., and R. Rossi. 1999. A population survey of the Brazos Water Snake, *Nerodia harteri harteri*, and other water snakes on the Brazos River, Texas, with notes on a captive breeding and release program. Bulletin of the Chicago Herpetological Society 34:251-253.

——. 2000. Comparison of growth, behavior, parasites and oral bacteria of Brazos Water Snakes, *Nerodia harteri harteri*, raised in an outdoor enclosure with related specimens raised indoors. Bulletin of the Chicago Herpetological Society 35:221-228.

Scott, N. J., Jr., and L. A. Fitzgerald. 1985. Status survey of *Nerodia harteri*, Brazos and Concho-Colorado Rivers, Texas. Unpublished Report, Endangered Species, U. S. Fish and Wildlife Service, Albuquerque, NM.

Scott, N. J., Jr., T. C. Maxwell, O. W. Thornton, Jr., L. A. Fitzgerald, and J. W. Flury. 1989. Distribution, habitat, and future of Harter's Water Snake, *Nerodia harteri*, in Texas. Journal of Herpetology 23:373-389.

Seigel, R. A., and H. S. Fitch. 1984. Ecological patterns of relative clutch mass in snakes. Oecologia 61:293-301.

Smith, D. D. 1983. Geographic distribution. *Nerodia harteri harteri* (Brazos Water Snake). Herpetological Review 14:84-85.

Stahle, D. W., and M. K. Cleaveland. 1988. Texas drought history reconstructed and analyzed from 1698 to 1980. Journal of Climate 1:59-74

Stefferud, S. 1986. 50 CFR Part 17. Endangered and threatened wildlife and plants; determination of *Nerodia harteri paucimaculata* (Concho Water Snake) to be a threatened species; final rule. Federal Register 51:31412-31422.

Tinkle, D. W., and R. Conant. 1961. The rediscovery of the water snake, *Natrix harteri*, in western Texas, with the description of a new subspecies. Southwestern Naturalist 6:33-44.

Tinkle, D. W., and G. N. Knopf. 1964. Biologically significant distribution records for amphibians and reptiles in northwest Texas. Herpetologica 20:42-47.

Texas Natural Resources Information System. 2008. TNRIS home page. Texas Water Development Board, Austin. <http://www.tnris.state.tx.us>. Accessed 26 August 2008.

Texas Parks and Wildlife Department. 2007a. Endangered and threatened reptiles and amphibians in Texas and the United States. Texas Parks and Wildlife Department, Austin. <http://www.tpwd.state.tx.us/huntwild/wild/species/endang/animals/reptiles_amphibians/>. Accessed 26 August 2008.

———. 2007b. Historic blooms in Texas: historical fish kill events involving the golden algae, *Prymnesium parvum*, in Texas. Texas Parks and Wildlife Department, Austin. <http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/ga/blooms.phtml>. Accessed 15 January 2009.

Texas Water Development Board. 2007. Water for Texas 2007. Texas Water Development Board, Austin.

Trapido, H. 1941. A new species of *Natrix* from Texas. American Midland Naturalist 25:673-680.

U.S. Geological Survey. 2008. USGS water data for Texas. <http://waterdata.usgs.gov/tx/nwis/>. Accessed 08 December 2008.

Upton, S. J., C. T. McAllister, P. S. Freed, S. M. Barnard. 1989. *Cryptosporidium* spp. in wild and captive reptiles. Journal of Wildlife Diseases 25:20-30.

Wade, V. E. 1968. A range extension of the water snake, *Natrix harteri harteri* Trapido. Texas Journal of Science 20:194-196.

Werler, J. E., and J. R. Dixon. 2000. Texas Snakes: Identification, Distribution, and Natural History. University of Texas Press, Austin.

Whiting, M. J. 1993. Population ecology of the Concho Water Snake, *Nerodia harteri paucimaculata*. Unpublished thesis, Texas A&M University, College Station.

