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Population Ecology of the Queensnake (*Regina septemvittata*) in an Urban Creek, 2008 to 2019

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Abstract.—**Habitat fragmentation is a common result of urbanization and species living in these fragments are at risk of extirpation. We conducted a 12-y (2008–2019) capture-mark-recapture study on snakes living in a 593-m section of Rock Castle Creek flowing through an urban area in central Virginia, USA. Our study site was occupied primarily by Queensnakes (*Regina septemvittata*). We used data from 168 individual Queensnakes to examine several aspects of their population ecology including survival rates (0.52), reproductive effort (21.3% juvenile to adult ratio), growth rates (68% and 30.6% increase for 1 to 2 y-old and 2 to 3+ y-old snakes, respectively), and sex ratio (1:1). Our population estimates, though with wide confidence intervals, showed that this population of approximately 25 adult snakes has persisted over time despite being in an urban environment. The life-history characteristics of this snake of limited movement, habitat specificity, diet specialization (eating only freshly molted crayfish, *Cambarus* spp.), and small body size likely reduced risks associated with nearby roads and parking lots. These same life-history characteristics, however, make Queensnakes vulnerable to extirpation should pollution cause declines in crayfish populations or otherwise make their habitat fragment inhospitable.**

Key Words.—ecology; natural history; population; urban ecology; watersnake

Introduction

Pockets of wildlife habitat persist in urban environments along streams and in forest fragments. The number and diversity of species in these habitat fragments is often surprising because these areas can be very close to shopping centers and roads (Alvey 2006; Purkayastha et al. 2011; Bonnet et al. 2016). When the species inhabiting these areas are snakes, their populations are at an even higher risk because some people will intentionally kill them if detected (Ernst and Barbour 1989; Whitaker and Shine 2000; Godley and Moler 2013) and mortality may also occur along roadways and from pollution in urban areas (Bernardino and Dalrymple 1992; Row et al. 2007; Snodgrass et al. 2008). Yet populations of snakes often persist in these small pockets of habitat (Reeder et al. 2015; Bonnet et al. 2016; Gangloff et al. 2017). One such habitat fragment is a portion of an urban stream in central Virginia, USA, occupied by Queensnakes (*Regina septemvittata*).

Queensnakes favor shallow streams with rocky substrates, banks that provide cover, and overhanging branches for basking (Branson and Baker 1974; Ernst 2003). One reason for this habitat specificity is because Queensnakes prey almost exclusively on crayfish (*Cambarus* spp.), particularly those that are freshly molted (Godley et al. 1984; Ernst and Barbour 1989; Gibbons and Dorcas 2004). Alteration to any of these conditions required by Queensnakes would likely have direct, adverse effects on them, including any environmental alterations that cause crayfish populations to decline (Godley et al. 1984; Ernst and Barbour 1989; Jackrel and Reinert 2011). Streams, particularly in urban areas, are being altered by contaminants, habitat destruction, and stormflow resulting from urban development (Coles et al. 2012); these changes represent challenges to the conservation of Queensnakes in urban streams.

Although Queensnake general natural history is well known, their population ecology has been less studied. Two comprehensive studies were done in rural creeks (Branson and Baker 1974; Ernst 2003) and more recent studies have examined Queensnake spatial ecology in streams located in forested and suburban areas (Leuenberger et al. 2019) and the effects of Snake Fungal Disease (SFD) on their short-term survival rates and movement patterns (McKenzie et al. 2021). Our study looks to extend knowledge about Queensnakes by examining, over 12 y, several life-history traits of a population living in Rock Castle Creek, which flows through an urban environment in central Virginia. Using capture-mark-recapture (CMR) methods, we estimated population size, annual survival and recapture rates, age-cohorts based on snake size, growth rates, sex ratios, movement patterns, and reproductive effort. We then considered Queensnake life-history traits in the context of how they may aid or hinder population persistence in urbanized landscapes.

