THE NARROW-HEADED GARTER SNAKE IN THE UNITED STATES (*THAMNOPHIS RUFIPUNCTATUS*): A REPORT ON ITS STATUS, NATURAL HISTORY, AND THREATS

Photo Courtesy of Pierson Hill

CENTER FOR BIOLOGICAL DIVERSITY

ANDREW HOLYCROSS

PHIL ROSEN

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TABLE OF CONTENTS

I. INTRODUCTION

The narrow-headed garter snake is among the most aquatic of all garter snakes. It lives in rugged terrain in and along rivers and streams in the American Southwest and northwestern Mexico. Unlike most other garter snakes, the narrow-headed garter snake lacks stripes and is recognized by its olive to brown coloration, irregular spots, and long narrow head. Often mistaken for a water snake, the narrow-headed garter snake is adapted to feeding on fish in streams, with its elongated head reducing drag during underwater strikes. Its range stretches from northern Durango, México in the Sierra Madre Occidental to the Gila Wilderness in New Mexico and Mogollon Rim in Arizona.

Scientists have observed declines across its range in the United States, and many remaining populations are small and isolated. The main causes of the declines are introduction of non-native species, such as centrarchid fishes (sunfish), ictalurid fishes (catfish), and crayfish; bullfrogs and habitat alteration have also been suggested as a cause of decline. These threats are leading to the decline of nearly the entire native aquatic fauna of the Southwest, and the narrow-headed garter snake is no exception.

To qualify for listing as a threatened or endangered species, the narrow-headed garter snake does not need to be imperiled across all of its range. The ESA provides for listing when a species is threatened with endangerment or extinction across a significant portion of its range. 16 U.S.C. § 1532(6); 16 U.S.C. § 1532(20). The narrow-headed garter snake qualifies for ESA listing because it is absent or extremely rare across a significant portion of its range in Arizona and New Mexico.

II. NATURAL HISTORY, BIOLOGY, AND STATUS OF THE NARROW-HEADED GARTER SNAKE

A. Taxonomy and Species Description

The narrow-headed garter snake was first described as *Chilopoma rufipuntatum* (Cope in Yarrow 1875) but is now recognized as *Thamnophis rufipunctatus* (tham-NO-fis rue-fih-punk-TAY-tus). "Rufipuntactus" refers to the reddish-colored spots found on some, especially young, snakes.

Given the morphology and feeding behavior of the species, the narrow-headed garter snake was proposed to belong to the water snake genus, *Nerodia* (Chiasson & Lowe 1989). But later work demonstrated that these snakes are not closely related and that the narrow-headed garter snake belongs in *Thamnophis* (de Queiroz & Lawson 1994). Still, the narrow-headed garter snake was believed to be a bridging species with the water snake genus (Shaw and Campbell 1974; de Queiroz & Lawson 1994), but this is no longer thought to be true (de Queiroz et al. 2002).

Based on morphological differences, Tanner (1985) recognized three distinct subspecies of narrow-headed garter snake (*T. r. rufipunctatus*, *T. r. unilabialis*, *T. r. nigronuchalis*). But

utilizing a multilocus analysis of nuclear DNA, Wood et al. (2011) found that these three subspecies likely warrant full species status, stating:

> Taken together, our analyses identify lineages concordant with previously recognized taxonomic divisions and geographic isolates (i.e. *rufipunctatus*, *unilabialis* and *nigronuchalis*) indicating that three separate species may exist within the *T. rufipunctatus* complex.

Our report focuses on the species *T. rufipunctatus*, or alternately the subspecies *T. r. rufipunctatus*, which is limited to the United States and is physically separated from the other two species or subspecies.

The narrow-headed garter snake is unique among U.S. garter snakes in lacking stripes on the dorsum and having a long narrow head (Degenhardt et al. 1996). The garter snake is olive to brown in color with dark irregular spots, which are redder in young snakes. Its tongue is black. Scales are keeled, with usually 21 rows at midbody (Arizona Game and Fish Dept. 2002). Degenhardt et al. (1996) report data showing that female snakes range in length from 338-1115 mm and males range from 373-836 mm. The eyes occur high on the laterally compressed head. The tail is prehensile, as in most snakes, and can use to anchor itself while pursuing prey in swift current.

B. Distribution

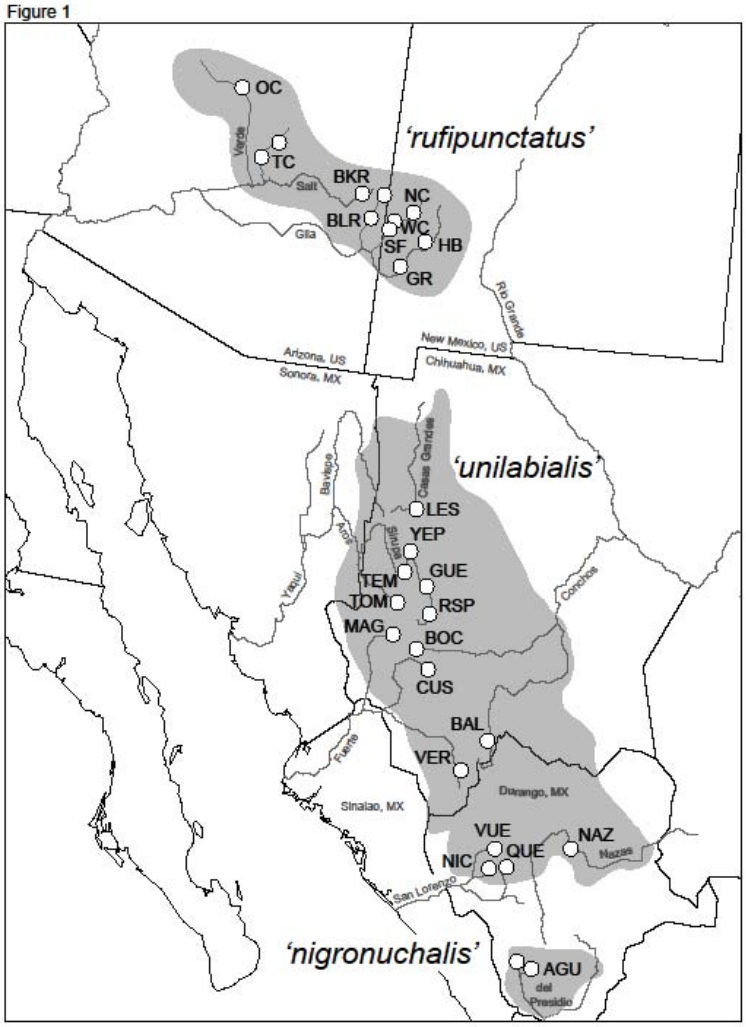
Little is known about the overall historic range of the narrow-headed garter snake, and no fossil record exists (Ernst and Ernst 2003, Tanner 1990). The current distribution of the narrow-headed garter snake group is split between populations in the United States and Mexico, as shown in the figure below. As explained above, this report focuses on narrow-headed garter snakes in the United States. The narrow-headed garter snake is believed to be gone from more than 60% of its historic range and to have experienced recent declines and extirpations (Rosen and Schwalbe 1988, Nowak and Santana-Bendix 2002, Holycross et al. 2006, Hibbitts et al. 2009, Wood et al. 2011).

