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Distribution, Habitat, and Future of Harter's Water Snake, *Nerodia harteri*, in Texas

NORMAN J. SCOTT, JR.,[1] TERRY C. MAXWELL,[2] OKLA W. THORNTON, JR.,[3] LEE A. FITZGERALD,[4] AND JOHN W. FLURY[2]

[1]*National Ecology Research Center, U.S. Fish and Wildlife Service, Museum of Southwestern Biology, University of New Mexico, Albuquerque, New Mexico 87131, USA*
[2]*Department of Biology, Angelo State University, San Angelo, Texas 76909, USA*
[3]*Colorado River Municipal Water District, Big Spring, Texas 79721, USA*
[4]*Department of Biology, University of New Mexico, Albuquerque, New Mexico 87131, USA*

ABSTRACT.—**Detailed studies of the distribution and habitat use of the endemic Texas snake *Nerodia harteri* were conducted from 1979 to 1987. The Brazos water snake *N. h. harteri* is restricted to the upper Brazos River drainage; it is found in about 303 km of stream plus two reservoirs, Possum Kingdom Lake and Lake Granbury. The Concho water snake, *N. h. paucimaculata* occupies 396 stream-km in the Concho-Colorado River drainage, and about 25 km of lake. As such, Harter's water snake has one of the smallest ranges of any North American snake species.**

Medium to large, flat rocks on an unshaded shore for hiding places and rocky shallows for feeding grounds appear to be important for juveniles. There is an ontogenetic habitat shift in *N. harteri* that may also be common in many other *Nerodia*. We found that adult *N. harteri* are not restricted to rocky riffles in flowing rivers but can inhabitat a much wider range of habitats in pools and lakes. Several sections of both the Brazos and Colorado rivers are uninhabited by *N. harteri*, apparently because juvenile habitat is lacking or scarce. Riffles are more isolated on the uninhabited stretches, and they may be too far apart to recolonize after catastrophic local population extinctions.

Past dam projects have eliminated populations of *Nerodia harteri* through habitat destruction by inundation and siltation. Fragmentation of populations may also prevent recolonization after local extinctions. A major dam being constructed on the Colorado River near Stacy, McCullough County, will inundate about 18% of the known habitat of *Nerodia h. paucimaculata* and perhaps degrade another 8% or more. A unique agreement whereby the dam-constructing authority will construct artificial habitats and fund biological studies could ameliorate the negative effects of the dam and reservoir on populations of the Concho water snake.

The only endemic Texas snake, Harter's water snake (*Nerodia harteri*), is known from the upper reaches of two river basins in the center of the state. Two subspecies are recognized: the Brazos water snake (*Nerodia harteri harteri*) in the upper Brazos River drainage, and the Concho water snake (*Nerodia harteri paucimaculata*) in the upper Concho-Colorado River drainage.

The species was discovered in 1936 in the Brazos River in Palo Pinto County, Texas, and described in 1941 (Trapido, 1941; Fig. 1). The Colorado-Concho form of *N. harteri* was found in 1942 (Marr, 1944) and described as *N. h. paucimaculata* by Tinkle and Conant (1961) from Robert Lee, Coke County, Texas (Fig. 2). Few collections were made of either subspecies, and little was known of the species until Williams (1969) completed an ecological study of *N. harteri* in the Colorado River at Robert Lee.

Although knowledge of the total distribution and population status was sketchy, a general concern for the survival of the species developed among several Texas biologists. Formal concern was expressed in 1975 when the Texas

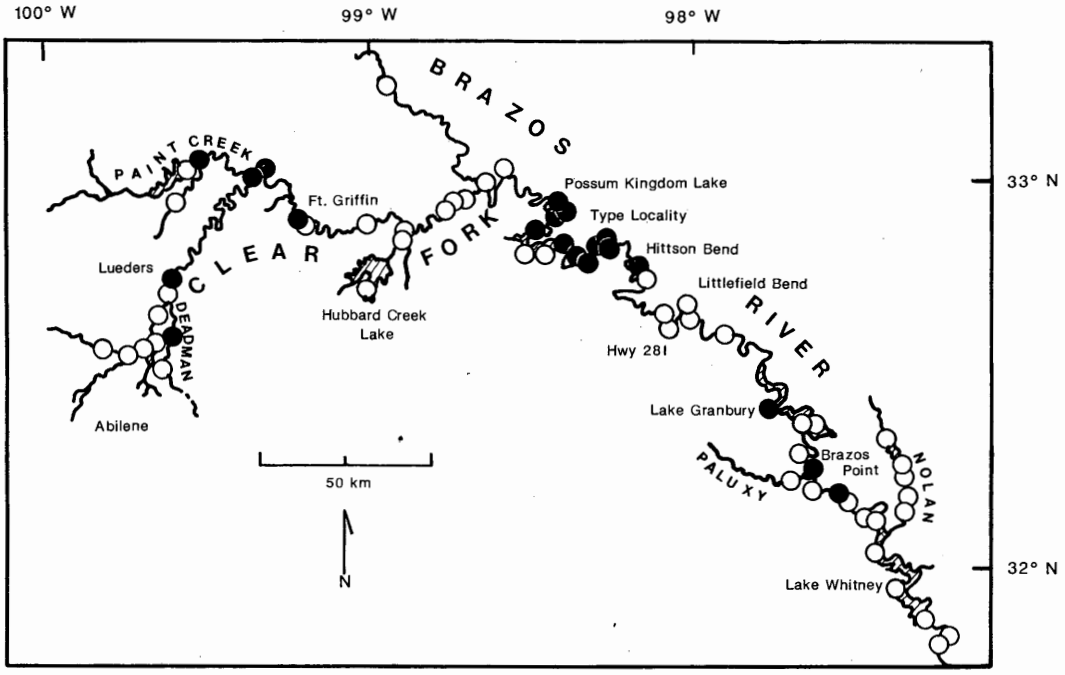

FIG. 1. Map of localities in Brazos River drainage, Texas, that were visited during this study, 1979–1987. Open circles indicate sites where *Nerodia harteri harteri* was not found; closed circles, where they were found. One circle may cover several adjacent sites. Localities on temporary streams where snakes were not found are not mapped.

Organization for Endangered Species placed *N. h. paucimaculata* on their list of threatened fauna. Two years later, the State of Texas placed both subspecies on the state list of endangered species.

This identified concern for the species, the lack of detailed populational and distributional data, and the imminent construction of at least one major dam within the range of *N. harteri*, prompted the U.S. Fish and Wildlife Service to sponsor several studies designed to fill the informational gaps. Using the results of these studies, the Service determined the Concho-Colorado River subspecies, *N. h. paucimaculata*, to be a threatened species (Stefferud, 1986). Subsequently, the Colorado River Municipal Water District initiated studies to further delineate the distribution of the subspecies. These studies provide a more detailed picture of the distribution and habitat of *N. harteri* than is known for any other snake species in the world. This paper discusses historic and current geographic distribution, habitat use, changes in populations through time, the effects of stream management practices, and the future of *N. harteri*.

MATERIALS AND METHODS

Field studies were carried out in the warm months between April 1979 and October 1987 by 1–10 person teams from Angelo State University; the National Ecology Research Center, Albuquerque; and the Colorado River Municipal Water District. The primary search technique consisted of looking for river access in preselected stretches of river or lakeshore, subjectively assessing the habitat for its suitability for *N. harteri*, then searching suitable habitat. Unsuitable habitat also was searched opportunistically to ensure that our habitat evaluations were accurate. The beginning and ending times of each search period were recorded. Search periods varied in duration and consisted of intensive search (turning stones, moving trash piles, peering in crevices) and movement between habitat patches. Six hundred thirty timed searches were made, 108 at night. This "time-constrained" technique provided a rough estimate of relative snake densities (Campbell and Christman, 1982). An additional 78 untimed searches were made. Descriptions of the habitat were recorded at each site.