Whiting, M. J., J. R. Dixon, and B. D. Greene. 1997. Spatial ecology of the Concho Water Snake (*Nerodia harteri paucimaculata*) in a large lake system. Journal of Herpetology 31:327-335.

Whiting, M. J., J. R. Dixon, B. D. Greene, J. M. Mueller, O. W. Thornton, Jr., J. S. Hatfield, J. D. Nichols, and J. E. Hines. 2008. Population dynamics of the Concho Water Snake in rivers and reservoirs. Copeia 2008:438-445.

Willette-Frahm, M. 1995. Blood collection techniques in amphibians and reptiles. In J. D. Bonagura and R. W. Kirk (eds.), Kirk's Current Veterinary Therapy XII Small Animal Practice, pp. 1344-1348. W. B. Saunders Company, Philadelphia, PA.

Woodhouse, C. A., and J. T. Overpeck. 1998. 2000 years of drought variability in the Central United States. Bulletin of the American Meteorological Society 79:2693-2714.

Worley, M. 1970. In search of *Natrix harteri*. Bulletin of the Chicago Herpetological Society 5:41-43.

APPENDIX 1

TABLE 5. Data for individual *N. h. harteri* captured along the upper Brazos River drainage, Texas, 2006-2008.

			Length (mm)[b]								Rock size (cm)[e]		
Date	County[a]	Coordinates	SVL	T	TL	T:TL[c]	Mass (g)	Sex	Age	MF no.[d]	T	L	S
1. 03 Sep 2006	PP	32°49.60′N 98°21.07′W[f]	730	201	931[g]	0.216	180.0	F	ad	-	-	-	-
2. 16 Sep 2006	PA	32°42.40′N 98°03.28′W	255	93	348	0.267	12.0	M[h]	juv	-	7	62	48
3. 16 Sep 2006	PA	32°42.40′N 98°03.28′W	245	78	323	0.241	9.5	F	juv	-	8	61	60
4. 16 Sep 2006	PA	32°42.37′N 98°03.26′W	248	78	326	0.239	9.0	F	juv	-	10	34	33
5. 07 Oct 2006	PA	32°38.91′N 98°01.21′W[f]	268	100	368	0.272	12.0	M[h]	juv	-	11	41	22
6. 07 Oct 2006	PA	32°38.91′N 98°01.21′W[f]	264	90	354	0.254	9.5	F	juv	-	6	35	25
7. 07 Oct 2006	PA	32°38.91′N 98°01.21′W[f]	249	82	331	0.248	9.5	F	juv	-	7	41	15
8. 22 May 2007	PP	32°46.26′N 98°11.70′W[f]	642	204	846	0.241	200.0	F	juv	-	-	-	-
9. 31 Jul 2007	PP	32°48.52′N 98°23.98′W	407	133	540	0.246	48.0	F	juv	-	-	-	-
10. 15 Sep 2007	PP	32°48.69′N 98°20.58′W	577	174	751	0.232	125.0	F[h]	ad	-	-	-	-
11. 08 Apr 2008	PP	32°45.05′N 98°10.25′W[f]	805	235	1040[g]	0.226	320.0	F	ad	27370	-	-	-
12. 08 May 2008	PP	32°48.46′N 98°23.90′W	248	91	339	0.268	7.5	M	juv	27371	7	30	22
13. 08 May 2008	PP	32°48.46′N 98°23.90′W	301	112	413	0.271	13.0	M[h]	juv	27372	6	46	37
14. 09 May 2008	PP	32°49.53′N 98°21.05′W[f]	470	160	630	0.254	63.0	M	ad	27373	-	-	-
15. 09 May 2008	PP	32°50.04′N 98°20.20′W	637	182	819	0.222	150.0	F	ad	27374	-	-	-
16. 14 May 2008	SO	32°14.62′N 97°41.03′W[f]	568	211	779	0.271	98.0	M	ad	27375	-	-	-
17. 14 May 2008	SO	32°14.55′N 97°40.95′W[f]	715	187	902	0.207	210.0	F	ad	27376	-	-	-
18. 14 May 2008	SO	32°14.60′N 97°41.03′W[f]	690	200	890	0.225	195.0	F	ad	27377	-	-	-

TABLE 5. Continued.