Within the United States, the narrow-headed garter snake currently occurs mostly or entirely at mid-high elevation streams and rivers in north-central Arizona and south-central western New Mexico (Nowak 2006). More specifically, the New Mexican distribution includes the Gila and San Francisco river drainages in Catron, Grant, and Hidalgo counties, at elevations of 1,125-2,100 meters (Degenhardt et al. 1996). In Arizona, this species occurred at elevations ranging from ca. 670 – 2400 meters in the Blue River, Salt River, Verde River, and Tonto Creek drainages from the White Mountains and along the Mogollon Rim to Oak Creek Canyon, in Apache, Coconino, Gila, Graham, Greenlee, Navajo, and Yavapai counties (NatureServe 2006), but it is now likely absent from elevations of around 1,000 meters or less.

The number of distinct occurrences or subpopulations has not been determined using consistent criteria. The Arizona Natural Heritage Program has recorded at least 51 occurrences, a few of which are believed to be not extant (NatureServe 2006). Tanner (1990) mapped six

collection sites in New Mexico, while Degenhardt et al. (1996) mapped 27 collection sites in New Mexico.

Figure 1



C. Habitat

The narrow-headed garter snake is regarded as one of the most aquatic of all garter snakes (Conant 1963). The garter-snake is most typically found in well-lit, cool, clear, rocky streams with overhanging vegetation (Degenhardt et al. 1996, Holycross et al. 2006).

Narrow-headed garter snakes were once thought to spend much of their active season in water, but telemetry data has demonstrated that the snakes use upland areas within 100 m of water during early fall and spring months and strongly associate with boulders in the floodplain during summer months (Nowak 2006). The snakes use upland areas several hundred meters out of the floodplain as hibernation sites (Nowak 2006). Extensive use of human structures (such as

rock walls) for retreat sites shows that the snakes appear to be adaptable to certain kinds of human development (Nowak 2006).

The snakes use vegetation and rocks both in and out of the water as basking sites and as cover for avoiding predators (Degenhardt et al. 1996, Nowak and Santana-Bendix 2002). Neonate narrow-headed garter snakes appear to favor shallow backwaters or edges with less current and with abundant vegetation (Nowak and Santana-Bendix 2002). Hibbitts et al. (2009) determined that narrow-headed garter snakes were more likely to be found in steam sections with a steep riverbed slope and large uniformly-sized rocks. Areas with broad expanses of small rock and sand, and streams that traverse meadows do not appear to be suitable habitat (Fitzgerald 1986, Degenhardt et al. 1996).

Streams in pinyon-juniper, oak-pine, or ponderosa pine and sheltered by deciduous trees (cotton-wood willow) are most commonly used (AGFD 2002). Important components of bank vegetation include shrub-sized and sapling Arizona alder, velvet ash, willows, and canyon grape (Rosen and Schwalbe 1988). An abundance of soft-rayed fish or trout are a prerequisite of suitable habitat (Holycross et al. 2006).

The photo below shows a typical rocky stream inhabited by the snake.

Photo Courtesy of Pierson Hill

D. Biology

Female narrow-headed garter snakes mature at two or three years and males at about two years. Mating occurs in warm microclimates along stream margins, with females leaving scent trails for males to follow. The narrow-headed garter snake is viviparous with births of 6-18 young occurring in summer (Behler and King 1979, Rosen and Schwalbe 1988, Goldberg 2003). Young snakes are on their own from birth. Snout-to-vent length for neonates at birth range from 16.0 – 20.5 cm (Pierce 2007). A photo of a young snake is provided below.

The narrow-headed garter snake is active in the day and evening. It is highly aquatic and is highly adapted to foraging in cold water (Degenhardt et al. 1996, Holycross et al. 2006, Wood et al. 2011). Fish are a major source of food for narrow-headed garter snakes, which also hunt frogs and tadpoles (USGS 2006, NMDFG 1985). In the Oak Creek Canyon of Arizona, the snakes feed primarily on smooth-bodied fishes with soft fins, especially nonnative brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), native suckers, and speckled dace (*Rhinichthyus osculus*) (Nowak 2006). In the San Francisco Hot Springs, the snakes feed primarily on introduced mosquitofish (*Gambusia affinis*) (Hibbitts et al. 2009). Fish with stiff, spiny fins may be unsuitable prey because they may puncture the digestive track and represent a choking hazard (USGS 2006).

The species' elongated narrow head is believed to be an adaption to reduce drag when striking prey in swift water and enhances their ability to hold position when facing into a current (Hibbitts and Fitzgerald 2005). They commonly anchor their tails around rocks to hold their position in a current (Werler and Dixon 2000). The snakes have also been observed holding position in a current with the body unanchored on the substrate to allow for forward directed strikes (Hibbitts and Fitzgerald 2005). The snake is a visually-oriented predator and forages along streamside banks and particularly between cobbles and boulders in the stream itself. Young narrow-headed garter snakes sometimes forage from a rock wall with the majority of their body above the water and their head below the water motionless waiting to ambush fish (Hibbitts et al. 2009).