Time-constrained searches were supplemented by visual searches while canoeing. Two people traveled by canoe down a river or along the shore of a lake and searched suitable habitat. The goal was to establish the presence of *N. harteri*, and only the total time spent on the entire trip was recorded. Thirty-five canoe trips were made, varying from 30 min to over 9 hr per day and up to 3.5 days in duration.

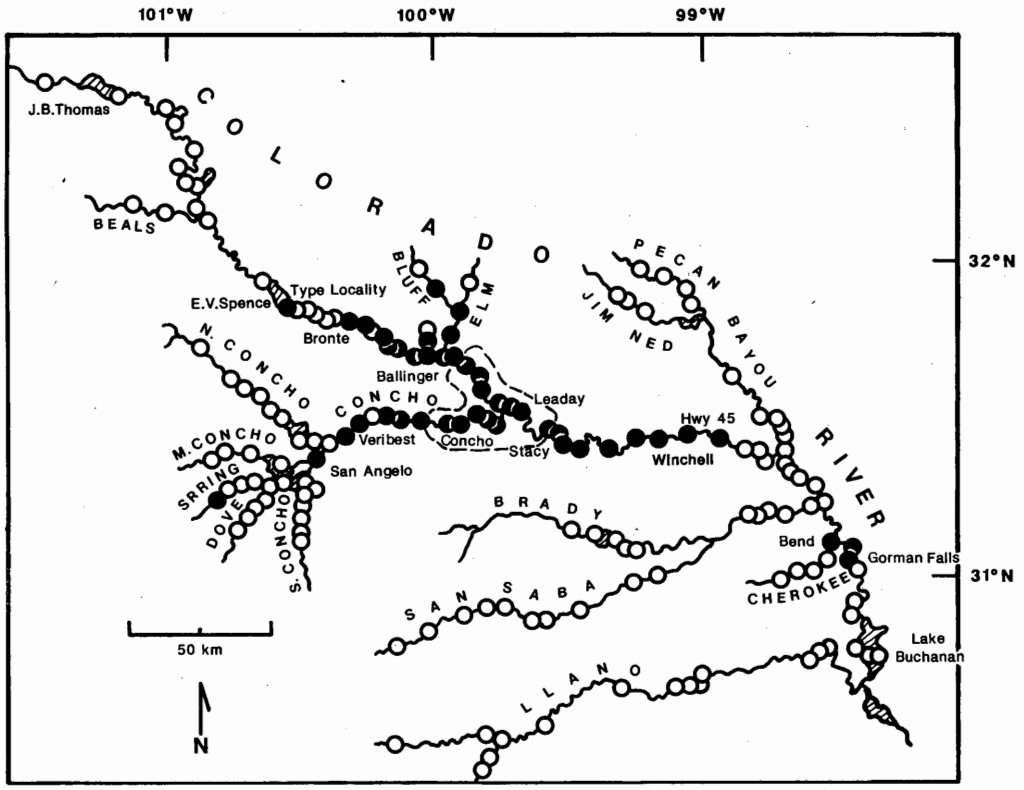

FIG. 2. Map of localities in Colorado River drainage, Texas, that were visited during this study, 1979–1987. Open circles indicate sites where *Nerodia harteri paucimaculata* was not found; closed circles, where they were found. One circle may cover several adjacent sites. The dashed line roughly delineates the area to be flooded by Stacy Dam. Surveyed sites on temporary streams where snakes were not found are not mapped.

Although the time-constrained surveys provide rough estimates of relative snake densities, they will not be used here to evaluate the status of the species since the relationship of relative densities to real densities is variable and unknown. Factors contributing to the variation include time of year, habitat configuration, water levels, and weather. Precise population estimates are much more demanding and depend on special conditions, such as a high probability of recapture, to be successful (Williams, 1969; Scott, unpubl. data). Instead, we chose to use the linear extent of occupied habitat as the primary measure of the distribution of the species, and the influences of various factors were assessed by their effect on the extent of occupied habitat.

Riffles, rock slides, rocky shelves, and gravel bars identified from aerial surveys were mapped on USGS 7½′ or 15′ topographic maps. Pecan Bayou below Brownwood, Brown County, and the Colorado River from the mouth of the Concho River to Lake Buchanan were surveyed from a Cessna 172 on 17 May 1985. Water levels were low. The Concho River downstream from the confluence of the North and South Concho was mapped from a helicopter on 17–18 September 1986, when water levels were high. The resulting river maps were partitioned into 5 km sections and the habitat in each section was tabulated. Three size classes of riffles were distinguished: small, less than 15 m in length; medium, 15–150 m; and large, greater than 150 m. The riffle frequency of river sections known to contain *N. h. paucimaculata* was compared by the Mann-Whitney *U*-test to sections lacking the snake.

The middle of the study period coincided with an intense drought in west-central Texas. Rain was much below normal in much of 1983, 1984, and 1985; and streams and rivers that were usually perennial ceased to flow. Flow in the Concho River at Paint Rock decreased gradually over the period until there was no recorded flow during 13 days in September 1984 and 29 days in August–September 1985, and many former riffles were dry. The Colorado River at Ballinger had no flow for 17 days in 1983 and for 18 days in 1984, but flowed every day in 1985. Overall in 1983–1984, annual discharges varied be-

tween 27% and 54% of normal at two gauging stations on the Concho River and between 13% and 28% of normal at four stations on the Colorado River (U.S. Geological Survey, 1984*a*; Buckner et al., 1985, 1986*a*). Much of the Brazos inhabited by *N. h. harteri* received a minimum flow of about 0.4 m^3/sec from Possum Kingdom Lake, but there were many larger pulses of water for power generation and release of storm flows (Buckner et al., 1986*b*). Flows in 1986 and 1987 returned to normal or above.

Snakes captured during 1983–1987 were sexed, measured, and usually weighed. Females were palpated for reproductive condition. These data will be presented separately. Before 1986, specimens were palpated for stomach contents, locality voucher specimens of *N. harteri* were taken, and individuals found dead were salvaged; they were deposited at Angelo State University or in the Museum of Southwestern Biology at the University of New Mexico (Appendix 1).

Letters of inquiry concerning specimens of *N. harteri* were sent to 56 museums and 46 replies were received.

Historic Distribution

The historic distribution of *N. harteri* is impossible to reconstruct fully. The Concho water snake may have been more widely distributed, but E. V. Spence Reservoir upstream and Lake Buchanan downstream have inundated many kilometers of potential habitat at both ends of the current range. No such limits to the distribution of the Brazos water snake are obvious on the upstream part of its range, but Lake Whitney below the most downstream record may have flooded former habitat, and recent changes in river flows may have caused extinctions outside the known range.

Mecham (1983) summarized the distribution of *N. harteri* based on published records and a few museum records; his map can be used as a representation of the snake's known distribution at that time. Since then, Smith (1983) published a 30 km range extension on Paint Creek in the Brazos River drainage. Tennant (1984) added several county records, but they were apparently not supported by either specimens or specific locality data. Dixon (1987) presented a more accurate map of county records supported by specimens.

The most upstream published locality for *Nerodia harteri harteri* was in Haskell County on Paint Creek, about 30 km above its mouth (Smith, 1983; Fig. 1). *Nerodia h. harteri* was also known from the Clear Fork of the Brazos below the mouth of Paint Creek in Throckmorton County (Tinkle and Knopf, 1964). The most downstream site on the main Brazos River was at a crossing 6 mi east of Glen Rose, above the mouth of the Paluxy River in Somervell County (Wade, 1968).

Nerodia harteri paucimaculata was collected from the South Concho River and Dove Creek which are tributaries to the Concho River west of San Angelo (Marr, 1944; Tinkle and Conant, 1961; Fig. 2). The farthest upstream records on the Colorado River were for the type locality of the subspecies south of Robert Lee, Coke County (Tinkle and Conant, 1961). Downstream, snakes were known as far as Gorman Falls, San Saba County (Mecham, 1983). The distributions between these end points were poorly known. Ten localities for *N. h. harteri* and nine for *N. h. paucimaculata* have been published previously (Appendix 1).

