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Article *in* Chelonian Conservation and Biology · June 2017

DOI: 10.2744/CCB-1166.1

Chelonian Conservation and Biology, 2017, 16(1): 000–000
doi:10.2744/CCB-1166.1

Hatching Success and Other Reproductive Attributes of Gopher Tortoises in Southwest Georgia

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ABSTRACT. – **Broad variation in egg hatching success observed in gopher tortoise (*Gopherus polyphemus*) populations led us to investigate hatching success and other reproductive attributes within a unique, high-quality site in the eastern portion of the species' range. We documented use of a juvenile tortoise burrow as a nest site, a mean clutch size of 5.9 eggs, long oviposition-to-hatchling emergence times (96–128 d), and 73% hatching success for predator-protected eggs. Although consistent with previous reports of greater hatching success in eastern gopher tortoise populations than in western ones, hatching success at our eastern site was on the low end of values from other eastern populations, possibly reflecting above average rainfall during this study.**

Gopher tortoises (*Gopherus polyphemus*) inhabit dry upland areas within the Coastal Plain of the southeastern United States from Louisiana to South Carolina. Habitat loss and alteration threaten gopher tortoises range-wide (Auffenberg and Franz 1982; US Fish and Wildlife Service [US FWS] et al. 2013), but in some populations, low egg-hatching success represents another threat to population stability (Epperson and Heise 2003; Ennen et al. 2010; Noel et al. 2012). When protected from predators, naturally incubated eggs from eastern populations (east of the Tombigbee River) exhibit high hatching success (67–97%; Landers et al. 1980; Smith 1995; Butler and Hull 1996). However, for uncertain reasons, predator-protected eggs from western populations, where gopher tortoises are listed as Threatened under the Endangered Species Act of 1973 (US FWS 1987), exhibit low hatching success (18%–47%; Epperson and Heise 2003; Hammond 2009; Noel et al. 2012).

To help document variation in gopher tortoise reproductive potential, we investigated egg hatching rates in an eastern population of gopher tortoises inhabiting a longleaf pine forest (*Pinus palustris*) in southwestern Georgia. The biologically diverse longleaf pine ecosystem is hypothesized to be a major ancestral habitat of the gopher tortoise (Guyer and Hermann 1997) but today is one of the most endangered ecosystems in North America (Noss et al. 1995; Van Lear et al. 2005). Our study site, Arcadia Plantation, was composed of mature longleaf pine forest and included the Wade Tract, one of only a few remaining old-growth longleaf pine stands. We were particularly interested in determining hatching rates of tortoise eggs at this site given its potential reference and conservation value and because tortoise egg-hatching success had not been previously investigated at this eastern location.

Methods. — We studied tortoise nests on Arcadia Plantation (30°45′N, 84°0′W), a 957-ha property located in Thomas County in southwestern Georgia, USA. Arcadia Plantation is dominated by mature (> 80 yrs) longleaf pine forest and is managed using frequent prescribed burns (≤ 2-yr return intervals). The study site included the Wade Tract, an 80-ha, old-growth research area that has never been heavily cut and contains many old (> 200 yrs) trees (Platt et al. 1988). Ground cover on both Arcadia Plantation and the Wade Tract was dominated by wiregrass (*Aristida stricta*), oaks (*Quercus* spp.), and a diverse assemblage of other native plants (Ambrose 2001). Soils at the site are a complex mosaic of sand and clay (National Resources Conservation Service 2016).

We located nests in May and June 2013 primarily by looking for evidence of nesting at tortoise burrow aprons (area of bare soil located in front of burrows), such as sand kicked behind burrow entrances (M. Hinderliter, *pers. comm.,* January 2013). We also searched for signs of nests at juvenile tortoise burrows and in other open areas. Additionally, we found some nests by setting time-lapse video cameras at adult burrows thought to contain female tortoises or to be potential nesting sites. Although we did not check potential nest sites daily, all discovered nests appeared to have been recently laid. We determined exact oviposition dates for 6 nests from video observations of nesting tortoises and for a seventh nest from a combination of video and visual observations. Upon finding an intact nest (one that was not damaged by a predator), we buried hardware cloth above the nest just below the ground surface, and, in most cases, secured the cloth using stakes to deter potential predators from excavating eggs. We did not handle or move eggs, but we did briefly partially uncover and examine (without moving) the top eggs of 3 nests later in the incubation period.