When encountered, the snake is often quick to dive underwater and seek shelter under the rocks in the bed of the stream (Stebbins 2003). Outside of the water, boulders and human-created structures (such as rock walls, chimneys and old water pipes) serve as retreat sites (Nowak 2006). When handled, the snake emits the foul-smelling contents of its anal scent glands and may try to bite, although it is not venomous (NMDFG 2011).

Along Oak Creek, Arizona, hibernation occurs from November to April in rocky areas well above the floodplain (Nowak and Santana-Bendix 2002, Nowak 2005, USGS 2006). Rocky outcrops are common hibernation sites (Nowak 2006). The snakes do not appear to enter the water regularly until after mid-May (Nowak 2006). Basking is likely a necessary behavior to maintain physiological function given that the species forages in cool waters (Ernst and Ernst 2003).

The snakes have small home ranges (1.1 ha for females and 1.8 ha for males) (Nowak 2006). During the summer, the snakes usually do not travel more than 0.8 km from their hibernation sites (USGS 2006). Ranges of narrow-headed garter snakes overlap, as the snakes do not defend territories (Nowak 2006).

E. Population Status

The narrow-headed garter snake has undergone dramatic range-wide declines in the last 30 years in the United States and is now almost entirely limited to small, isolated populations that are at risk of extirpation (Nowak and Santana-Bendix 2002, Holycross et al. 2006, Nowak 2006, Pierce 2007, Hibbitts et al. 2009, Jennings et al. 2010, Wood et al. 2011). Wood et al. (2011), for example, concluded:

> Historical surveys indicate that *T. rufipunctatus* has been extirpated from more than 60% of its historic range in the United States, with remaining populations becoming increasingly more isolated and/or experiencing local extirpation (Rosen & Schwalbe 1988; Nowak & Santana-Bendix 2002; Holycross *et al*. 2006; Hibbitts *et al*. 2009). . . . Given the small size of populations, their apparent isolation from each other, and the rapidity with which populations are disappearing, *T. rufipunctatus* (*sensu novo*) appears to be highly vulnerable to extinction.

Scientists first documented declines in the 1980s. A 1985-1986 survey conducted by Rosen and Schwalbe (1988) in selected regions of Arizona indicated that the species was abundant in very few localities, and was nearly eliminated from some areas where formerly it was abundant. Surveys by Nowak and Santana-Bendix (2002) in 1999-2001 found few individuals in most historic locations and some historic locations lacked any narrow-headed garter snakes.

In a comprehensive survey of historic garter snake populations, Holycross et al. (2006) observed narrow-headed garter snakes at only 5 (31%) of 16 historic sites, further observing that at sites they sampled where garter snakes persist, trap rates were "exceptionally low." Of particular concern, narrow-headed garter snakes were not observed at several sites despite thousands of person- and trap-hours, including Eagle Creek at P-Bar, East Verde River at Highway 87, and San Francisco River at Alma Bridge and San Francisco Hot Springs, where the species was easily captured and observed to be relatively abundant in the 1980s (Holycross et al. 2006). Also concerning is the fact that they were able to document the snakes at just 2 of 24 sites surveyed in the Salt River watershed (Holycross et al. 2006). And in those two sites, capture rates were low when compared to previous surveys.

Additionally, there is abundant evidence that the species has declined along the lower portions of Oak Creek, in north-central Arizona, where it is now scarce or absent below Oak Creek Canyon and has suffered significant declines in lower Oak Creek Canyon (Rosen and Schwalbe 1988, Nowak and Santana-Bendix 2002, Nowak 2005, Nowak 2006, USGS 2006). Oak Creek historically contained one of the largest populations of this species in the United States (Nowak and Santana-Bendix 2002). Surveys in 1985 and 1986 in Oak Creek resulted in an estimate that the creek contained fewer than 1000 adults and subadults (Rosen and Schwalbe 1988). About 15 years later, in 1999-2001, 129 narrow-headed garter snakes were detected in the creek (Nowak and Santana-Bendix 2002), indicating they were still abundant in most of the canyon, but Nowak (2006) found less than 10 adults and subadults at what was formerly the most populous site. Such dramatic declines have not been widely observed in the upper reaches of Oak Canyon (Nowak 2006), with the exception of Slide Rock State Park where substantial population declines may have occurred, likely due to greatly increased recreation in the area, the subsequent loss of suitable near shore habitat, and increased killing of snakes by humans (Nowak and Santana-Bendix 2002).

Nowak and Santana-Bendix (2002) did not find narrow-headed garter snakes south of Oak Creek Canyon, even though there are several records and anecdotal reports of the species occurring at Chavez Crossing in Sedona, Arizona. The authors conclude that populations of the species south of canyon are either very low or extirpated (Nowak and Santana-Bendix 2002). The species is also believed to be extirpated from Wall Lake, Arizona, and from adjacent parts of the East Fork of the Gila River in New Mexico (Rosen and Schwalbe 1988). Nowak (2009) surveyed several locations in the upper Verde River of Prescott National Forest with a total of 314 trap-nights and extensive visual encounter surveys but did not find a single narrow-headed garter snake, leading her to conclude that the snake is extirpated from most sites. But a population of the snakes was discovered in 2010 along the Verde River near Prospect Point in the Prescott National Forest (Inside NAU 2010).

Extirpation of the narrow-headed garter snake at San Francisco Hot Springs in New Mexico was documented by Hibbitts et al. (2009), who conducted extensive studies of the ecology of the species at the site in the mid 1990s, when they found an estimated 7.2 snakes/ha. Return visits to the site in 2004 and since failed to document any individuals, leading Hibbitts et al. (2009) to conclude:

> This population of *T. rufipunctatus* was one of the most robust in the United States and it has completely disappeared in <10 years… The presumed disappearance of *T. rufipunctatus* from San Francisco Hot Springs is disturbing. This population was one of the largest in the United States. This event highlights the dangers that populations face.

