Like putting out fires: saving a secretive endangered snake from extinction

The ecology and population dynamics of most snake species are still poorly known, and many of the ones we have recently began to understand are showing alarming signs of population declines. This is especially true for species that have a specialized niche, i.e. they are highly adapted to living in a certain kind of environment or consuming only certain types of prey. In the worst-case scenario, they are adapted to both, and human-induced changes in their physical environment as well as in their prey base are threatening their survival. This is the story of one such snake species.

The narrow-headed gartersnake (*Thamnophis rufipunctatus*) is a member of the Colubridae family and Natricinae subfamily. It occurs solely in southwestern United States, in the states of Arizona and New Mexico. The species belongs to the *Thamnophis* gartersnake genus but has several characteristics that tell it apart from a 'typical' gartersnake. For example, *Thamnophis rufipunctatus* lack the dorsal and lateral stripes present in all other North American gartersnakes; instead, *Thamnophis rufipunctatus* coloration is a combination of olive to brown base combined with red to dark brown irregular spots along the body. Especially in young individuals the spots may be reddish, hence the name 'rufipunctatus'. Additionally, as the common name states, the species has an elongated head that narrows to the snout, and the eyes are set high on the head. The species is nonvenomous like other gartersnakes of this genus.

Thamnophis rufipunctatus is a small to medium-sized snake, with adult female total length 41-112 cm and males 37-84 cm. Out of the ca 30 species described in the *Thamnophis* gartersnake genus, *Thamnophis rufipunctatus* is by far most adapted to a life in streams and rivers. These snakes feed exclusively on fish and have a prehensile tail that enables them to anchor themselves underwater in swift currents. Typically *Thamnophis rufipunctatus* can be found in well-lit, cool, clear, rocky streams with overhanging vegetation. However, recent radio-tracking studies have revealed that although highly aquatic, individuals of this species spend considerable amounts of time out of water. During early spring and early fall the snakes use upland habitats up to 100 m from the water, and during the summer months they are strongly associated with boulders and rock crevices in the floodplain. During the summer months, telemetered *Thamnophis rufipunctatus* in Arizona were found in the water during less than 25% of the times they were tracked, yet were frequently found within 100 m of the water's edge (Nowak 2006, unpublished). Riverbank vegetation and vegetated islands in streams enable thermoregulation while offering shelter from predators; for example, the snakes may use shrub- and sapling-sized plants for basking at the water's edge and simply dive down when threatened. *Thamnophis rufipunctatus* are active from March-April to November, mostly during the day and dusk, until they enter hibernation. The hibernation sites in rocky outcrops may occur as far as 200 m upland, out of the floodplain. However, summer home ranges may reside less than 800 m away from the hibernation site. *Thamnophis rufipunctatus* are viviparous (giving birth to live young, which are contained within placentas) and breed annually, with females giving birth to 4-18 offspring around mid-July to early August. Individuals reach sexual maturity around 2 (males) or 2-3 years (females) of age in the wild and have a lifespan of at least 10 years.

Most aquatic snakes use a sideways head sweep to capture prey and appear to rely mostly on tactile cues in detecting underwater prey. *Thamnophis rufipunctatus*, on the other hand, use fast forward strikes to capture their prey and possess improved underwater visual acuity to detect it (Alfaro 2002). The head shape of *Thamnophis rufipunctatus* is presumed to be an additional adaptation to this predation mode: compared to the heads of generalist taxa, the elongated wedge-shaped head reduces drag during underwater strikes, especially during mouth opening in order to grab the prey item. *Thamnophis rufipunctatus* do not actively search for prey in open water; instead they are ambush predators that prefer striking at prey from a submerged refuge, such as rocks and other submerged structures. Most *Thamnophis rufipunctatus* prey consist of fish 2-6 cm long, including

native species such as Sonora sucker (*Catostomus insignis*), desert sucker (*C. clarki*), speckled dace (*Rhinichthys osculus*), roundtail chub (*Gila robusta*), Gila chub (*Gila intermedia*), and headwater chub (*Gila nigra*) (Hibbitts et al. 2009). They also prey on non-native species like western mosquitofish (*Gambusia affinis*) and fingerling size classes of brown trout (*Salmo trutta*). On the other hand, *Thamnophis rufipunctatus* fall prey to many species of birds and mammals, including raptors, herons and raccoons, as well as other snake species. Non-native crayfish and predatory fishes also consume them.