Thirty-two museums contained 758 specimens of *N. harteri*. Sixty-nine percent (524) came either from the type locality of *N. harteri* on the Brazos River north of Palo Pinto (Fig. 1) or the type locality of *N. h. paucimaculata* on the Colorado River below Robert Lee (Fig. 2). The remaining specimens included 38 specific locality records, which were confirmed by our field work with one exception: TCWC 8713 from the sandy riverbed at the Highway 281 crossing of the Brazos below Mineral Wells. We were unable to find *N. harteri* in this area, where the river flows through a sandy or muddy bed, but their occasional presence here is corroborated by a literature record from Littlefield Bend in Palo Pinto or Parker County (Wade, 1968).

Present Distribution

Most of the sites where we found Harter's water snake were along perennial rivers and streams, but populations were also found living along the shores of four of 20 reservoirs searched: Possum Kingdom Lake, Lake Granbury, Moonen Lake (near Ballinger), and E. V. Spence Reservoir (Figs. 1, 2). With one exception, an extensive survey of intermittent streams in the Brazos and Colorado drainages failed to yield *N. harteri* (Appendix 2). The exception was a Concho water snake found in Grape Creek, Coleman County, about 1 km upstream from its confluence with the Colorado River. The snake was probably driven up this normally dry streambed by flood flows on the Colorado.

In the discussion below, we give a detailed description of the present distribution of *N. harteri*. Within each major drainage, the text describes the upstream and downstream limits of the species, followed by a summary, including tributaries, of the overall distribution within these limits.

Brazos River Drainage (Fig. 1).—Upstream, on the Clear Fork of the Brazos River, we found *N. h. harteri* at Lueders, Shackelford County,

TABLE 1. Stream- and lake-kilometers inhabited by *Nerodia h. harteri* in the Brazos River drainage in central Texas, and the length of uninhabited river between population segments. Lake-kilometers are measured along the stream channel flooded by the lake. Each barrier is a significant natural or man-made gap in the distribution that may be sufficient to prevent gene flow.

	Inhabited kilometers	Uninhabited kilometers
Deadman Creek	16	
Barrier—Lake Shackelford		25
Clear Fork of the Brazos and Brazos River		
Lueders to Fort Griffin	132	
Paint Creek	32	
Barrier—Brazos River		
Fort Griffin to headwaters of Possum Kingdom Lake		184
Upper Possum Kingdom Lake	17	
Barrier—Lower Possum Kingdom Lake and Morris Sheppard Dam		31
Brazos River		
Morris Sheppard Dam to Hittson Bend	75	
Barrier—Brazos River		
Hittson Bend to upper Lake Granbury		100
Lake Granbury	53*	
Brazos River		
De Cordova Bend Dam to headwaters of Lake Whitney	48	
Totals		
Stream-kilometers	303	—
Lake-kilometers	70*	—
Totals	373*	340

* These are maximum figures because the exact distribution in Lake Granbury is unknown.

which is about 90 stream-km above the previous record in Throckmorton County (Tinkle and Knopf, 1964). Above Lueders, the Brazos River is impounded (Lake Shackelford), but we took specimens on Deadman Creek, a tributary to the Clear Fork of the Brazos near Lake Fort Phantom Hill north of Abilene. This locality is about 26 stream-km above Lueders and is the farthest upstream record in the Brazos drainage. Smith (1983) published records of specimens taken in 1956–1968 from Paint Creek just below Lake Stamford Dam, Haskell County. We also found *N. h. harteri* on Paint Creek about 2 km below the dam and the species is probably found throughout approximately 32 km of Paint Creek below the dam.

Downstream, Wade (1968) recorded a specimen from 6 mi east of Glen Rose (probably at the US 67 bridge over the Brazos River), Somervell County, which was the farthest downstream that the species was known on the Brazos. We found specimens at the Farm Road 200 crossing east of Rainbow and at the Farm Road 1118 bridge east of Brazos Point, Bosque County. The latter is about 26 stream-km downstream from Wade's (1968) locality. Much of the riverbed in this area is scoured and lacks concealing rocks, and a few kilometers downstream the river is impounded by Lake Whitney. We did not find it in the Paluxy and Nolan rivers, which are the main tributaries to the Brazos in this area. At one time, *N. h. harteri* may have occurred further downstream, but the construction of Lake Whitney and other downstream impoundments may have extirpated these populations.

Although an apparently isolated colony of *N. h. harteri* is known from Deadman Creek, Jones County, near Abilene, any long, continuously inhabited stretches of the Clear Fork of the Brazos probably start 25 km downstream at Lueders, Shackelford County, below Lake Shackelford (Table 1). From there downstream, habitat and populations are more or less continuous to near Fort Griffin, Shackelford County, a distance of about 132 stream-km. They are probably also present along approximately 32 km of Paint Creek below Lake Stamford, Haskell County. The snake is probably not found in the Salt and Double Mountain forks of the Brazos, as these rivers are intermittent and flow in generally sandy or muddy beds without the gravelly riffles used by *N. h. harteri.* The 184 km stretch from Fort Griffin to the uppermost reaches of Possum Kingdom Lake does not appear to contain *N. h. harteri,* probably because most of the Clear Fork and Brazos rivers flow in a sandy or muddy channel with little rock. *Nerodia h. harteri* occurs along about 17 km at the upper end of Possum Kingdom Lake, but we did not find it on the lower lake. River habitat for *N. h. harteri* starts at Morris Sheppard Dam on Possum Kingdom Lake and extends downstream about 75 km to Hittson Bend below

Mineral Wells. Downstream from Hittson Bend, the riverbed is generally quite sandy and the populations are few and localized as far as Lake Granbury, a distance of about 100 km. *Nerodia h. harteri* occurs in Lake Granbury and downstream about 48 km to near Brazos Point. At maximum, *N. h. harteri* inhabits about 303 km of stream, plus two reservoirs. This area is not continuously inhabited as the rocky riffles important for juvenile *N. h. harteri* ordinarily compose only about 5–10% of any long stretch of river and many lakeshores do not provide suitable habitat.

Colorado River Drainage (Fig. 2).—Considerable effort was spent surveying the Colorado River and its tributaries above E. V. Spence Reservoir. The aquatic habitat in this part of the upper Colorado drainage has been drastically altered by the three large reservoirs in the area: Lake Colorado City, Champion Creek Reservoir, and Lake J. B. Thomas. Because droughts often occur in the area, there are long periods when no water is released from the dams. Tributaries surveyed included Champion Creek, which is impounded, and Beals Creek. Immediately above Lake Thomas, Borden County, on the main stem of the Colorado River, the riverbed is an arid wash. Here the river is too dry for too long to support water snake populations. The four crossings we visited between E. V. Spence and Champion Creek reservoirs and between Lake Thomas and Lake Colorado City were completely dry except for rain puddles.

Beals Creek at State Highway 163 was flowing in mid-August 1984. The stream at this locality had numerous bends and short riffles (less than 10 m in length) between 2 m deep pools. Willows (*Salix*) and salt cedars (*Tamarix*) lined the banks. Four observers searching 45 min each found no snakes. Beals Creek at Farm Road 821 runs through an oil field and is straight and ditch-like. The banks are lined with willow and salt cedar, and the creek bed is muddy. Again, no snakes were found.

Previous studies found abundant *N. h. paucimaculata* immediately below Robert Lee, Coke County (Tinkle and Conant, 1961; Williams, 1969). Since then, the construction of E. V. Spence Dam about 4 km upstream has altered the Colorado River near Robert Lee, such that neither Brnovak (1975) nor we found *N. h. paucimaculata* in the Colorado River any farther upstream than the vicinity of Bronte, Coke County, which is about 27 stream-km below Robert Lee. However, we did discover an isolated population along 24 km of Lake E. V. Spence (Table 2).