Currently, the narrow-headed garter snakes are easily found at few sites: Oak Creek Canyon (Nowak 2006 and therein), Whitewater Creek (Holycross et al. 2006), and a few small streams in Gila National Forest (L. Hellekson, T. Brennan, P. Rosen, unpublished). Recruitment of young was observed in 2006 although fewer were observed in 2007 (Pierce 2007). Whitewater Creek and Oak Creek Canyon are strong population sites with little negative impacts of livestock grazing and nonnative species, while streams with strong populations in Gila National Forest are impacted by grazing and crayfish but have strong native fish populations. At other known sites, the garter snake is either extirpated or at low densities and is difficult to find.

The total population size of the narrow-headed garter snake is unknown. NatureServe (2006) ranks the narrow-headed garter snake's global status as "Vulnerable," while its status in Arizona is "Critically Imperiled" and its status in New Mexico is "Imperiled." NatureServe (2006) explains that "abundance and number of subpopulations have declined" and that "some populations are susceptible to local extirpation with no adjacent populations for recolonization." The species is also included in the International Union for Conservation of Nature (IUCN) Red List, and the IUCN notes that is may qualify for "near threatened" or "vulnerable" if it is declining in Mexico as has been recorded in the United States (Hammerson 2007).

III. THREATS ANALYSIS

Section 4 of the Endangered Species Act and its implementing regulations (50 C.F.R. Part 424) set forth the procedures for adding species to the federal list of endangered and threatened species. FWS may determine a species to be endangered or threatened due to one or more of the five factors described in section 4(a)(1) of the Act. Each of these factors is discussed below.

A. Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

The loss and degradation of the vast majority of Southwest aquatic and riparian habitats in the last 100 years has been abundantly documented (Hendrickson and Minckley 1984, Krueper et al. 2003, Webb and Leake 2005, Holycross et al. 2006, Haney et al. 2008). Any anthropogenic alterations to the landscape may have a negative impact on habitat specialists such as the narrow-headed garter snake (Holycross et al. 2006, Hibbits et al. 2009, Wood et al. 2011). The threats posed by livestock grazing, recreation, and roads are discussed below

Livestock grazing

Livestock grazing has eliminated riparian vegetation across large stretches of the snake's range through browsing, trampling and stream bank erosion (Hendrickson and Minckley 1984, Ohmart et al. 1988, Zwartjes et al. 2005, p. 21). This can directly impact the garter snake, which depends on riparian vegetation for cover and basking sites (Degenhardt et al. 1996, Holycross et al. 2006). Removal of cover for basking could expose the snakes to predators, such as hawks (P. Rosen, personal communication). However, narrow-headed garter snakes have often been found abundant in heavily grazed riparian areas, where they may use rocks, snags, flood wrack, and shrubs for cover and basking (P. Rosen, personal communication).

Livestock grazing also causes sedimentation of waterways through bank erosion and riparian vegetation loss. Stream sedimentation reduces foraging visibility and buries rocky stream bottoms utilized by the snake (e.g. Trimble and Mendel 1995, Pearce et al. 1998, Hibbits et al. 2009). However, livestock-caused sedimentation has not been documented as a clear cause of decline for this species.

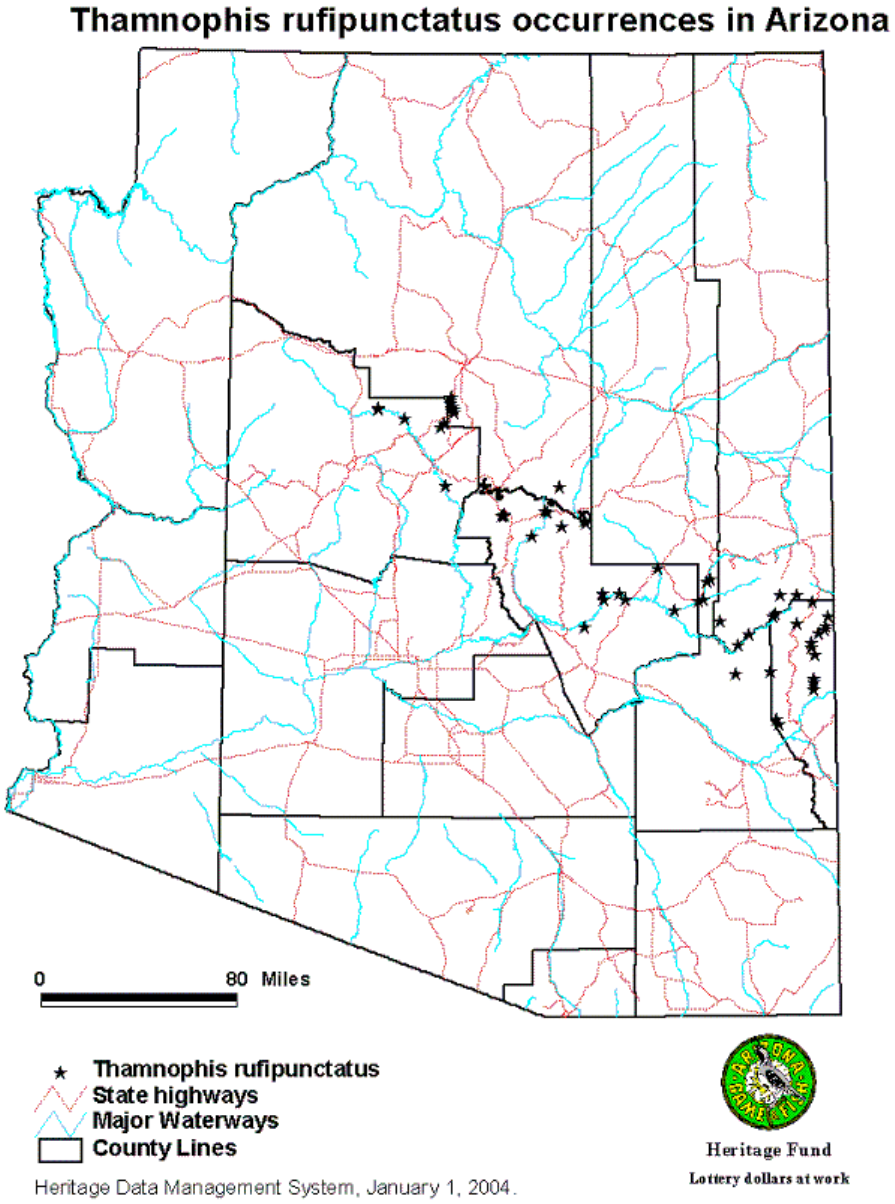
Livestock grazing may also impact the garter snake by altering the composition and community structure of aquatic fauna. The aquatic invertebrate community may change because of altered stream channel characteristics, higher water temperatures induced by loss of riparian vegetation, sediment deposition or substrate size changes, or nutrient impoverishment or enrichment (Rinne 1988, Jones et al. 1997). This change in the food base of many aquatic vertebrates, particularly fish, may contribute to a change in the overall vertebrate community, and could have a negative impact on the garter snake (e.g. Covich et al. 1999).