In late July, we replaced nest protectors with cages that would continue to protect nests yet also allow hatchlings to emerge and be retained. We constructed nest cages ($40 \times 40 \times \sim 6$ cm [width × length × height]) using hardware cloth, staked them into the ground above nests, and buried their edges in the substrate. We affixed a small piece of burlap to one or more sides and corners of each nest cage to provide a small shaded area for emerging hatchlings (Epperson and Heise 2003; Noel et al. 2012). Beginning in early August, we visited each nest site daily to check for hatchlings. When hatchlings began to emerge in early September, we increased visit frequency.

When emerged hatchlings were encountered, we removed them from the nest cage. In some instances, we also removed hatched siblings if they had resorbed the yolk sac to prevent potential depredation by red imported fire ants (*Solenopsis invicta;* Landers et al. 1980; Smith 1995) prior to complete nest emergence. In one case, we loosened hard-packed clay from above a nest where hatchlings could be heard trying to scratch through to the surface. These hatchlings had already dug nearly to the surface and likely would have emerged without assistance by the following day when heavy rains loosened soils. In late October, > 2 wks later in the year than when hatchlings at this latitude are known to emerge (Landers et al. 1980; Smith 1995; Butler and Hull 1996; Epperson and Heise 2003; Noel et al. 2012), we excavated all nests to determine the number of remaining live hatchlings, dead hatchlings, or unhatched eggs.

We compared monthly rainfall totals at our site in 2013 (recorded by a mobile weather station) with historical monthly rainfall totals recorded at a Global Historical Climatology Network weather station (Station ID: GHCND:USC00098666) located ~ 20 km northeast of our study site. Complete data were available for most years during 1893–2012 from the National Oceanic and Atmospheric Administration National Climate Data Center (available at ncdc.noaa.gov, accessed 4 March 2015). Summary statistics are presented as means ± 1 standard deviation.

Results and Discussion. — From 28 May to 16 June 2013 we located 20 recently laid gopher tortoise nests. Predators destroyed 2 nests and disturbed 1, leaving 17 nests for monitoring. These 17 nests were distributed among the following locations: aprons of adult tortoise burrows (13); in a dirt road (1); in the apron of a juvenile gopher tortoise burrow (1; burrow entrance width ~ 13 cm); next to a cut tree stump (1); and in a sparsely vegetated area not directly associated with a tortoise burrow (1). Gopher tortoises frequently nest in the aprons of adult burrows (Landers et al. 1980; Butler and Hull 1996; Epperson and Heise 2003; Noel et al. 2012; but see Smith 1995), but observations at our site indicate they also nest in the aprons of juvenile tortoise burrows. We located 2 tortoise nests at juvenile burrow (burrow entrance widths ~ 13 and ~ 18 cm) aprons at this site in previous years while setting bucket traps to capture young tortoises (T.A.R., unpubl. data, 2011, 2012).

Female tortoises potentially use juvenile burrow aprons as nest sites for some of the same reasons that they nest at adult burrow aprons. For example, relative to surrounding areas, both adult and juvenile burrow aprons contain less vegetation that can interfere with nest excavation (Landers et al. 1980; T.A.R., unpubl. data, 2013). Additionally, these bare sites are likely warmer than surrounding microhabitats, which may be important for successful incubation. Burrow aprons are also located next to a refuge that hatchlings can temporarily occupy following nest emergence (Radzio et al. 2009). To avoid damaging tortoise eggs, investigators setting bucket traps in front of burrows of juvenile tortoises during the incubation season are advised to check carefully for nests.