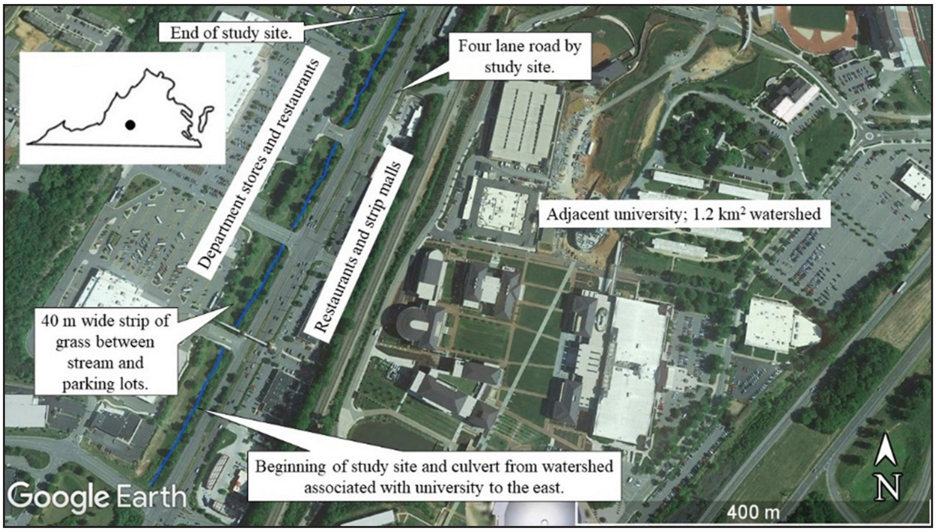

Figure 1. Aerial photograph of the urban study site in central Virginia, USA, and the surrounding development on 15 May 2017. Rock Castle Creek is represented by the thin blue line to the west of the four-lane road. (Image taken from Google; https://www.google.com/earth).

Materials and Methods

Study site.—Our study site was a 593-m section of Rock Castle Creek, an urban, second-order stream in central Virginia, USA, that flows northward, eventually running into the James River (Fig. 1). The stream was approximately 5 m wide and ranged in depth from 6–60 cm. There were seven riffles totaling 210 m and the rest of the stream was composed of runs and pools. At the onset of the study in 2008, we searched for snakes approximately 300 m upstream and downstream of our study site. The area upstream was above a culvert carrying water under a four-lane road from the watershed associated with the nearby university property (Fig. 1). Water from this watershed nearly doubled the water volume of the creek and helped maintain stream volume, especially during dry months. Downstream of the study site the creek entered three large metal pipes underneath a roadway and thereafter became steep-sided and had sluggish water flow. No snakes were found up or downstream of the study site.

On the southeast bank, Rock Castle Creek was bordered by a four-lane road approximately 8 m from the edge of the water at the top of a steep slope, whereas the northwest bank was more gradual and buffered by an approximately 40-m wide strip of grass before turning into major department store parking lots (Fig. 1). Where the banks were gradual and sunny, we placed black landscape fabric structures (tarp-like material; Fig. 2) to facilitate finding snakes (Burst 2013).

Human disturbance of the study site was substantial. Three automobile bridges crossed Rock Castle Creek in our study area and human traffic was evident under these bridges as seen by footprints, graffiti, and people occasionally camped out. The stream was also cluttered with trash such as beverage containers, plastic bags, metal pipes, toys, and discarded food wrappers.

Field methods.—We used the CMR method over a 12-y period from 1 May 2008 to 5 June 2019. One to four collectors averaged eight trips (range, 2–17 trips) to the study site per year, most of which occurred from April to June (81% of field trips). Throughout the study site, we annually set up 7–10 structures made of black landscape fabric folded over large rocks to provide warm places in which the snakes could take refuge (Fig. 2). We placed additional rocks on the landscape fabric

Figure 2. Representative snake structure constructed of black landscape fabric folded over with rocks between the folded material as well as on top to hold the structure in place when stream levels rose after storm surges. (Photographed by Rachel Beiler).

to secure the structure when stream volume increased following rainfall. The locations for our structures could change annually depending upon changes in the stream banks and at times, structures were lost due to high water velocity from storms. For each collection trip, we walked in or on the bank of the stream along the entire length of the study site looking for snakes in the water, basking on vegetation, and opportunistically under rocks, as we made our way to check each landscape fabric structure. We walked in the stream because much of the bank was either steep or covered with vegetation. Each trip ranged from 2–4 h, depending upon the number of snakes collected.