Although livestock have been removed from some of the riparian areas that provide habitat for the narrow-headed garter snake, Holycross et al. (2006) observed livestock impacts to several historic and current narrow-headed garter snake streams, noting, for example, that "exceptionally heavy grazing concentrated in the riparian corridor" of Eagle Creek at the Phelps Dodge pumping station had "profoundly and adversely impacted this system," and that the garter snake appeared to be extirpated from the site. By contrast, the one site where narrow-headed garter snakes were still encountered with relative frequency was ungrazed and appeared to be in good condition (Holycross et al. 2006). Yet there is evidence that the narrow-headed garter snake thrived in these and many other areas prior to replacement of native fishes by exotic fishes, despite heavy livestock grazing (e.g., Rosen and Schwalbe 1988). As such, it is unclear whether livestock grazing is having significant negative effects on the narrow-headed garter snake relative to the threat posed by exotic fishes.

Finally, diversion of stream water in Eagle Creek and Blue River, Arizona, for livestock and ranch-based farming appeared to de-water parts of these streams and eliminate the narrow-headed garter snake (Rosen 1987, in Fernandez and Rosen 1996).

Roads

Roads may impact narrow-headed garter snake habitat through direct destruction and fragmentation, contribution of sediment and other pollutants, and by facilitating access for recreation and urbanization (e.g. Andrews and Gibbons 2005, Roe et al. 2006). Roads are also a source of direct mortality of snakes, as humans may accidentally or intentionally strike snakes on roadways. The figure below shows the major roads bisecting habitat of the narrow-headed garter snake in Arizona.



Construction and maintenance of roads and highways can be a source of sediment and pollutants in adjacent waterways (Waters 1995, Wheeler et al. 2005). Sediment can adversely affect fish populations used as prey by the narrow-headed garter snake by (1) interfering with

respiration; (2) reducing the effectiveness of fish's visually-based hunting behaviors; and (3) filling in interstitial spaces of the substrate, which reduces reproduction and foraging success of fish (Wheeler et al. 2005, p. 145). The underwater foraging ability of narrow-headed garter snakes is also directly compromised by excessive turbidity caused by sedimentation of water bodies because this snake locates its prey visually.

Metal contaminants, including iron, zinc, lead, cadmium, nickel, copper, and chromium, are associated with highway construction and use (Hopkins et al. 1999, p. 1260; Campbell et al. 2005, p. 241; Wheeler et al. 2005, pp. 146-149) and are bioaccumulative. A mid- to higher-order predator, such as a garter snake, may therefore accumulate these types of contaminants over time in their fatty tissues, which may lead to adverse health effects. Several studies have addressed the effects of bioaccumulative substances on watersnakes. These studies are relevant because watersnakes and the narrow-headed garter snake have very similar life histories and prey bases and, therefore, the effects from contamination of their habitat from bioaccumulative agents are expected to be similar. Campbell et al. (2005, pp. 241-243) found that metal concentrations accumulated in the northern watersnake (*Nerodia sipedon*) at levels six times that of their primary food item, the central stoneroller fish (*Campostoma anomalum*). Metals, in trace amounts, affect the structure and function of the liver and kidneys of vertebrates and may also act as neurotoxins, affecting nervous system function (Rainwater et al. 2005, p. 670). Hopkins et al. (1999, p. 1261) found that metals may even interfere with metabolic rates of banded watersnakes (*Nerodia fasciata*), altering the allocation of energy between maintenance and reproduction, reducing the efficiency of energy stores, and forcing individuals to forage more often, which increases activity costs (the energy expended in hunting, which affects the net nutritional intake of an organism) and predation risk.

Vehicles are a source of mortality for narrow-headed garter snakes, especially accidental killing of snakes at low water crossings (USGS 2006). Vehicles on roads in the upland areas adjacent to waterways also undoubtedly kill some narrow-headed garter snakes. Snakes derive heat from warm surfaces, which often compels them to slow down or even stop and rest on road surfaces that have been warmed by the sun as they attempt to cross (Rosen and Lowe 1994, p. 143). Because they are diurnal, garter snakes are often active when traffic densities are greatest (Rosen and Lowe 1994, p. 147). However, road mortality appears surprisingly rare for the narrow-headed garter snake. For example, there are no records of narrow-headed garter snakes being killed by vehicles in Oak Creek Canyon, where a busy highway closely parallels the creek over much of the occupied stream.

Perhaps the most common factor in road mortality of snakes is the propensity for drivers to intentionally run over snakes (Langley et al. 1989, p. 47; Shine et al. 2004, p. 11). This driving behavior is exacerbated by the general animosity that many humans have toward snakes. In fact, Langley et al. (1989, p. 47) conducted an experiment on the propensity for drivers to hit reptiles on the road using turtle and snake models and found that many people have a greater desire to hit a snake on the road than any other animal; several drivers actually stopped and backed-over the snake mimic to ensure it was dead. The effect of road mortality of snakes becomes most significant in the case of small, highly fragmented populations where the chance removal of mature females from the population may appreciably degrade the viability of a population.