Taxonomical and population status of narrow-headed gartesnakes

Traditionally *Thamnophis rufipunctatus* has been considered as one species with a disjunctive distribution in the United States and north-central Mexico. In 1985 Wilmer Tanner recognized three different subspecies based on their morphology, and only one of these occurred in the US (Tanner 1985). Over 20 years later Wood et al. (2011) stated that *T. rufipunctatus* is in fact a species complex. Based on multilocus analysis of nuclear DNA they recognized taxonomic divisions and geographic isolates that coincide with the three subspecies described by Tanner (1985). The species currently recognized include Mogollon Narrow-headed Gartersnake *T. rufipunctatus* (distribution in the US, in the states of Arizona and New Mexico), Madrean Narrow-headed Gartersnake *T. unilabialis* (in north-central Mexico), and Southern Durango Spotted Garter Snake, *T. nigronuchalis* (in southern Mexico). Of these three, the ecology and status of *Thamnophis rufipunctatus* is most well-known.

The recent separation of these species has important conservation implications, as it means that two US states alone are responsible for the well-being and survival of *Thamnophis rufipunctatus*. The historic range of *Thamnophis rufipunctatus* in Arizona and New Mexico has shrunken by at least 60% in the last 30 years, with very recent declines and extirpations. The current distribution is limited to two primary watersheds (Gila and Salt river systems) in north-central Arizona and southwestern New Mexico. This general distribution is divided into subpopulations that occur in mid- and high-elevation streams and rivers (> 1000 m a.s.l.) connected to these primary watersheds. Based on genetic analyses, both the populations in the two primary watersheds and the subpopulations within each of those watersheds are genetically isolated (Woods et al. 2011). All populations exhibit low levels of nuclear DNA diversity, and Woods et al. (2011) concluded that "*T. rufipunctatus* (sensu novo) appears to be highly vulnerable to extinction."

This vulnerability is also obvious when looking at the 41 known *Thamnophis rufipunctatus* locations sampled sporadically since 1911: over 75% (31 localities) are 'likely not viable' and five are considered 'likely extirpated' (US Fish and Wildlife Service 2014). The San Francisco River population serves as an example of a recent, drastic decline which led to a "likely not viable" status: the population disappeared in less than 10 years, without any known catastrophic event (Hibbitts et al. 2009). With only five 'likely viable' populations remaining, the US Fish and Wildlife Service declared *Thamnophis rufipunctatus* as 'threatened' in 2014. This means that the species is 'likely to become endangered in the foreseeable future throughout all or a significant portion of its range'. One should note that there are differences in the threatened species categories between US legislation and the IUCN (International Union for Conservation of Nature). The current Red list assessment of *Thamnophis rufipunctatus* from 2007 considers populations in the US and Mexico as one species, hence the species has been categorized as 'least concern' (Hammerson 2007).

To increase uncertainty, this species is not an easy one to observe and survey in order to assess its population status: "Narrow-headed gartersnakes are well-camouflaged, secretive, and very difficult to detect in structurally complex, dense habitat where they could occur at very low population densities, which characterizes most occupied sites." (US Fish and Wildlife Service 2014). At low population densities the species can thus go unnoticed for long periods of time. At moderate to high densities the presence of the species can be reliably confirmed with reasonable search efforts.

Systematical surveys of *Thamnophis rufipunctatus* are conducted using two nonexclusive methods, live-trapping and visual encounter surveys (VES). For live-trapping minnow traps are set along river banks to lure fish prey and snakes moving along the riverside to enter the trap. Traps are left only half submerged so that any captured snakes can still breathe. Visual encounter surveys consist of 2-3 persons wading in the river and roaming along the banks on both sides, looking for any snakes swimming, hiding or basking in the area and trying to capture all observed individuals. For research purposes all snakes are measured, weighted, and marked for individual identification. Modelling recapture rates of previously marked individuals allows estimation of e.g. population size and survival.

Multiple threats to *Thamnophis rufipunctatus* existence

Human activities are threatening *Thamnophis rufipunctatus* survival in many different ways. Immediate threats to a mostly aquatic species are related to physical changes in habitat, including availability of water as well as the structure of stream banks and substrates in the stream. Anthropogenic land use has modified the wetlands and waterways in the southwest US since mid-1800s. For example, dams, diversions, flood-control projects, and groundwater pumping have resulted in one third of Arizona wetlands either drying out or becoming otherwise unsuitable. Overall, at least 35 percent of Arizona's perennial rivers have already been dewatered, and water use is constantly increasing. Residential and commercial development near riparian zones usually results in the loss of stream flow, changing perennial streams into ephemeral ones. Development also modifies riparian vegetation and leads to increased human use of the riparian zone, i.e. *Thamnophis rufipunctatus* habitat.