After capture, we subcutaneously implanted 8–12 mm Passive Integrated Transponder (PIT) tags (AVID Identification Systems Inc., Norco, California, USA; BIOMARK Inc., Boise, Idaho, USA) in the posterior third of the body of the snake anterior to the cloaca (Oldham et al. 2016). For all neonates and juveniles too small to PIT tag, we gave the snake a small mark using a red permanent marker (Sharpie, Newell Brands Inc., Atlanta, Georgia, USA), which provided a temporary mark until the snake shed. In addition to marking, we also measured the snout-vent length (SVL) of every captured snake. Three different field researchers performed the SVL measurements after they were trained by NR. We also determined the sex of each snake visually by examining tail morphology if the snake was large enough (> 30 cm SVL; Conant and Collins 1998). We used a GPSMAP® 60CSx (Garmin Ltd., Olathe, Kansas, USA) to record capture location (Universal Transverse Mercator [UTM] coordinates) and described the habitat unless the snake was captured under one of our landscape fabric structures. We recorded any physical abnormalities such as lesions that could be evidence of SFD caused by *Ophidiomyces ophiodiicola* (Guthrie et al. 2016; Lorch et al. 2016; Baker et al. 2019). We only re-measured snakes recaptured between years and not snakes recaptured in the same year. After processing, we immediately released all the snakes at the same location where we captured them.

On 29 April 2019, we measured crayfish abundance in Rock Castle Creek in three random locations within each riffle, run, and pool. We counted crayfish using a 0.5 × 0.5 m quadrat placed in the water surrounded on three sides by a hand seine on the downstream side. We overturned and shuffled the rocks within the quadrat to force any crayfish to float/swim back into the seine where we could easily count them.

Size-age cohorts.—The smallest snakes we captured (16–17 cm SVL) were too small to tag with the older style AVID PIT tags (8–12 mm tags that were thicker than our newer 8 mm BIOMARK tags) used in the spring of 2008 through the summer of 2018. Until the fall of 2018, we were only able to PIT tag juvenile snakes that were 25 cm SVL or longer. Starting in August 2018, we tagged juvenile snakes as small as 17 cm SVL using the thinner 8 mm BIOMARK PIT tags.

We identified Queensnake cohorts to determine age (1-y-olds, 2-y-olds, and 3+ y-olds) using a histogram of the SVLs of all captured snakes found in April and May, months when the cohorts were most easily distinguishable (Wood and Duellman 1950). To compare SVLs between male and female snakes of the 3+ y-old cohort, we used the Mann-Whitney U test (Version 27, SPSS Inc., Armonk, New York, New York, USA; $\alpha = 0.05$) because the data were not normally distributed. To compare our Queensnake SVLs to other studies, we calculated the mean SVLs from male and female snakes found throughout the year that we could confidently determine their sex (≥ 30 cm).

We used the number of juvenile Queensnakes (1-y-old cohort) to adults (2+ y-old cohort) as a measure of reproductive effort (Roe et al. 2013). We then evaluated this ratio for stability over the years of the study using a Chi-square analysis ($\alpha = 0.05$) where the ratio of juveniles to all snakes captured over the course of the entire study was used to determine expected values. To assess homogeneity of a 1:1 sex ratio over the years of the study, we used a Chi-square analysis ($\alpha = 0.05$) on all Queensnakes where sex was determinable, excluding only recaptures within a year (Branson and Baker 1974; Ernst 2003).

Growth rate.—We calculated the mean growth rates for 2-y-old and 3+ y-old PIT-tagged snakes for the duration of the active season (1 April–30 September, totaling 183 d) from individual recaptured snakes in their respective age cohort whether they were caught in consecutive years or had gap years between captures. For example, the growth rate for a snake caught on 1 April in one year and then found again on 1 May the next year had its SVL difference divided by 213 (183 + 30 d). To analyze the growth rates from PIT-tagged Queensnakes, we used Analysis of Covariance (ANCOVA) and included the initial capture SVL, year of capture, and sex in the model. We first assessed interactions between initial SVL, capture year, and sex for significance before fitting a reduced model that did not include any variables with P values > 0.05 (data normally distributed; Wilk's Shapiro $W = 0.97$, n = 33, $P = 0.641$). We converted our growth rates to mean percentage changes in growth to make comparisons between Queensnakes from our study to those from other studies (Raney and Roecker 1947; Wood and Duellman 1950; Branson and Baker 1974). We calculated percentage changes of growth for the 1-y-old to 2-y-old cohort and 2-y-old to 3+ y-old cohort from the increase of the mean SVL between cohorts.