While snakes of all species may suffer direct mortality as a result of attempting to cross roads, Andrews and Gibbons (2005, pp. 777-779) found that many individuals of small, diurnal snake species avoid open areas (e.g., roads) instinctively in order to lower predation rates, which represents a different type of threat from roads. Shine et al. (2004, p. 9) found that the common garter snake typically changed direction when encountering a road. These avoidance behaviors affect movement patterns and may ultimately affect reproductive output within populations (Shine et al. 2004, pp. 9, 17-19). Not crossing roads can fragment and reduce the amount of habitat available for individual snakes to find prey, mates, and shelter.

Finally, roads create access to areas that were previously visited only infrequently or were inaccessible to humans, increasing the frequency and significance of anthropogenic threats to riparian areas, such as introduction of exotic species and heavy recreational use, which are discussed below (Rosen and Lowe 1994, pp. 146-148; Andrews and Gibbons 2005, p. 772).

Recreation

Many known localities for the narrow-headed garter snake are used for hiking and fishing (Pierce 2007, Nowak and Santana Bendix 2002). And scientists have documented degradation of the snake's habitat caused by heavy recreational use (Rosen and Schwalbe 1988, Nowak and Santana-Bendix 2002, Nowak 2005, Holycross et al. 2006).

Recreation in the form of heavy human foot traffic compacts stream banks, removing suitable growing conditions for terrestrial and emergent vegetation (Nowak and Santana-Bendix 2002). Heavy foot traffic can also remove basking sites and suitable cover for the snakes and physically destroy shallow backwater areas that neonate snakes favor (Nowak and Santana-Bendix 2002).

Heavy recreational use can also cause erosion and sedimentation of waterways. As explained above (in the context of impacts from road construction), sedimentation can negatively affect narrow-headed garter snakes through impacts on its prey. Sedimentation also impacts foraging ability of snakes, decreasing visibility and filling in the interstitial spaces between rocks used for foraging (Turnpenny and Williams 1980, Queiroz 2002, Nowak and Santana-Bendix 2002).

Off-road vehicle use along and within streams can negatively impact the species' habitat and cause direct mortality (Pierce 2007). Snakes resting under rocks and foraging in streams would be killed in large numbers by OHV use in small stream systems especially. Off-highway use (OHV) use affects narrow-headed garter snake habitat by reducing vegetation cover and plant species diversity, reducing infiltration rates, increasing erosion, and reducing habitat connectivity (Ouren et al. 2007, pp. 6 – 7, 11, 16). The threat from OHVs may be even more extensive than from conventional vehicles because OHV trails often travel through undeveloped habitat and often cross directly through waterways. OHV use has grown considerably in the Southwest. For example, as of 2007, 385,000 OHVs were registered in Arizona (a 350 percent increase since 1998) and 1.7 million people (29 percent of the Arizona's public) engaged in offroad activity from 2005-2007. 73 Fed. Reg. 71799 (Nov. 25, 2008). Given the pervasive use

of OHV's on the landscape, OHV-related mortalities are likely a threat to narrow-headed garter snakes.

Heavy recreational use may be a factor contributing to several observed declines of narrow-headed garter snakes. Heavy recreational use of Oak Creek Canyon has resulted in localized trampling of habitat used by young snakes and fish for spawning sites (USGS 2006, Nowak and Santana-Bendix 2002). In addition, recreational use might possibly have contributed to the extirpation of the San Francisco Hot Springs population (Hibbits et al. 2009). Degradation of narrow-headed garter snake habitat near Slide Rock State Park has also been observed, including terrestrial and nearshore stream habitat degradation, siltation, and episodic outbreaks of coliform bacteria (Burns et al. 1998). The species still persists with much reduced abundance in the most heavily recreated site in its range, Slide Rock in Oak Creek Canyon.

It is likely that recreational pressure will increase as the population of Arizona and New Mexico grows. The populations of Arizona and New Mexico increased by 24.6% and 13.2% from 2000 to 2010, respectively (U.S. Census Bureau 2011). For example, in 1995, 1.3 million people visited the Red Rock Ranger District, and five years later, in 1999, the district received over six million visitors (Nowak and Santana-Bendix 2002). Rosen, Nowak, and Brennan (2012, in review) hypothesized that heavy recreation may be reducing pool use by narrow-headed garter snakes in Oak Creek Canyon, but could not separate the effects of recreation and exotic species impacts on pools.

B. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Needless killing and excessive collecting may be having a negative impact on narrow-headed garter snakes (New Mexico Department of Game and Fish 1997; Nowak and Santana-Bendix 2002; Rosen and Schwalbe 1988, 2002; Rossman et al. 1996). Humans kill the snakes because of a perceived need to do away with a potential competitor for sport fishes, and out of fear, as the garter snakes are often confused with venomous water snakes (Nowak and Santana-Bendix 2002, Nowak 2006). Collection pressure may be increasing in response to increased conservation interest in the species.

Rosen and Schwalbe (1988) documented sources of mortality of narrow-headed garter snakes in Oak Creek and roughly estimated that human-caused mortality accounted for 44 percent of total annual mortality of non-neonates. Nowak (2006) also noted human-caused mortality in Oak Creek. As a result of her recommendations, signage to support snake conservation was installed. Enforcement efforts by state employees against those that kill garter snakes have also increased (P. Rosen, personal communication).

As a result of these efforts, killing of snakes by recreationists in Oak Creek Canyon has probably declined in recent years. During intensive studies in 2007-2008, Rosen, Nowak, and Brennan (2012, in review) found only 3 apparently human-killed snakes in the canyon, and Rosen (personal communication) believes this translates into direct human-caused mortality that is now 1/6 or less than what was occurring in the mid-1980's.