In addition to habitat loss and alteration, humans represent an immediate threat to *Thamnophis rufipunctatus*. Although a federally protected species, *Thamnophis rufipunctatus* are still illegally captured by collectors of rare reptile species. Increasing recreation use and human visitation rates of riparian zones increase the potential for snake encounters in general and adverse human interactions specifically. Unfortunately, these encounters often lead to the capture, injury, or death of the snake. *Thamnophis rufipunctatus* are vulnerable to detrimental interactions with recreating humans, partly because they are often mistakenly assumed venomous due to the narrowing head shape, and partly because they are often confused with other snake species. Most often *Thamnophis rufipunctatus* are misidentified as the venomous water moccasin (cottonmouth, *Agkistrodon piscivorus*), which, however, occurs over 1000 km away of the *Thamnophis rufipunctatus* distribution range! Dogs running off leash are suspected to occasionally kill *Thamnophis rufipunctatus*.

Even if we managed to conserve all current waterways with *Thamnophis rufipunctatus* and all illegal killing and capturing would end this minute, the species would still not be safe. Several nonnative species, transported to new environments by humans either intentionally or unintentionally, threaten *Thamnophis rufipunctatus* survival by competing for the same prey and also by preying on *Thamnophis rufipunctatus*. The most harmful nonnative fish in this regard is the largemouth bass (*Micropterus salmoides*). Also nonnative crayfish (*Orconectes virilis*) compete for the same fish prey with *Thamnophis rufipunctatus* and prey on juvenile snakes. Crayfish also change the structure and abundance of aquatic vegetation by grazing, and their burrowing activities may increase siltation of stream bottoms. While the exact effect of nonnative species on *Thamnophis rufipunctatus* survival is yet unknown, *Thamnophis rufipunctatus* abundance often declines in rivers where nonnative fish increase in abundance.

Habitat changes, nonnative species, killing and capturing all erode *Thamnophis rufipunctatus* numbers slowly over time. Yet another phenomenon, forest fires, can rapidly wipe out an entire snake population. Low-intensity fires are a natural recurring phenomenon in southwestern US, but the existing wildfire suppression policies have altered fuel loads in the ecosystems and have thus in fact increased the probability of high-intensity wildfires. The frequency of large fires has increased

especially since mid-1980s, and such fires have already occurred within *Thamnophis rufipunctatus* distribution range more than once. For example, the Whitewater-Baldy Complex Fire in SW New Mexico in 2012 burned 1 214 km^2 of forest and grassland habitats and caused two *Thamnophis rufipunctatus* populations to decline dramatically. One of these populations has apparently been completely extirpated, as no *Thamnophis rufipunctatus* have been observed since three surviving individuals were found in 2014 (Nowak and Drost 2015, unpublished).

Snakes can escape forest fires by diving into the water or hiding underground and surviving there for those days when smoke blacks out the sun. The actual threat materializes after the fire has died down, in the shape of monsoon rains, which in the Southwest typically begin in early July. The rains pouring down will wash away all the ash from the dry, burned ground and carry that ash and soil down to the river. The ash and other debris flowing into the rivers and creeks interfere with the respiration of fish and other aquatic animals by directly clogging their gills; in effect fish die from suffocation. The decaying organic material also decreases water oxygen levels, which reduces fish reproductive success. This leaves surviving *Thamnophis rufipunctatus* without prey, and although they can fast for a while, in the end they starve to death. The ash and silt flowing into the river system also has structural effects in the habitat, important both for the fish and the snakes: the silt fills all crevices and holes that fish use to lay their eggs and the snakes use to hide in order to ambush their prey. Increased water turbidity may also lower the hunting success of visually oriented *Thamnophis rufipunctatus*. The negative impacts of a large forest fire in a river ecosystem may last for years.

When the worst thing imaginable happens

On Tuesday 20.5.2014 fire broke out in a forest just north of Slide Rock State Park near Sedona. Humans recreating in Oak Creek likely started the fire, and it spread rapidly despite all effort to contain it. In the end the fire raged uncontrolled for 16 days, and by this time it had ravaged about 85 km^2 of land and the costs were estimated at ca 9.5 million € (10.1 million US $). The fire raised special concerns in herpetologists and researchers as it hit exactly one of the few strongholds of the species, with the largest and densest population of *Thamnophis rufipunctatus* known. Because of this several researchers, with Dr. Erika Nowak and the US Fish and Wildlife Service at lead, urgently began planning measures to rescue the Oak Creek *Thamnophis rufipunctatus* population from possible extirpation. The first mission of the operation was to estimate the status of the population before the monsoon rains began.