Hatchlings emerged from 2 September until 10 October 2013. Peak hatchling emergence occurred during 17–27 September, when the first hatchlings emerged from 10 of 16 nests. For 16 nests that produced hatchlings, mean time from discovery of a nest to emergence of the nest's first hatchling was 108.3 ± 8.7 d, but varied by > 4 wks (range = 96–128 d). For 7 of these nests with known oviposition dates, mean time from oviposition to emergence of the nest's first hatchling was 112.6 ± 10.5 d (range = 97–128 d). Mean and maximum oviposition-to-hatchling emergence times were longer, generally substantially, than reported for other northern gopher tortoise populations (Landers et al. 1980; Smith 1995; Butler and Hull 1996; Noel et al. 2012). We hypothesize that above average rainfall resulted in lower incubation temperatures, leading to the long hatchling-emergence times observed in this study. Additionally, the nest with the longest hatchling-emergence time (128 d) was in a relatively shaded burrow apron.

Mean hatching success of individual nests was 69.4% ± 34.7% (*n* = 17). Seventy-four of 101 (73%) eggs hatched, which is on the low end of hatching rates reported for other eastern gopher tortoise populations (67%–97%; Landers et al. 1980; Smith 1995; Butler and Hull 1996), but still higher than reported for tortoise eggs from western sites (18%–47%; Epperson and Heise 2003; Hammond 2009; Noel et al. 2012). Sixteen of 17 nests produced ≥ 1 live hatchling, and 7 of 17 nests exhibited complete hatching success. Of 27 eggs that failed to hatch, only 4 (15%) contained dead hatchlings that were almost fully developed (i.e., scutes present). The low proportion of late-stage egg failures in our study is consistent with the results of Butler and Hull (1996), the only study to report development stage of failed eggs for an eastern population of gopher tortoises. However, late-stage failures accounted for up to 53% of unhatched eggs in western populations (Epperson and Heise 2003; Hammond 2009; Noel et al. 2012). Mean clutch size was 5.9 ± 1.8 (range = 3–9 eggs).

Although our observations are consistent with previous reports of greater hatching success in eastern gopher tortoise populations than in western ones (Epperson and Heise 2003; Hammond 2009; Noel et al. 2012), hatching success at our eastern site was on the low end of values reported from other eastern populations (Landers et al. 1980; Smith 1995; Butler and Hull 1996). Notably, rainfall was much higher than average during much of the incubation period in our study. Total July rainfall at the study site (25.7 cm) was greater than was observed at a nearby weather-sampling site in all but 8 of 85 preceding years and was also high in late June. Very high soil moisture can reduce hatching success of turtle eggs (Ragotzkie 1959; Kraemer and Bell 1980), even when soils are not fully saturated with water (McGehee 1990). Future work should examine whether egg hatching success at this site is greater in drier years.

Acknowledgments. — We thank M. Hinderliter, B. Mills, and J. Smolinsky for valuable assistance in the field. This work was funded by a McLean Fellowship in Ornithology and Environmental Science from the Department of Biodiversity, Earth, and Environmental Science at Drexel University; the Wade Tract Endowment Fund; Chicago Herpetological Society; Minnesota Herpetological Society; Western Digital Foundation; Biology Department at Drexel University; National Aeronautical and Space Administration; and Betz Chair Endowment in Environmental Science at Drexel University. We are also grateful to L. Baggett for logistical support. We thank P. Wade, the Wade Family, and the entire staff of Arcadia Plantation including P. Massey for allowing access to their property and for their ongoing support of research at the site. This work was approved by the Drexel University Institutional Animal Care and Use Committee and permitted by the Georgia Department of Natural Resources.

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Received: 3 June 2015
Revised and Accepted: 21 February 2017
Published Online: 19 May 2017
Handling Editor: Jeffrey E. Lovich