Narrow-headed garter snakes may also be threatened by collection (Nowak 2006; Rosen, Nowak, and Brennan 2012, in review). In midsummer 2005, herpetological enthusiasts were documented trying to collect the species from Oak Creek, Arizona before the collecting season was officially closed (Pierce 2007). Although difficult to maintain in captivity, the potential exists for the snake to be of interest to collectors, given its rarity and unique morphology for a garter snake (Pierce 2007). Internet postings can be found from individuals asking where to collect the snake (Thamnophis.com 2011).

In sum, killings and collection is a minor threat overall but may be a significant threat to already small and isolated populations.

C. Disease or Predation

Nowak (2006) suspected that disease may be a stressor for narrow-headed garter snakes studied in Oak Creek Canyon. One of her telemetered snakes died of acute bacterial infection. Oak Creek Canyon is frequently polluted by outbreaks of fecal coliform bacteria from heavy recreation and residential sewage disposal systems (Southam 1996). These or other bacteria may cause systemic disease in snakes with immune systems already compromised by other stressors. Nowak (2006) posits that narrow-headed garter snakes have lower disease resistance in areas where water temperatures have increased due to reduction or removal of native streambank and in-stream vegetative cover, for example in lower reaches of Oak Creek. However, Rosen, Nowak, and Brennan (2012, in review) found no evidence for disease or illness of narrow-headed garter snakes in Oak Creek Canyon or anywhere else.

The narrow-headed garter snake has a long list of likely predators, including hawks, wading birds, corvids (jay, ravens and crows), skunks, coyotes, raccoons, crayfish, predatory fishes, bullfrogs, and other snake species (USGS 2006, Pierce 2007). Native fishes do not appear to be a threat but attack or predation by introduced crayfish appears to be a significant threat (Rosen 1987; Holycross et al. 2006; Rosen, Nowak, and Brennan 2012, in review), and bullfrog predation may be a threat in some areas (Pierce 2006).

Introduction of nonnative fish has been identified as the primary threat to the narrow-headed garter snake (Rosen and Schwalbe 1988, 2002; Rosen, Nowak and Brennan 2012, in review). The primary impact is decimation of prey populations (primarily native fishes but also amphibians) by predation and competition by larger introduced fishes, especially centrarchids and ictalurids (Rosen, Nowak and Brennan 2012, in review). While the snake eats some nonnative fish species (Nowak and Santanna-Bendix 2002; Nowak 2006), many nonnative species are spiny and garter snakes that prey on them may die from choking or punctures (Nowak and Sanatana-Bendix 2002). Another possible reason that many nonnative fish are unsuitable prey is that nonnative fish live higher in the water column and thereby avoid predation by the garter snake, which predominately forage by crawling on the substrate bottom and striking at prey underwater (Nowak and Sanatana-Bendix 2002). In addition, some nonnative fish may prey on young snakes (Knapp 2005, Matthews et al. 2002). To be sure, low densities and historical declines in the White Mountains correlate closely with the history of fish introductions (Rosen and Schwalbe 1988). Likewise, introduced fish may have contributed to (Hibbitts et al.

2009) or likely were the primary cause of (Rosen, Nowak and Brennan 2012, in review) extirpation of the San Francisco Hot Springs population.

Another major, more recently emerging factor contributing to population declines of narrow-headed garter snakes is nonnative crayfish (Rosen 1987; Holycross et al. 2006; USGS 2006; Rosen, Nowak and Brennan 2012, in review). Rosen (1987) described an inverse relationship between the abundance of narrow-headed garter snakes and crayfishes in Eagle Creek and Blue River, Arizona. Crayfish pose numerous problems for the snakes (Fernandez and Rosen 1996, Nowak and Sanatana-Bendix 2002, Nowak 2005, USGS 2006). To begin, crayfish prey on the young snakes. Holycross and others (2006) observed that most narrow-headed garter snakes in the upper Blue River and in Campbell Blue Creek had scars and missing tail tips probably attributable to crayfish, and all the snakes captured in the Black River had scars or incomplete tails. Crayfish also prey upon native fishes, competing with narrow-headed garter snakes for this food source. Crayfish further reduce the availability of the snake's native fish prey by competing with the fish for food and cover. Rosen, Nowak and Brennan (2012, in review) found a strong correlation between crayfish abundance and injuries to narrow-headed garter snakes and found a negative correlation between abundance of crayfish and native dace. Crayfish also alter the physical structure of habitat for the snake and its prey by removing aquatic vegetation (Nowak 2006).

There is also indirect evidence that the introduction of bullfrogs has eliminated populations of narrow-headed garter snakes in Wall Lake (see Fleharty 1967) in East Fork of Gila River, New Mexico (New Mexico Department of Game and Fish 1997, Rosen and Schwalbe 2002). Bullfrogs prey upon the young snakes and, to a lesser extent, may compete with the snakes for food.

D. Inadequacy of Existing Regulatory Mechanisms

Existing regulatory mechanisms have failed to mitigate the decline of the narrow-headed garter snake in the United States. The following state and federal agencies share primary responsibility in managing the snake: U.S. Fish and Wildlife Service, U.S. Forest Service, Arizona Game and Fish Department, and New Mexico Department of Game and Fish.[1] State and federal regulatory mechanisms affecting narrow-headed garter snakes are discussed below.

There is currently no federal protection or federal recovery goals for the narrow-headed garter snake. In 1991, the narrow-headed garter snake was listed as a Candidate Species in Category 2. 56 Fed. Reg. 58804, 58836 (Nov. 21, 1991). It remained in Category 2 until this category was terminated by the FWS in 1996. The snake is no longer considered a candidate for ESA listing. The New Mexico Ecological Services Field Office lists the snake as a "species of concern" but this status provides no protection and is for planning purposes only (USFWS New Mexico Ecological Services Field Office 2011).

Region 3 of the U.S. Forest Service (Southwestern Region) lists the narrow-headed garter snake as a sensitive species (USFS 2007). But sensitive species designations afford little

[1] A record of the snakes at Fort Apache Indian Reservation exists (Hulse 1973) but it is unknown whether the snakes still exist there so tribal regulatory mechanisms are not analyzed.

protection, requiring only that the impacts be considered but not preventing actions that would harm the snake. Thus, the Forest Service can conclude in a Biological Evaluation that individuals or populations will be harmed or destroyed by an action, but still carry out this action.