- The survey and rescue mission required extensive manpower and collaboration over bureaucratic borders. Overall the team included over 40 people from the US Fish and Wildlife Service, US Forest Service, Arizona Game and Fish Department, Northern Arizona University (NAU) graduate students and undergraduate interns, as well as non-governmental organizations such as Oak Creek Ambassadors and several other volunteers. Working through the survey areas was extremely dangerous due to the possibility of rockslides and dead, burned tree snags lining the burned areas of the creek that could fall. The creek was closed to all visitors and we had to get special permission to do our work. We had to wear hard hats and be accompanied at all times by a certified Forest Service firefighter, Nowak explains.

The second part of the mission was perhaps more controversial: the team wanted to capture and salvage snakes to keep them in captivity. This way at least some of the genetic variation of the *Thamnophis rufipunctatus* population would be saved in case the worst thing imaginable happened and the floods would wipe out the whole population. The team succeeded in capturing 43 *Thamnophis rufipunctatus* before the monsoon season. Of these 11 juvenile snakes (6 males and 5 females) were transferred to holding facilities at NAU.

- However, keeping *Thamnophis rufipunctatus* alive and well in captivity is no easy task because they are very sensitive. They get easily stressed by handling and are prone to both heat stress and

dehydration in normal indoor conditions that suit most snakes just fine. This eventually makes them susceptible to infection by pathogenic bacteria and kidney diseases, says Nowak.
Fortunately Nowak, NAU and Phoenix Zoo had previous experience on the matter, as they had attempted to keep and breed *Thamnophis rufipunctatus* in captivity since 2007. During those early years over half of the captured animals died before the best husbandry practices for the species were understood.

The captured Oak Creek juveniles thrived during their first year and a half of captivity, growing quickly to reproductive size. Even one male that was found severely wounded recovered and grew normally. Following previous standard protocol the animals were hibernated in aquaria in commercial refrigerators with the temperature adjusted to <10 °C. However, keeping the snakes hydrated enough during hibernation proved challenging, and during winter 2015 and spring 2016 three individuals died. They succumbed not only due to dehydration but also because of an explosion of microscopic blood-sucking mites that the snakes were apparently carrying when they were brought in from the wild. The mites lived on the snakes' skins and transmitted bacterial infections through bites. In the following winter the hibernation conditions were improved and snakes were treated for mites. Yet two more captives died in 2016, one from a tumor and one of a long-standing bacterial infection that could not be resolved.
- After all this it remained clear that even with the best attempts to provide the most optimal situations in captivity, this species does not do well in typical indoor aquaria settings, Nowak summarizes.

In the meantime, the Phoenix Zoo had pioneered a new kind of facility- a semi-outdoor vivarium that included running water and a pool for swimming and hunting live fish, subterranean hiding spaces, vegetation, rocks, and climbing opportunities. The *Thamnophis rufipunctatus* they had been keeping in indoor tanks were transferred to this facility and their health and survival improved substantially. Hence, in 2015-2016 NAU built their own vivarium and transferred all surviving snakes (three males and three females) there in the fall of 2016. The vivarium includes two pools, a stream with riffles, a waterfall, rock walls, native plants, underground heated hibernation boxes, heated basking spots, and logs for climbing. The soil in the vivarium was sourced from the natural habitat of the snakes in Oak Creek, as do the native prey fish species that also live in the water feature.
- *Thamnophis rufipunctatus* appear to be doing much better in their new facility, exhibiting normal behaviors, including successfully hunting the fish. We expect first offspring to be born in 2017. If everything goes according to plan, after at least a year of growing in captivity they will released back into the wild to augment the population in Oak Creek or in other connected river drainages, Nowak explains.

A glimmer of hope for *Thamnophis rufipunctatus* survival?
In the meantime, the wild population in Oak Creek lucked out relative to the Slide Fire: the post-fire effects were not nearly as bad as were expected. Some ash and silt was washed into the creek in the months after the fire during the summer monsoon in 2014; however, in most areas this was not enough to kill fish or substantially change the habitat. In addition, the US Forest Service conducted aerial reseeding to encourage vegetation to grow in the most heavily burned areas, which reduced erosion even further. *Thamnophis rufipunctatus* detections in yearly surveys are similar to numbers seen before the fire.