Below Bronte, populations appear to be fairly continuous to about the Highway 45 bridge upstream from the mouth of Pecan Bayou, Mills County, a distance of approximately 256 stream-km. Elm and Bluff creeks, Runnels County, are inhabited about 29 km above their mouths, and *N. h. paucimaculata* is found in newly created Lake Moonen near Ballinger. Concho water snakes are probably absent in the 129 km between the Highway 45 bridge over the Colorado River and Bend, San Saba County. At Bend, Sulphur Springs, and Gorman Falls 18 km of stream, at most, have populations.

Concho River Drainage.—Although specimens exist for *N. h. paucimaculata* from Dove Creek (Tinkle and Conant, 1961) and the South Concho River (Marr, 1944) above San Angelo in Tom Green County, we were unable to find the species despite intensive canoe and shoreline searches. F. L. Rose (pers. comm.) in 1985 found two *N. h. paucimaculata* on Spring Creek, Irion County, a tributary to Twin Buttes Reservoir above San Angelo. The geographic extent of the Spring Creek population is not known, but surveys in the vicinity indicate that the habitat is limited to at most 2 km of stream. This is farther upstream in the Concho River drainage than any other recent record.

Although the Concho River has been dammed and channelized within the city of San Angelo, a population of Concho water snakes persists just below the Bell Street bridge. This colony and the Spring Creek population are probably isolated enough to preclude genetic exchange with other populations. In the Concho River below San Angelo, we could not find Concho water snakes for about 8 km. From this point they are present in all suitable habitat to the mouth, a distance of about 90 km.

Pecan Bayou.—Pecan Bayou is a major tributary to the Colorado River. It is controlled by a high dam near Brownwood, Brown County. Below Lake Brownwood, water flows are normally low or nonexistent. Much of Pecan Bayou flows in a mud-banked channel with no habitat for Harter's water snake, but some riffles near the mouth appear promising. However, 10 surveys at road crossings and a short canoe trip on Pecan Bayou failed to yield any trace of the species.

San Saba and Llano Rivers.—The San Saba and Llano rivers are clear-flowing tributaries to the Colorado River. They have continuous flows, even in drought periods. Parts of these rivers have muddy, tree-lined banks, but other stretches flow over extensive gravel beds or through bedrock channels with little or no loose rocks. Some parts of each river appear to contain suitable *N. harteri* habitat. We searched many parts of the Llano and San Saba rivers without finding *N. harteri.* During this study, we visited 12 sites on the San Saba and eight on the Llano without finding *N. harteri.* These included six short canoe surveys. Brady Creek, a perennial

TABLE 2. Stream-kilometers inhabited by *Nerodia h. paucimaculata* in the Concho-Colorado River drainage in central Texas, and the locations and lengths of barriers between population segments. The barriers are distributional gaps which are either a lack of suitable juvenile snake habitat or large impoundments.

	Inhabited kilometers	Uninhabited kilometers
Colorado River Drainage		
Lake E. V. Spence	24	
Barrier—E. V. Spence Dam to Bronte		31
Bronte to Highway 45	256	
Lake Moonen	1	
Elm and Bluff Creeks	29	
Barrier—Highway 45 to Bend		129
Bend to Gorman Falls	18	
Concho River Drainage		
Spring Creek	2*	
Barrier—Lower Spring Creek, Twin Buttes Reservoir, Lake Nasworthy		63
City of San Angelo	1*	
Barrier—City of San Angelo effluent to Highway 380		8
Highway 380 to mouth	90	
Totals		
Stream-kilometers	396*	—
Lake-kilometers	25	—
Totals	421	231

* These are maximum figures because exact distributions in Spring Creek and in the City of San Angelo are unknown.

tributary to the San Saba, was surveyed at four sites without finding *N. harteri* or appropriate habitat.

Lakes and Reservoirs.—Previous workers have assumed that the impoundment of rivers inhabited by *N. harteri* eliminated the species in the inundated portions (Williams, 1969; Mecham, 1983; Tennant, 1984, 1985). During this study, we surveyed the shorelines of 20 lakes behind high dams that were capable of completely stopping all water flows in the streams that they controlled (Appendix 3). We also surveyed the impoundments behind numerous low water dams that restrict low flows but allow flood waters to pass. We found *Nerodia h. harteri* in two large reservoirs, Possum Kingdom Lake and Lake Granbury, and behind several of the low flow dams, and *Nerodia h. paucimaculata* is present in Lake E. V. Spence and Moonen Lake.

HABITAT

All *N. harteri* observed were either swimming or on land within 3 m of the shoreline of a river or lake, and the great majority were within 1 m of water. They may go a short distance up intermittent streams during high water flows, but we only found a single Concho water snake in the more than 50 temporary streams we examined.

In riparian habitats, juveniles were most often found under small, flat rocks next to shallow water flowing over a rocky substrate. They were seldom seen swimming in the daytime nor were they taken from deep crevices or under large (greater than 0.4 m diameter) rocks. They were never found on steeply sloped shorelines. In at least three instances, juvenile *N. harteri* were taken from under the only rock or log large enough to hide them on the whole beach.

Adults were more widespread. They were more often seen swimming during the day, often in water more than 1 m deep, and their rocky refuges were generally deeper and more secure than those of the juveniles. Effectively, the more large rocks we turned, the more adult snakes we found. In spring, fall, and after cool periods in the summer, subadult and adult *N. harteri* basked as much as 2 m high on the limbs of trees overhanging the water. Juveniles never were seen in this situation.

The habitat of *N. harteri* was similar in the four lakes where they were observed. Most of the snakes were found under small or large, flat slabs of rock within 1 m of the water. A few adults and subadults were taken as they foraged (as evidenced by prey in their mouths) or swam in deep water, and other adults were taken from beneath rocks, beached boats, or from the foundations of boathouses. The rocky cover where we found juvenile *N. harteri* was both bedrock exposed in situ and rock riprap that had been brought in to stabilize the shoreline. The lake bottom adjacent to the juvenile hiding places was usually quite shallow.

During the aerial surveys of portions of the

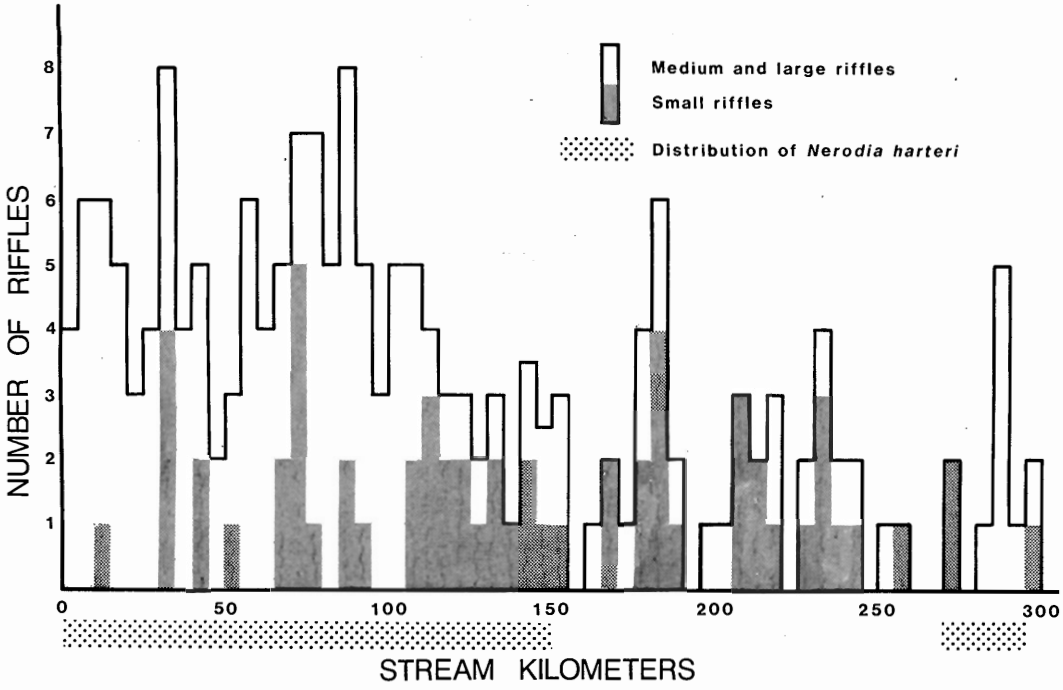

FIG. 3. Histogram of the number of riffles in each 5 km section of the Colorado River from the mouth of the Concho River (left margin) to Lake Buchanan (right margin), compared to the distribution of *Nerodia harteri*. Large and medium riffles are those longer than 15 m; small riffles are shorter.