The narrow-headed garter snake has been documented on five national forests managed by the U.S. Forest Service: Apache-Sitgreaves, Coconino, Gila, Prescott, and Tonto (USFS 2007). We reviewed the land and resource management plans for these forests. None of the plans for national forests in Arizona have management standards specifically aimed at benefitting the narrow-headed garter snake. In fact, none of these plans even mention the narrow-headed garter snake (USFS 1985, 1986b, 1987a, 1987b).

Only the plan for the Gila National Forest in New Mexico specifically mentions the narrow-headed garter snake, as one species in the list of state and federally listed endangered and threatened species on the forest (USFS 1986a). The Gila National Forest includes some standards relating to forest management for the benefit of endangered and threatened species, such as: "Accomplish threatened and endangered species habitat improvements as identified through approved management and recovery plans" (USFS 1986a). Projected activities under this standard vary by management area but include measures such as construction of protective fencing and stream improvements. Cattle exclosures along occupied creeks would benefit the snake (A. Holycross, personal communication), and it appears that livestock have been largely excluded from streams in the Gila National Forest since at least 2003, except for a few points to allow cattle to drink (Pierce 2007). Although the Gila National Forest has enforceable standards that could benefit the snake, the Gila National Forest covers only a small proportion of the range of the snake. In addition, the standards do not adequately address all of the threats to the persistence of the snake. In particular, introduced fishes and other nonnative predators pose a significant threat to the snakes on national forest lands.

The narrow-headed garter snake is not receiving adequate protection at the state level either. Arizona does not have an endangered species law but the narrow-headed garter snake is listed on Arizona's "Wildlife of Special Concern" list (AGFD 2010). This means that the species is or may be in jeopardy, or has known or perceived threats or population declines (AGFD 2011). But this list serves only to notify of the species' status, and does not require any conservation or management actions. It is illegal to kill or collect the snakes in Arizona.

In New Mexico, the narrow-headed garter snake was listed as threatened in 1975 and was later determined to be a species of greatest conservation need for New Mexico under the Comprehensive Conservation Strategy (New Mexico Dept. of Game and Fish 2006). It is illegal to kill or collect the snakes in New Mexico. The New Mexico Department of Game and Fish has taken some measures to benefit the snake, including drafting a recovery plan in 2007. Yet there is no guarantee that the conservation measures recommended in the recovery plan will be implemented. The NMDGF does not manage habitat and therefore can only make voluntary recommendations on how to manage habitat for the snake. And the New Mexico Wildlife Conservation Act has no provision for restricting private property use to protect any species (Pierce 2007). The fact that the narrow-headed garter snake in New Mexico continues to decline provides convincing evidence that existing regulatory mechanisms are insufficient.

None of the various federal and state designations for the garter snake offer adequate protections to the species or its habitat. In particular, although almost all the primary prey species for the narrow-headed garter snakes, which are native fishes, are federally or state protected, prey declines have continued and expanded into new areas (Unmack and Fagan 2004; Olden and Poff 2005). And while much of the land around the rivers is managed by federal agencies, surrounding areas are mainly privately owned, where no formal measures to protect narrow-headed garter snake habitat are in place and native fish conservation may be obstructed in some cases. As the International Union for the Conservation of Nature (Hammerson 2007) explained, "There are few if any adequately protected occurrences of the species." For all these reasons, the existing regulatory mechanisms are inadequate.

E. Other Natural and Anthropogenic Factors

Climate Change

As habitat specialists, narrow-headed garter snakes are highly susceptible to climate change (Wood et al. 2011). Change in climate might alter the riparian systems the narrow-headed garter snake inhabits (Meyer and Pulliam 1991). For example, alteration of climate might lead to greater flooding events that could potentially increase sedimentation, which in turn would affect the spawning of native fishes, the main prey base for the snake (Pierce 2007). Conversely, flood scour disproportionately reduces exotic fish populations, benefiting native fishes (Meffe and Minckley 1987; Minckley and Meffe 1987), which may positively affect the narrow-headed garter snake, while low-water periods with little flooding may allow exotic fishes to increase in relative abundance and impacts on native species (Probst et al. 2008).

Climate change may offer new opportunities for the spread of exotic, predatory, warmwater fishes, such as centrarchids and ictalurids, up into remaining headwaters populations of the narrow-headed garter snake, while simultaneously causing increased evaporation and, probably, decreased precipitation and streamflow (Dominguez et al. 1010, and therein), putting downward pressure on narrow-headed garter snake populations and driving them toward lower elevations that are already severely impacted by these fishes.

Isolation

Many remaining breeding populations of narrow-headed garter snake are small and isolated. Wood et al. (2011) concluded that the narrow-headed garter snake is "highly vulnerable to extinction" due to "the small size of populations and their apparent isolation from each other." Small effective population sizes or low gene flow among populations can act to reduce population viability via inbreeding depression (Saccheri et al. 1998). In addition, small, isolated populations are more susceptible to extirpations due to stochastic events (which are likely in the unstable, exotics-invaded aquatic communities in the American Southwest and northwestern Mexico), human impacts, and environmental factors (Soulé 1987; Begone et al. 1990). Once extirpated, isolation precludes recolonization of habitat.

A notable concern for the narrow-headed garter snake is the isolation of the central Arizona populations in Oak Creek Canyon and East Verde River (NatureServe 2006). The near-

absence of a mainstream population makes repopulation of these streams during local extinction events highly unlikely. Similar problems occur throughout most the species' range in the U.S.: in the Salt, Gila, and San Francisco river mainstems, narrow-headed garter snakes are, as in the Verde, either gone or nearly gone, and likely declining if and where they do still occur.

IX. CONCLUSION

We have assessed the best scientific information available regarding the past, present, and future threats faced by the narrow-headed garter snake and have determined that it likely to become endangered or extinct throughout all or a significant portion of its range. Based on this information, we believe that the narrow-headed garter snake should be listed as a threatened or endangered species under the Endangered Species Act.

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