Movement.—We used the differences in UTM coordinates for Queensnake capture/recapture locations to determine distances moved by snakes within a year as well as for snakes found between years. Because the study site portion of Rock Castle Creek was fairly straight, we calculated the linear distances moved with these UTM coordinates (Fig. 1). We determined the percentage of snakes that moved from initial capture locations and for the snakes that moved, we calculated summary statistics on distance moved. When a particular snake was found multiple times within a year or between multiple years, we used the mean movement distance for that individual.

Population estimates and survival rates.—We calculated the annual survival and recapture rates for PIT-tagged Queensnakes of the 2+ y-old cohort using Program MARK (http://www.phidot.org/software/mark/). We started with four models where survival and recapture rates were either constant or time-dependent. We then used corrected Akaike Information Criterion (AICc) to rank candidate models and if any models had ΔAICc values < 2.0, we considered them to have some support (Cooch and White. 2001. Using MARK - A Gentle Introduction. 2nd Edition. Available from http://www.phidot.org/software/mark/docs/book/ [Accessed 11 November 2018]). We estimated the annual population size for all PIT-tagged snakes of the 2+ y-old cohort using the Jolly-Seber method (Krebs 1999; Program JOLLY. Available from https://www.mbr-pwrc.usgs.gov/software/jolly.html [Accessed April 2019]). We calculated linear densities from Jolly-Seber population estimates divided by the longest distance between Queensnake captures in our study site (525 m).

Results

Snake community.—We recorded 408 snake captures (including records for recaptured snakes) from 2008 to 2019 in and along the banks of Rock Castle Creek. Our records included four Common Gartersnakes, *Thamnophis sirtalis* (range, 45–50 cm SVL; zero recaptures between years), two Eastern Ratsnakes, *Pantherophis alleganiensis* (range, 89–109 cm SVL; zero recaptures between years), 109 Northern Watersnakes, *Nerodia s. sipedon* (range, 17–72 cm SVL; mean SVL 28.6 cm; maximum SVL for males 54 cm and females 72 cm; three recaptures between years), and 168 *R. septemvittata* (range, 16–51 cm SVL; mean SVL 33.3 cm; maximum SVL for males 47 cm and females 51 cm; 33 recaptures between years; Table 1). We detected no overt, external symptoms of SFD, as described by Lorch et al. (2016), in any species of snake we caught.

Queensnake and crayfish population characterization.—Over the 12 y of the study, we had 260 records (including captures and recaptures) of 168 individual Queensnakes, mostly found under rocks and other debris near the creek and in our tarp structures (89.2%). Other Queensnakes we found either basking on branches (6.9%) or swimming/foraging (3.9%). Of the 168 Queensnakes, 99 were large enough for us to PIT tag. We caught 71 of these PIT-tagged snakes only one time, and we recaptured 28 individuals 33 times between years (Table 1). Of the 28 snakes we recaptured, 15 were caught two times in consecutive years, eight were caught two times with gaps between years, and five were caught three times in consecutive years. Sex ratio did not significantly deviate from 1:1 across the years of the study (χ^2 = 10.7, df = 10, P = 0.399). The mean number of crayfish in 2019 was 0.3 ± (standard deviation [SD]) 0.5 crayfish/0.5 m^2 (n = 9) in pools, 1.1 ± 1.7 crayfish/0.5 m^2 (n = 21) in runs, and 1.7 ± 1.9 crayfish/0.5 m^2 (n = 24) in riffles.