Colorado and Concho rivers, 374 riffles and 12 rocky ledges were tabulated. Riffle frequency differed markedly between the Concho and Colorado rivers and between the portions of the Colorado that are and are not inhabited by *N. h. paucimaculata* (Fig. 3). With one possible exception, each 5 km section of river that contained Harter's water snake had at least one riffle. The inhabited portion of the Concho River had a median of nine riffles per 5 km section with a range of 4 to 21. Portions of the Colorado River with *N. h. paucimaculata* had a median of four riffles per 5 km (range 0–8). In the parts of the Colorado between Highway 45 and Bend, where we did not find the snake, six of 24 5 km sections lacked riffles and the median was 1.5 riffle per 5 km (range 0–6). The difference in the number of riffles between the inhabited and uninhabited sections of the Colorado River was highly significant ($P < 0.0001$).

DISCUSSION

Habitat of Nerodia harteri.—The habitat of *Nerodia harteri* is thought to be restricted to rocky or gravelly areas in and adjacent to shallow parts of flowing streams and rivers (Trapido, 1941; Marr, 1944; Tinkle and Conant, 1961; Conant, 1975; Mecham, 1983; Tennant, 1984, 1985) although data from Wade (1968) and Williams (1969) indicated that adults at least are found in a much wider range of habitats. To the contrary, our single most important finding was that *N. harteri* populations can persist under certain conditions after their river habitats have been inundated by deep reservoirs, and that riffle habitats are not necessary for the survival of populations.

At least two factors appear to be important to juvenile *N. harteri* at the sites studied: medium (greater than 0.1 m diameter) to large flat rocks on an unshaded shore for hiding places, and rocky shallows, presumably for foraging. Juvenile *N. harteri* feed almost entirely on small minnows, which seem to be especially common and vulnerable in shallow riffles (Williams, 1969). The fact that juveniles were found most commonly under flat rocks a few centimeters thick may be an artifact, because these types of rocks are the easiest to turn; however, the observed relationship is probably real and perhaps necessary to juvenile survival and growth. Distributions of adults, on the other hand, seem to be limited only by the need for deep, secure rocky refuges and the distance that they can travel from suitable habitat for juveniles.

Speculation on the role that flat, unshaded rocks on the shoreline and rocky shallows play in the biology of juvenile *N. harteri* may be pre-

mature, but it can yield testable hypotheses. Flat rocks probably warm up faster than large round rocks each day and in the spring, and juveniles may need the higher daytime temperatures to maintain a high growth rate. Most of their foraging seems to take place in the water at night, so even if flat rocks cool off rapidly after dusk, the snakes may not be affected seriously. The rocky shallows probably provide young snakes a safe foraging ground that concentrates prey and is inaccessible to large predatory fish. Juvenile *N. harteri* were almost never seen in deep water unless they were forced to swim there, but adults commonly occurred in deep pools or lakes.

Ontogenetic habitat shifts may be common in *Nerodia* although they do not seem to have been studied or even recognized as a general life history pattern. The young of *N. erythrogaster* also were found under rocks in the same riffles as *N. harteri*, and small *N. rhombifera* were occasionally present. The adults of all three species were more commonly found in deeper water in or close to deep, secure hiding places. Adult *N. rhombifera* were especially associated with deep, calm water. The persistent belief that *N. harteri* is restricted to gravelly or rocky shallow-water riffles stems from the fact that these are the areas where the young are most easily and reliably found. Except for a short period in midsummer and a longer period in the winter, a riffle known to harbor the species will yield specimens. However, the majority of these will be juveniles less than 1 yr old. Adult *N. harteri* will only be found by searching a wide variety of habitats and will never be found in large numbers.

Uninhabited River Sections.—Several sections of both the Brazos and Colorado rivers appear to be uninhabited by *N. harteri*. Habitat suitable for juveniles is scarce or lacking and repeated searches have failed to discover populations. Four such habitat barriers are located along the Brazos River: 25 km in Lake Shackelford, 184 km between Fort Griffin and upper Possum Kingdom Lake, the uninhabited parts of Possum Kingdom Lake, and 100 km between Hittson Bend and Lake Granbury (Table 1). Between Fort Griffin and Possum Kingdom Lake, the Brazos River flows through a red clay bed that is only rarely interrupted by short rocky riffles and ledges. Below Hittson Bend, the Brazos lies in a sandy bed that does not have cover for *N. h. harteri*. Although old museum records exist from two sites in this section of river, subsequent searches have failed to yield Harter's water snake; populations, if present, must be sparse and are probably ephemeral. These barriers divide the range of *N. h. harteri* into five separate populations. If the populations of any segment were extirpated, they would probably not be readily recolonized.

The most significant gap in the range of *N. h. paucimaculata* is 129 km on the Colorado River between Highway 45 and Bend. As revealed by the aerial surveys, the uninhabited stretch of river contains many fewer foraging riffles for juveniles than do stretches where the snake does occur. We expended considerable effort to determine whether or not *N. harteri* was present in this area. Prior to 1985, we spent a total of 9.0 hr plus four canoe trips looking for Harter's water snake in this segment. After the aerial survey in mid-May 1985, we examined 15 of the 43 riffles between Highway 45 and Bend. A median search time of 3.5 hr was spent at each of eight riffle complexes where all accessible habitat was examined, and *N. harteri* was not found. In contrast, at 14 sites on the Concho-Colorado where *N. h. paucimaculata* was found, a median of 1.1 hr was spent per snake and at only one of these was more than 2.0 hr required per snake. Thus, a median of 3.5 hr spent at a site should be sufficient to find Harter's water snake if it is present.

The reason for this hiatus is unknown. Judging by our knowledge of the better-known riffles, a maximum of 15–40 juveniles appear each year. Based on an average of 17–20 young per female (Williams, 1969) only about 1–3 adult female *N. harteri* contribute to the yearly recruitment in each riffle. On this assumption, we speculate that stochastic catastrophic events could eliminate a population from a given riffle or riffle complex. In areas where riffles occur about every kilometer, as they do upstream from Highway 45, a riffle without snakes could be rapidly recolonized. However, if the nearest occupied riffle was as far as 3 km away, recolonization might not occur for many years, during which time other riffle populations in the same stretch of river could become extinct. We believe that the distances between riffles rather than their quality is the reason for the hiatus in the distribution of *N. h. paucimaculata*.

Changes in Populations and Habitats through Time.—In order to evaluate the effects of the construction of high dams on *N. harteri*, we examined the history of three dams or dam complexes: Possum Kingdom Lake and Morris Sheppard Dam on the Brazos River in Palo Pinto County, E. V. Spence Dam on the Colorado River above Robert Lee in Coke County, and the O. C. Fisher Lake–Twin Buttes Reservoir–Lake Nasworthy complex on the Concho River west of San Angelo in Tom Green County. Each project completely controls the flows in the respective rivers.

In the original description of *N. harteri*, Trapido (1941) included a photograph and descrip-

tion of the Brazos River type locality. These were provided by Philip Harter, who first brought the snake to the attention of the scientific community, and by Catherine D. Hemphill. The photograph can almost be duplicated today and the description of the area and the snake populations in the vicinity leave little doubt that they are essentially unchanged since 1940. Our studies show that the snake is abundant in the proper habitat for many kilometers above and below the type locality.

In 1941, Morris Sheppard Dam was closed and the impoundment of Possum Kingdom Lake was begun. Because the dam generates electricity, water is always released even when Possum Kingdom Lake is very low. During the drought year October 1982 to September 1983, the water volume of the reservoir decreased by 15%. However, the flow at the type locality of Harter's water snake, 32 km downstream, never fell below 0.5 m^3/sec, and occasional high flows as great as 76 m^3/sec were recorded (U.S. Geological Survey, 1984*b*). In wetter years, such as 1957, momentary flows as high as 2400 m^3/sec may pass through the type locality (U.S. Geological Survey, 1964).