On the whole, however, the future of the species looks rather bleak. For example, nonnative predatory fish are known to occur in 85% and crayfish in 75% of the historical distribution (US Fish and Wildlife Service 2014), while survey sites consisting of only native fish communities are getting rarer. At this time, other than manual removal of non-native predators, and chemical removal of fish through piscicides (e.g. rotenone), there are few viable ways of removing non-

native predators from *Thamnophis rufipunctatus* habitats. In addition, predictions from different climate change models suggest a shift to increasing aridity in the Southwest. This means that a large proportion of snake habitats within the current distribution may be at risk of becoming ephemeral or drying out completely. Rising temperatures may also enhance the spread of nonnative species by providing more suitable habitat for them, while species adapted to cooler environments (such as *Thamnophis rufipunctatus* and their prey) find their surroundings increasingly unsuitable. Diminishing populations experiencing increasing isolation are also at risk from intrinsic negative genetic effects like inbreeding. Climate change may also exacerbate emerging pathogens like snake fungal disease.

Despite all this, researcher and herpetologist Erika Nowak is hopeful. With *Thamnophis rufipunctatus* listed as federally threatened by the US government, awareness has been raised of the plight of this enigmatic species, and additional funding is available to assist with ongoing monitoring and new research. Experiences of releasing captive-bred animals into the wild have been encouraging.

- A wild population of *Thamnophis rufipunctatus* that was translocated from creeks impacted by a large forest fire in New Mexico to a similarly nonnative-free creek in 2012 has survived, and is now breeding in its new environment. In August 2016 captive-born juveniles from the Phoenix Zoo were released into a creek that was protected from invasion by nonnative aquatic species by virtue of its geography. Most individuals survived at least the first few months after release, and their persistence will be monitored in coming years, Nowak explains.

Ongoing *Thamnophis rufipunctatus* research examines the role of disease both in the wild and in captivity with a goal toward improving captive husbandry conditions even more. Additional funding is needed to build more vivaria to ensure that the genetics of all remaining *Thamnophis rufipunctatus* populations are secure.

- Longer-term research could focus on developing methods for nonnative species removal in the wild, so that captive-bred animals may repopulate historic locations and successfully augment currently struggling populations. I have to keep some hope regarding the future of this species; otherwise I could not go on, Nowak states.

#info box

Short biography: Erika M. Nowak

Born in 1969 in upstate New York, Erika has always been outdoor person and interested especially in amphibians and reptiles. After working as a field assistant and a zookeeper intern as well as earning her BS in Wildlife Biology (1991, Cornell University) in the East, she turned her course to southwest and arrived in Arizona in 1992. Erika's MSc thesis in Biology (1998, Northern Arizona University) handled the biological effects and management effectiveness of nuisance rattlesnake translocation, a topic still close to her heart. In her PhD (2009, NAU) she investigated the ecology and potential predatory roles of venomous reptiles living in place in national parks, as well as the trophic-level impacts of provisioning food and water to rattlesnake prey in human-developed areas. Currently she works in Flagstaff, Arizona as a Herpetologist at the USGS Colorado Plateau Research Station and part-time lecturer at Northern Arizona University. Erika is well known for her work with declining gartersnakes, including Northern Mexican gartersnakes in addition to *Thamnophis rufipunctatus*. She is also regionally famous for her safe and humane rattlesnake handling and translocation trainings for state, federal, and local agencies and private groups. The trainings encourage safe coexistence with and management of venomous snakes. Her research focuses on the ecology, behavior, conservation, and management of herpetofauna, with the aim of providing science-based data and policy reviews for management and policy makers. Along with research, Erika also focuses on education and student supervision at all levels, as well as providing public outreach and volunteer training. She has been awarded several times for her efforts in education and conservation.

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abstract

The narrow-headed gartersnake (*Thamnophis rufipunctatus*) is a non-venomous, highly aquatic snake species that feeds exclusively on fish. Its distribution is limited to two primary watersheds in the states of Arizona and New Mexico in the USA, where the species is federally listed as

‘threatened’. The population has declined due to a multitude of factors, including killing by humans, habitat degradation and destruction, competition with and predation by nonnative species, changes in aquatic habitat after forest fires, and inbreeding due to increasing isolation. However, recent successes in captive breeding as well as translocation and release of captive-born individuals give hope for the species’ survival.

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