Date	County[a]	Coordinates	Length (mm)[b]			T:TL[c]	Mass (g)	Sex	Age	MF no.[d]	Rock size (cm)[e]		
			SVL	T	TL						T	L	S
19. 15 May 2008	PP	32°54.53′N 98°29.57′W	582	165	747	-	105.0	M	ad	27378	-	-	-
20. 15 May 2008[i]	PP	32°54.53′N 98°29.57′W	-	-	-	-	-	-	ad	-	-	-	-
21. 15 May 2008[i]	PP	32°58.37′N 98°24.78′W	-	-	-	-	-	-	ad	-	-	-	-
22. 16 May 2008[i]	PP	32°54.58′N 98°29.67′W	-	-	-	-	-	-	ad	-	-	-	-
23. 16 May 2008[j]	PP	32°54.53′N 98°29.58′W	-	-	-	-	-	-	-	-	-	-	-
24. 16 May 2008	PP	32°58.25′N 98°24.98′W	617	195	812	0.240	148.0	F	ad	27379	-	-	-
25. 16 May 2008[i]	PP	32°58.24′N 98°25.02′W	-	-	-	-	-	-	ad	-	-	-	-
26. 16 May 2008	PP	32°58.24′N 98°25.02′W	555	171	726	-	108.0	M	ad	27380	-	-	-
27. 16 May 2008	PP	32°57.91′N 98°23.51′W	518	146	664	-	80.0	M	ad	27381	-	-	-
28. 20 May 2008	HA	33°05.08′N 99°32.54′W	257	80	337	0.237	10.5	F	juv	27382	12	40	24
29. 20 May 2008	HA	33°05.72′N 99°31.48′W[f]	417	142	559	0.254	57.0	M	ad	27383	7	117	78
30. 20 May 2008	HA	33°05.76′N 99°31.36′W[f]	333	93	426	0.218	23.5	F	juv	27384	4	49	34
31. 20 May 2008[k]	HA	33°05.76′N 99°31.37′W[f]	-	-	-	-	-	-	-	-	-	-	-
32. 20 May 2008[l]	HA	33°05.76′N 99°31.37′W[f]	-	-	-	-	-	-	juv	-	-	-	-
33. 20 May 2008	HA	33°05.76′N 99°31.37′W[f]	303	91	394	0.231	19.5	F	juv	27385	7	110	58
34. 21 May 2008	HA	33°05.99′N 99°31.21′W[f]	276	91	367	0.248	15.5	M	juv	27386	6	44	26
35. 21 May 2008	HA	33°06.01′N 99°31.21′W[f]	578	227	805	0.282	130.0	M	ad	27387	-	-	-
36. 23 May 2008	JO	32°40.60′N 99°37.04′W[f]	524	183	707	0.259	90.0	M	ad	27388	-	-	-
37. 23 May 2008	SH	32°49.60′N 99°33.73′W[f]	555	136	691	-	118.0	F	ad	27389	-	-	-

TABLE 5. Continued.

Date	County[a]	Coordinates	Length (mm)[b] SVL	T	TL	T:TL[c]	Mass (g)	Sex	Age	MF no.[d]	Rock size (cm)[e] T	L	S
38. 27 May 2008	TH	32°59.98'N 99°23.39'W[f]	494	185	679	0.272	68.0	M	ad	27390	-	-	-
39. 03 Jun 2008	PA	32°42.38′N 98°03.24′W	386	73	459	-	32.0	M	ad	27391	15	82	72
40. 03 Jun 2008	PA	32°42.40′N 98°03.28′W	455	141	596	0.237	52.0	F	juv	27392	10	58	49
41. 03 Jun 2008	PA	32°42.43′N 98°03.34′W	374	136	510	0.267	29.0	M	juv	27393	14	127	58
42. 03 Jun 2008	PA	32°42.42′N 98°03.30′W	439	152	591	0.257	50.0	M	ad	27394	12	61	46