The only evident effect of the Morris Sheppard Dam on the Brazos River is an inundation of about 80 km of river, and reductions in the total flow, flow variation, and water temperature below the dam. None of these appears to have had a serious impact on Harter's water snake. Lower temperatures have probably eliminated self-maintaining *N. harteri* populations immediately below the dam. We found only one in about 5.0 work-hr of search in water 11–14°C, but at a point about 2 km downstream we found one *N. harteri* in 1.3 hr of search in water at 21°C.

The management of Possum Kingdom Lake mimics, to a large degree, patterns of natural, uncontrolled flows. As will be discussed below, the occasional high flows are probably more important to the well-being of *N. harteri* populations than is the maintenance of continuous low flows. The fact that *N. harteri* lives along part of the shoreline of Possum Kingdom Lake partially mitigates the direct effects of flooding 80 km of river that probably once contained many good riffles.

In 1960, Tinkle and Conant (1961) reported that *N. harteri* was abundant on the upper Colorado River below Robert Lee, Coke County. In 1966–1967, Williams (1969) recorded an estimated population of 473 juveniles in a study area consisting of about 900 m of the river. He also estimated that the study area contained about 52 adults and 48 subadults in midsummer. Williams (1969) concluded that E. V. Spence Dam, then under construction upstream from his study site, would probably destroy much of the value of the downstream habitat for *N. harteri*.

Williams' fears were well-founded. Brnovak (1975), working 4–6 yr after the closure of E. V. Spence Dam, was unable to find *N. harteri* in Coke County, and Mecham (1983) confirmed his observations. During our study, we took advantage of a rare pulse of water released from E. V. Spence Dam to survey by canoe about 70 km of the Colorado River below Robert Lee. The first 27 km, which included the areas studied by Tinkle (Tinkle and Conant, 1961) and Williams (1969), appear now to be devoid of *N. harteri* habitat, and we did not find the species above the Highway 277 bridge near Bronte, Coke County.

We found that the habitat immediately below Robert Lee was very different from the same area figured by Williams (1969; Fig. 4A). Instead of a swift-flowing stream running over rocky riffles between shallow and deep pools, we found a muddy, sluggish trickle choked with salt cedar and other vegetation (Fig. 4B). Apparently, the lack of scouring floods allowed the rocky streambed to become covered with silt, which provided a substrate for the invasion of salt cedar and other perennial trees, grasses, and sedges. Brnovak (1975) noted similar changes as early as 1973–1975. About 31 km below the Robert Lee Dam, silt deposition was noticeably less, rocky riffles appeared, salt cedar was much less common, and we found the first *N. harteri*. Downstream from this point near Bronte, the species seemed to be regular if not abundant.

Before E. V. Spence Reservoir was constructed, average flows in the Colorado River at Robert Lee were 5.9 m^3/sec; the average for 17 yr since the closure of the dam was 0.1 m^3/sec (Buckner et al., 1986*a*). However, the reduction of the amount of water per se has not eliminated the snake. Because of the drought, flows in the parts of the Colorado and Concho rivers inhabited by *N. harteri* were sometimes extremely low or nonexistent during our survey, but the populations were persisting and reproducing in the remaining pools. Only where a lack of floods has permitted the accumulation of silt in the riverbed and subsequent perennial plant invasion, has Harter's water snake been eliminated.

In the 1940s, Marr (1944) and Tinkle and Conant (1961) recorded *N. h. paucimaculata* from the South Concho River and Dove Creek, Tom Green County, respectively. Museum specimens exist and there is no reason to doubt these records. Both rivers are spring-fed and are tributary to the Concho River above San Angelo. The flows at the collection sites do not seem to be dramatically changed or controlled up to the present time. Both are characterized by rela-

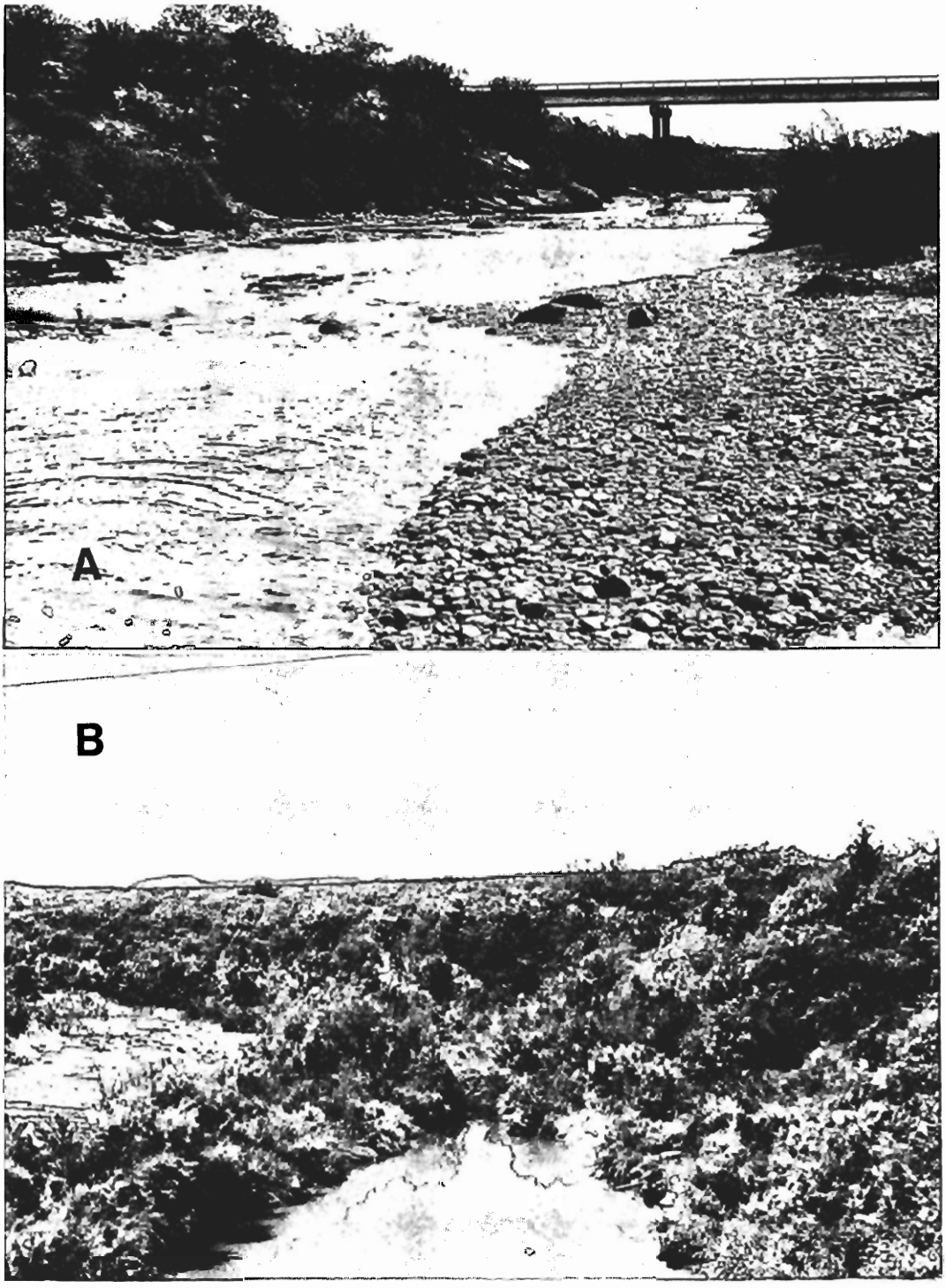

FIG. 4. A. Colorado River, looking downstream below Robert Lee, Coke County, July 1967, showing Williams' (1969) study site and good *Nerodia harteri* gravel bar habitat. State Highway 208 bridge is in background. Photograph by N. R. Williams. B. Upstream from State Highway 208 bridge on Colorado River below Robert Lee, Coke County, May 1985, showing invasion of salt cedar (*Tamarix*) and other perennial vegetation onto Williams' (1969) study site. Silt-covered remnant of gravel bar is seen at left. Photograph by N. J. Scott, Jr.

tively constant flows, even in the drought year of 1983, and small riffles apparently suitable for *N. harteri* persist.