Age cohorts and growth rates.—We determined three age cohorts for snakes we found in the spring. Juveniles (1-y-old cohort) were born the previous summer/fall based on typical Queensnake birth size (Branson and Baker 1974; Ernst 2003) and ranged from 16–22 cm SVL with a mean SVL of 18.8 cm (Fig. 3). The snakes born the prior summer were the 2-y-old cohort and ranged from 26–35.5 cm SVL with a mean SVL of 31.7 cm. Snakes with SVLs > 36 cm were in the 3+ y-old cohort with a mean SVL of 41.4 cm. Sexual dimorphism existed in 3+ y-old cohort with females (43 cm median SVL) growing to a significantly larger size than males (39 cm median SVL; U = 305.5, n = 70, P < 0.001). Mean male and female SVLs were 37.8 cm (range, 30–47) and 41.0 (range, 25–51), respectively. The number of juveniles to adults did not deviate

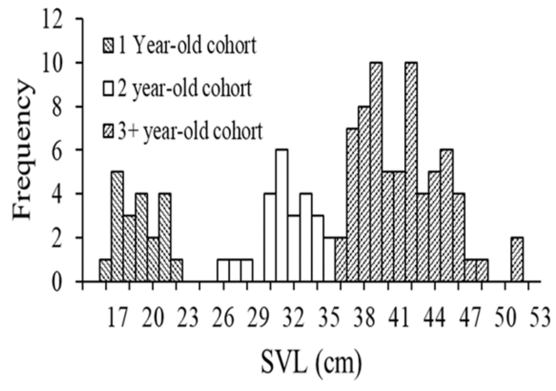

Figure 3. Snout-vent lengths (SVL) of Queensnakes (*Regina septemvittata*) in an urban section of Rock Castle Creek, Virginia, USA, in April and May 2008–2019. We used the size distribution to determine ages as indicated in the legend.

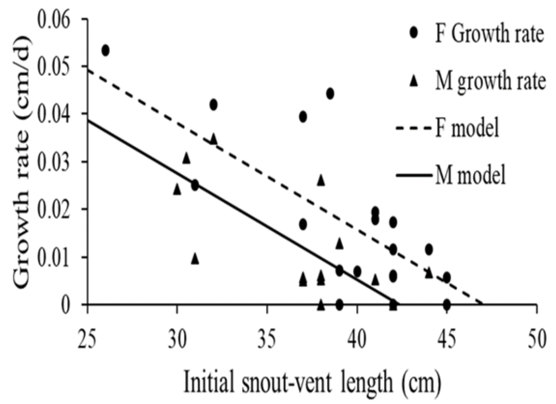

Figure 4. Growth rates (cm/d) of recaptured Queensnakes (*Regina septemvittata*) from an urban section of Rock Castle Creek, Virginia, USA, 2008–2019, including ANCOVA model results. Solid line and triangles represent male (M) growth rates and dashed line and dots represent female (F) growth rates.

significantly from the mean of 21.3% juveniles across the years of the study ($\chi^2 = 13.1$, df = 8, $P = 0.107$).

The oldest Queensnake, based upon mark/recapture data, was at least 7 y old. When we first caught this male snake, its SVL was 31 cm, which placed it in the 2-y-old cohort (Fig. 3). Five years later, we recaptured it and its SVL was 40 cm.

Growth rates declined with increasing SVL for both sexes and females grew significantly faster than males (Growth rate [cm/d] = 0.105 – 0.00224 SVL [cm] – 0.01046 sex [where male = 1 and female = 0]; $r^2 = 0.54$, $F_{2,23} = 18.0$, $P < 0.001$; $t_{SVL} = 5.82$, $P < 0.001$, $t_{sex} = 2.85$, $P = 0.008$; Fig. 4). There were no significant interactions between sex and SVL ($t = 0.32$, df = 26, $P = 0.752$). Capture year was also not a significant variable in the model ($t = 2.02$, df = 29, $P = 0.052$) with growth rates not deviating significantly over time. On a percentage basis, snakes increased in length from their first year of life to their second year by 68.6% and from their second year of life to their third year by 30.6%.

Movement.—We found most of the snakes recaptured within a year under the same structure or location where we initially caught them (60%, n = 35), whereas between years, this percentage dropped to 42.9% (n = 28). The mean and maximum linear distances of snakes found within a year at new structures or locations (i.e., excluding snakes found under the same structure or location) were 22.4 ± 22.2 m and 80 m (n = 14), respectively, whereas between years, the mean and maximum were 68.0 ± 64.6 m and 210 m (n = 16), respectively. Only two snakes, both recaptured between years, moved away from a location and back again. One female travelled 7 m to a new tarp structure and then back and one male snake travelled the maximum distance recorded (210 m) to a new tarp structure and back again.