[a]PP = Palo Pinto, PA = Parker, SO = Somervell, HA = Haskell, JO = Jones, SH = Shackelford, TH = Throckmorton.
[b]SVL = snout-vent length, T = tail length, TL = total length.
[c]Tail length:total length ratio calculated for snakes with complete tails.
[d]MF Tissue Catalog no. at Texas State University - San Marcos Department of Biology (Michael Forstner, curator).
[e]T = thickness, L = long axis, S = short axis.
[f]New locality record ≥1 km from previously reported records.
[g]> largest known specimen (Werler and Dixon, 2000).
[h]Corrected sex based on tail length:total length ratio.
[i]Observation only.
[j]Recapture of no. 19.
[k]Recapture of no. 29.
[l]Escaped after capture.

APPENDIX 2

FIGURE 7. Photograph of the largest *N. h. harteri* captured along the upper Brazos River drainage, Texas, in hand for scale reference, 2006-2008. Total length = 1040 mm.

APPENDIX 3

Pictures of habitat encountered during this study and examples of habitat occupied by *N. h. harteri*.

FIGURE 8. *Nerodia h. harteri* habitat along Deadman Creek near the Rising Sun Cemetery, Jones County, Texas, May 2008.

FIGURE 9. Muddy flat upstream of dam on Paint Creek, Haskell County, Texas, approximately 2 km below Lake Stamford Dam, May 2008.

FIGURE 10. *Nerodia h. harteri* habitat along Paint Creek, Haskell County, Texas, May 2008.

FIGURE 11. Historic locality of *N. h. harteri* along the Clear Fork of the Brazos River at an old dam and grist mill near Lueders, Jones County, Texas, looking downstream, May 2008.

FIGURE 12. Historic locality of *N. h. harteri* along the Clear Fork of the Brazos River at an old dam and grist mill near Lueders, Jones County, Texas, looking upstream, May 2008.

Figure 13. Historic locality of *N. h. harteri* along the Clear Fork of the Brazos River at Paint Crossing on the Lambshead Ranch, Throckmorton, County, Texas, April 2008.

FIGURE 14. Example of one of the seven low-head dams along the Clear Fork of the Brazos River within the range of *N. h. harteri*, April 2008. This dam is east of the U.S. Highway 183 crossing, Stephens County, Texas.

FIGURE 15. *Nerodia h. harteri* habitat in Possum Kingdom Lake along the mouth of Ramsey Creek, Palo Pinto County, Texas, May 2008.

FIGURE 16. *Nerodia h. harteri* habitat in Possum Kingdom Lake near the end of Farm-to-Market 1148, Palo Pinto County, Texas, with a snake peering out from the rocks at the center of the photograph, May 2008.

FIGURE 17. *Nerodia h. harteri* habitat in Possum Kingdom Lake near the end of Farm-to-Market 1148, Palo Pinto County, Texas, May 2008.

FIGURE 18. *Nerodia h. harteri* habitat along the Brazos River at Fortune Bend, Palo Pinto County, Texas, May 2008.

FIGURE 19. *Nerodia h. harteri* habitat along the Brazos River at Dalton Bend, Palo Pinto County, Texas, May 2008.

FIGURE 20. *Nerodia h. harteri* habitat along the Brazos River at Littlefield Bend, Parker County, Texas, September 2006.

FIGURE 21. Historic locality of *N. h. harteri* along the Brazos River at the U.S. Highway 67 crossing east of Glen Rose, Somervell County, Texas, May 2008.

FIGURE 22. Historic locality of *N. h. harteri* along the Brazos River at the old Farm-to-Market 200 crossing, east of Rainbow, Somervell County, Texas, May 2008. Note the new Farm-to-Market 200 crossing in the background.

FIGURE 23. *Nerodia h. harteri* habitat along the Brazos River east of Glen Rose, Somervell County, Texas, May 2008.