Since the time that collections of *N. harteri* were made in their headwaters, the downstream combined flow of Dove Creek, the South Concho River, and four other major Concho River tributaries (Spring Creek, Middle Concho, North Concho, Pecan Creek) has been regulated by three large impoundments on the western edge of San Angelo. We did not find *N. harteri* in these reservoirs and suitable habitat is lacking on their shores. We surveyed most of the flowing sections of Dove Creek, Spring Creek, and the South Concho River above Twin Buttes Lake and below Christoval at least twice without finding the species. Pecan Creek and the Middle and North Concho rivers are intermittent. We included several surveys of the 1940s collection sites. Apparently the population discovered by F. L. Rose in Spring Creek above Mertzon is the only remnant above San Angelo.

Although the large dam complex above San Angelo does not seem to have degraded downstream habitat to the same degree that E. V. Spence Dam has on the Colorado River, there has probably been habitat loss for about 8 km below San Angelo. The differences between the effects of E. V. Spence Dam and the San Angelo dam complex are probably a result of differences in water flows and geologies. Evaluation of the downstream effects of the San Angelo dams is confounded by the effects of the city of San Angelo, which contains several low-head dams and releases treated sewage into the Concho River. The effects of the sewage are apparent in the algal blooms that blanket the gravel riverbed immediately below the city.

Impact of the Proposed Stacy Dam.—A major dam on the Colorado-Concho is under construction by the Colorado River Municipal Water District near Stacy, Coleman County. The resulting reservoir will inundate 52 km of the Colorado River and 23 km of the Concho River, comprising about 18% of the range of *N. h. paucimaculata*. Below Stacy Dam, the magnitude of habitat loss depends on a multitude of unanswered questions, such as how much water will be released and when, but any effect is almost certain to be detrimental in a manner analogous to the effects of E. V. Spence Dam on the upper Colorado River. In sum total, the current range of *N. h. paucimaculata* may be reduced as much as 25%. As can be seen in Fig. 2, the Concho water snake is found almost continuously throughout the area destined to be affected by Stacy Dam. Thus, the area inundated by Stacy Dam is the heart of the highest quality habitat for *N. h. paucimaculata*.

Nerodia h. paucimaculata now consists of one large continuous population, plus six small isolated colonies at Spring Creek, San Angelo, Lake Spence, Lake Moonen, Elm Creek, and Bend. Stacy Reservoir will fragment the largest habitat block into three parts. Depending on how well the snake survives in Stacy Reservoir, the Concho and Colorado rivers populations may or may not remain in genetic contact. Judging by the long-term persistence of the small populations in Spring Creek, San Angelo, and Lake Spence, the much larger population fragments created by Stacy Reservoir are not likely to die out as a result of habitat fragmentation alone.

Smaller populations are more susceptible to extinction from anthropogenic factors such as pollution and insufficient water flows. San Angelo sewage effluent may have rendered uninhabitable several kilometers of the Concho River immediately below the city, and Ballinger and Winters also released treated sewage directly into water occupied by Concho water snakes. An increase in human population, industrialization, and more intensive agriculture will jeopardize and possibly eliminate segments of the *N. h. paucimaculata* population.

Future of *Nerodia harteri*

No evidence suggests that *N. harteri* ever had a much more extensive range. The species has differentiated to the degree that it is not easily allied with any other species of *Nerodia*, which probably means that it has evolved in situ for a rather long time (Lawson, 1987). *Nerodia harteri* has one of the smallest distributions of any snake in the United States. Of the approximately 118 snake species found north of Mexico, only *Tantilla oolitica*, a Florida endemic, has a smaller range. In addition, within its range, Harter's water snake is restricted to perennial streams and a few reservoirs. These restrictions make it uniquely susceptible to environmental perturbations, both natural and man-made.

At many localities, *N. harteri* is remarkably abundant. This demonstrates that populations can be vigorous and are probably not extirpated easily. They have adapted to low flows on the upper Colorado and high flows on the Brazos below Possum Kingdom Lake. They have colonized at least four artificial impoundments. All of this is characteristic of a species that will persist as long as suitable habitat is available.

Dams have undoubtedly been the most important factor in reducing the total amount of habitat for *N. harteri*, but other more subtle effects must be noted. Siltation and a lack of flushing floods are continuing to bury the riffle habitats of *N. harteri* and reduce them to mud flats. We predict that this threat will increase through the inevitable conversion of grazing land to

intensive agriculture. Sewage effluents, which cause the riffles to become matted with algae, will continue to increase. Habitat in the Brazos drainage is more secure because of the flushing, diluting effects of greater precipitation; the Concho-Colorado is more vulnerable because of a general scarcity of water and the frequency of droughts.

The Brazos water snake seems to be relatively secure. Inhabiting over 300 km of river, including at least two tributary streams and two reservoirs, the Brazos subspecies would seem to be able to withstand the encroachment on its rivers by future dams and development projects. The subspecies may lose some habitat, but it is difficult to envision any sort of catastrophe or long-term habitat degradation that could threaten all segments of the population with extinction.

The Brazos River Authority is planning to build the South Bend Dam just below the confluence of the Clear Fork with the main Brazos River. The reservoir will not inundate any known locality for *N. h. harteri*, but some of the area has not been well surveyed and unknown populations may exist within the reservoir site.

The proposed Village Bend Pumped Storage Project includes a high dam at Inspiration Point in southeastern Palo Pinto County that would inundate a considerable stretch of the Brazos, including the type locality of *N. h. harteri*. However, this project has been placed on indefinite hold because it is not economically feasible (F. M. Bushnell, Jr., Brazos Electric Power Cooperative, pers. comm.). We are not aware of any other large projects that will affect the habitat of *N. h. harteri* in the near future.

Tennant (1984, 1985) presented an extremely pessimistic scenario of the history and future of the habitat of the Concho water snake. Fortunately, his statistics are inaccurate and the picture is not as bleak as painted. Tennant (1984, 1985) claimed that E. V. Spence Dam inundated over half of the original habitat of this subspecies; in fact no records indicate that the snake ever occurred in more than a small fraction of the area flooded by the dam. Tennant (1984, 1985) also wrote that 69 mi (111 km) of the Concho-Colorado system was inhabited by *N. h. paucimaculata*; our studies show that about 421 km are inhabited to one degree or another. Finally, Stacy Dam will inundate about 75 km of habitat, not the 40 km (24.8 mi) claimed by Tennant (1984, 1985).

The anticipated negative impacts of Stacy Dam are being partially countered by a unique agreement between the Colorado River Municipal Water District, the U.S. Army Corps of Engineers, and the U.S. Fish and Wildlife Service. The Water District has agreed to implement a broad-based plan that includes habitat creation, both in the rivers and on the new lake shore, population monitoring, and research into the basic biology of the Concho water snake. This degree of concern for a snake taxon, unique in our experience, signals a level of maturity that previously had been lacking in the interactions between agencies concerned with development and those charged with the enforcement of the Endangered Species Act. However, it is too early to assess the effectiveness of these measures and the future of *N. harteri* must be considered to be precarious.

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APPENDIX 1

Museum specimen records and first published localities for *Nerodia harteri*. Museum acronyms as in Leviton et al. (1985) plus AS (Angelo State University Collection, San Angelo, Texas) and BWMC (Bobby Witcher Memorial Collection, Avila College, Kansas City, Missouri). In some cases, several museum localities may refer to the same geographic site; these are indicated in parentheses. A few imprecise museum localities are associated with the nearest site with a definite record. Localities are listed from upstream to downstream on each watercourse.