Table 1. Data collection by year, including the number (#) of trips we took to the study site, number (#) of captured Queensnakes (*Regina septemvittata*), number (#) of 2+ y-old PIT-tagged snakes, number of recaptured Queensnakes between years, and Jolly-Seber population estimates with associated 95% confidence intervals (CI) for 2+ y-old cohort snakes. The total number of Queensnakes captured includes all recaptures. The total number of pit-tagged snakes for 2+ y-old cohort of Queensnakes includes recaptures between years and excludes recaptures within a given year. The abbreviation RBY = number of recaptures between years and Pop Est = population estimate.

Year	# trips	# captured	# PIT-tagged	#RBY	Pop Est (95% CI)
2008	11	21	14	--	--
2009	12	37	13	1	31 (14–47)
2010	5	10	5	2	12 (4–20)
2011	2	2	1	1	3 (0–6)
2012	5	9	6	0	16 (5–27)
2013	9	25	12	2	30 (15–47)
2014	3	14	10	4	23 (11–35)
2015	5	20	14	4	33 (16–49)
2016	7	38	14	6	31 (16–46)
2017	2	8	5	2	16 (7–25)
2018	17	42	19	4	45 (23–67)
2019	16	34	14	7	34 (17–51)

Survival, recapture, and population estimates.—The model that held survival and recapture rate constant over the 12 y of the study had the greatest amount of support based upon AICc. The next closest model (constant survival rate and recapture rates that varied with time) had a ΔAICc of 9.1. Estimated annual survival for the 2+ y-old cohort of Queensnakes was 0.52 (95% confidence interval [CI] = 0.40–0.63) and annual recapture probability was 0.43 (95% CI = 0.27–0.61). Population estimates for 2009–2019 oscillated around a mean of 25 snakes of the 2+ y-old cohort (range, 3–45 snakes; Table 1). Mean linear density across years for the Queensnakes was 0.048 snakes/m (range, 0.0064–0.0864 snakes/m).

Discussion

Branson and Baker (1974) described the optimal habitat for Queensnakes as a small to medium, shallow stream with a moderate current and rocky banks/bottom. We found these characteristics within our study site at Rock Castle Creek, which included ample cover for snakes on the banks. There were many branches overhanging the creek, resulting in 5.8% of our captures being basking snakes as compared to 1.8% by Branson and Baker (1974). Rock Castle Creek also had an abundance of crayfish, the primary prey for Queensnakes (Branson and Baker 1974; Ernst and Barbour 1989;

Burst 2013), likely due to the ideal environment of riffles found throughout 210 m of our study site.

Queensnakes at Rock Castle Creek are sexually dimorphic, as others have noted (Wood and Duellman 1950; Branson and Baker 1974; Ernst 2003) with female snakes having, on average, longer SVLs relative to males. Queensnake SVLs from Rock Castle Creek are, on average, shorter by 2–8 cm compared to those from other locations, though the range of SVLs overlap with those from other studies (Wood and Duellman 1950; Branson and Baker 1974; Mitchell 1994; Hulse et al 2001; Ernst 2003).

During our study, we most commonly found individual Queensnakes only once (71.7%) which was similar to Ernst (2003; 92.2%). Finding snakes only once was likely because of the relatively low survival rate (0.52) and secretive behavior of the species that limited our ability to recapture snakes. Low recapture rates were affected by our variable number of annual site surveys over the years of the study in addition to our method of hand capture of snakes, where individuals under rocks or in crayfish burrows were not detected or basking individuals dropping out of trees and into the water were not caught (Oldham et al. 2016; Leuenberger et al. 2019). Other studies commonly report low recapture rates for snakes (Steen 2010; Durso and Seigel 2015), often resulting in population estimates with wide confidence intervals. Although Queensnake annual survival rates were not available in the literature, our values were comparable to other early maturing colubrids: *N. s. sipedon* (range, 0.28–0.71; Roe et al. 2013), Lake Erie Watersnake, *N. s. insularum* (range, 0.39–0.91; Stanford 2012), Santa Cruz Gartersnake, *T. atratus* (range, 0.56–0.64; Lind et al. 2005), Terrestrial Gartersnake, *T. elegans* (range, 0.34–0.86; Bronikowski and Arnold 1999), Plains Gartersnake, *T. radix* (range, 0.35–0.45; Stanford and King 2004), and San Francisco Gartersnake, *T. sirtalis tetrataenia* (range, 0.75–0.78; Halstead et al. 2011).