Nerodia harteri harteri

BRAZOS RIVER: Palo Pinto Co.: Possum Kingdom Lake, FWM, MSB; Below Morris Sheppard Dam, FWM, TTU, Tinkle and Conant (1961); Highway 16 Crossing, SDSNH; 3 mi downstream from Morris Sheppard Dam, LTU; Fortune Bend, AMNH, Tinkle and Conant (1961); Chick Bend, AMNH, FWM, Tinkle and Conant (1961); Dalton Bend, FWM; Mouth of Dark Valley Creek, 8 mi N Palo Pinto, type locality of *N. harteri*, AMNH, AS, CM, CU, DMNH, FMNH, FWM, INHS, LACM, LSUMZ, MSB, MSUM, NLU, SDNHM, SMBU, TCWC, TNHC, TTU, UCM, UF-FSU, UIMNH, UMMZ, UOMZ, USNM, Trapido (1941); Highway 180 Crossing W Mineral Wells, FWM, LSUMZ, TCWC, TNHC; 10 mi S Mineral Wells, TCWC; Littlefield Bend (probably Parker Co.), Wade (1968). Hood Co.: Lake Granbury at Highway 426, MSB; 1 mi below Walters Bend, Wade (1968); De Cordova Bend, FWM, Wade (1968). Somervell Co.: 6 mi E Glen Rose, Wade (1968). Bosque-Johnson Co.: Brazos Point Crossing, MSB.

CLEAR FORK OF THE BRAZOS RIVER: Shackelford Co.: Lueders, A. S. Throckmorton Co.: Reynolds Bend (28.5 mi NW Albany), AS, TTU, Tinkle and Knopf (1964).

DEADMAN CREEK: Jones Co.: 3 mi E, 2.5 mi N Lake Fort Phantom Hill, MSB.

PAINT CREEK: Haskell Co.: Below Lake Stamford, BWMC, KU, MSB, Smith (1983).

Nerodia harteri paucimaculata

COLORADO RIVER: Coke Co.: Robert Lee to 2 mi downstream, type locality for *N. h. paucimaculata*, AMNH, ANSP, CM, DMNH, FMNH, FWM, KU, MCZ, SRSU, TCWC, TU, TTU, UF-FSU, UIMNH, UMMZ, USNM, UTA, Tinkle and Conant (1961); 9 mi S Robert Lee, TTU, Mecham (1983); 2 mi SW Bronte, TCWC. Runnels Co.: near mouth of Valley Creek, MSB; Ballinger and E of Ballinger, KU, TTU, Tinkle and Knopf (1964). Coleman-Concho Co.: Leaday Crossing, CM,

KU, MSB, UMMZ, UTEP, Tinkle and Knopf (1964); About 7 mi downstream from Leaday (6 mi NW Millersview, 5 mi S Leaday), TTU, UTA. Coleman-McCullough Co.: Stacy Crossing (5 mi N Doole, 29.6 mi SE Ballinger, 20 mi S Valera), KU, MSB, SMBU, TCWC, Tinkle and Knopf (1964); 1.5 mi E Stacy, KU; 22 mi S Valera, TCWC; 4 mi S Rockwood, MSB. Brown-McCullough Co.: Winchell Crossing, TTU, UTA, Tinkle and Knopf (1964). Mills-San Saba Co.: Highway 45 Crossing, MSB. San Saba-Lampasas Co.: Sulphur Springs, MSB; Gorman Falls, AS, MSB.

CONCHO RIVER: Tom Green Co.: 3 mi NNW Veribest, AS; Mullins Crossing and 1 mi downstream, AS. Concho Co.: Paint Rock, AS, MSB; 3 mi W Concho, KU; Concho Crossing, AS, MSB, Mecham (1983); ?Tickle Crossing at FM 1929 (2 mi S Leaday), SMBU.

DOVE CREEK: Tom Green Co.: Knickerbocker Crossing, KU, Tinkle and Conant (1961).

ELM CREEK: Runnels Co.: 0.3 mi S Highway 67, MSB.

SOUTH CONCHO RIVER: Tom Green Co.: Near Christoval, CAS, Marr (1944).

APPENDIX 2. Tributaries surveyed without finding *Nerodia harteri*. Most of these are considered temporary, that is they are dry during part of most years, and their locations are not plotted in Figs. 1 and 2. All of the repeated names (e.g., Elm Creek, Mustang Creek) are different streams.

	County	Tributary to
Brazos River Drainage		
Paint Creek Drainage		
California Creek	Haskell	Paint Creek
Lampasas-Little River Drainage		
Lampasas River	Lampasas	Little River–Brazos River
Bennett Creek	Mills	Lampasas River
Simms Creek	Lampasas	Lampasas River
School Creek	Lampasas	Lampasas River
Barkley Creek	Lampasas	School Creek
Lucy Creek	Lampasas	Lampasas River
Little Lucy Creek	Lampasas	Lucy Creek
Sulphur Creek	Lampasas	Lampasas River
Colorado River Drainage		
Champion Creek	Mitchell	Colorado River
Yellow Wolf Creek	Coke	Lake Spence
Oak Creek	Runnels	Colorado River
Valley Creek	Runnels	Lake Ballinger
Elm Creek Drainage		
Mud Creek	Runnels	Elm Creek
Coyote Creek	Runnels	Elm Creek
Big Coyote Creek	Runnels	Coyote Creek
Little Coyote Creek	Runnels	Coyote Creek
Mustang Creek	Runnels	Colorado River
Concho River Drainage		
North Concho River Drainage		
Grape Creek	Tom Green	North Concho River
Middle Concho River Drainage		
Big Rocky Creek	Irion	Middle Concho River
South Concho River Drainage		
Pecan Creek	Tom Green	South Concho River
Red Creek	Tom Green	Concho River
Willow Creek	Runnels-Tom Green	Concho River
Battle Creek	Tom Green	Willow Creek
Lipan Creek	Concho	Concho River
Little Concho Creek	Concho	Concho River
Kickapoo Creek	Concho	Concho River
Elm Creek	Coleman	Colorado River
Mustang Creek	Concho	Colorado River
Panther Creek	Coleman	Colorado River
Salt Creek	McCulloch	
Bull Creek	Coleman	Colorado River
Elm Creek	McCulloch	Colorado River
Cow Creek	McCulloch	Colorado River
Bluff Creek	McCulloch	Colorado River
Cedar Creek	McCulloch	Colorado River
Home Creek	Coleman	Colorado River
Mustang Branch	Coleman	Home Creek
Red Bank Creek	Coleman	Home Creek
Deep Creek	McCulloch	Colorado River
Clear Creek	Brown	Colorado River
Cottonwood Creek	San Saba	Colorado River
Buzzard Creek	San Saba	Spring Creek-Colorado River
Pecan Bayou Drainage		
Jim Ned Creek Drainage		
Hords Creek	Brown	Jim Ned Creek
Blanket Creek	Mills	Pecan Bayou
Browns Creek	Mills	Pecan Bayou
Lynch Creek	Lampasas	Colorado River
Browns Creek	Lampasas	Lynch Creek

APPENDIX 3. Lakes and reservoirs searched for *Nerodia harteri* during the study 1979–1987. Asterisks indicate impoundments harboring *N. harteri*.

Brazos River Drainage		Colorado River Drainage	
Stream	Lake	Stream	Lake
Elm Creek	Fort Phantom Hill	Colorado	J. B. Thomas
Paint Creek	Stamford	Morgan	Colorado City
Hubbard Creek	Hubbard Creek	Champion	Champion Creek
Brazos	*Possum Kingdom	Oak	Oak Creek
Brazos	*Granbury	Colorado	*E. V. Spence
Brazos	Whitney	Valley	Ballinger
		Valley	*Moonen
		Elm	Elm Creek
		North Concho	O. C. Fisher
		Several	Twin Buttes
		Pecan Bayou	Brownwood
		Brady	Brady
		Colorado	Buchanan
		Colorado	Inks