Our percentage changes in growth (1-y-old to 2-y-old snakes = 68.6%, 2-y-old to 3+ y-old snakes = 30.6%) were comparable to mean percentage changes in Queensnakes in other studies. In southwestern Ohio, Wood and Duellman (1950) reported an approximately 50% increase in length of Queensnake neonates born in late summer compared to their next year of life. Neonates born in September in western New York increased in length by 78.4% by the time they were a year older (Raney and Roecker 1947). Branson and Baker (1974) state that yearlings increased in mean length by 75% when compared to neonates and found that second-year snakes increased by 45% from yearlings. All studies reported substantially decreased growth rates after passing the second full year of life, which matched our findings (Raney and Roecker 1947; Wood and Duellman 1950; Branson and Baker 1974).

Queensnakes in Rock Castle Creek did not need to move far (mean movement of 22.4 m within a year) because foraging areas, basking sites, and potential hibernacula were all within the stream and its immediate banks. These findings corroborate the limited movements of Queensnakes that others have noted. For snakes recaptured within a year, 11 of the 13 recaptures moved < 30.5 m (Branson and Baker 1974), 80% of 75 recaptures moved < 25 m (Ernst 2003), and mean movement was 37.3 m for adults from May to July (Oldham et al. 2016). The Rock Castle Creek Queensnake population reflects the same 1:1 sex ratio as found in rural locations (Branson and Baker 1974; Ernst 2003) but differs from the unusual finding from Burst (2013) of a male to female ratio of 2.76:1. Linear densities per year (range, 0.0065–0.086 snakes/m) at Rock Castle Creek were lower than the densities at a rural study site in Kentucky, USA (0.18–0.26 snakes/m, Branson and Baker 1974), but similar to six sites in forested and suburban areas of central Kentucky (0.006–0.063 snakes/m; Leuenberger et al. 2019).

Overall, Queensnakes from this urban creek were similar to those from rural locations in terms of sex ratio, movement patterns, growth rates, size sexual dimorphism, and linear densities, but were shorter in length (Raney and Reocker 1947; Wood and Duellman 1950; Branson and Baker 1974; Ernst 2003; Leuenberger et al. 2019). Reproductive effort, growth rates, and sex ratios did not show any significant changes over the 12 y of the study. Our population estimates, though with wide confidence intervals, showed that this population of approximately 25 snakes in the 2+ year cohort had, at the very least, continued over time despite being in an urban environment.

This Queensnake population, which has persisted in Rock Castle Creek for over 12 y, contrasted with population declines noted worldwide in 65% of the snake species examined using long-term studies (Reading et al. 2010). Low fecundity, small home ranges, sit-and-wait foraging strategies, habitat and dietary specialization or feeding at higher trophic levels, and living in an area exposed to increased human pressure represented character traits of declining or more vulnerable species whereas snakes with high fecundity, large home ranges, and active foraging, usually in areas protected from human pressure, characterized species that had stable or less vulnerable populations (Foufopoulos and Ives 1999; Reed and Shine 2002; Webb et al. 2002; Reading et al. 2010; Todd et al. 2017). The Queensnake has some characteristics of snake species that had stable populations, such as being an active forager and having high fecundity (early maturation and shorter generation length; Branson and Baker 1974; Ernst 2003), but Queensnakes also have characteristics similar to species that have shown declines over time: small home range, occurring in an area with increasing human influence, habitat specialization, and dietary specialization. Limited movement and small home range and rarely venturing far from water keep Queensnakes from Rock Castle Creek away from the nearby roads and parking lots, decreasing potential road mortality, which can negatively affect more wide-ranging species (Bonnet et al. 1999; Row et al. 2007; Mitrovich et al. 2018). Nevertheless, the natural-history characteristics of habitat and food specialization and small home range make the Queensnake vulnerable to major environmental events (pollution, siltation, crayfish declines) in this small stretch of stream (Ernst and Barbour 1989; Burst 2013).

Rock Castle Creek has exhibited degradation over time (2008–2016). Declines in two indices (Index of Biological Integrity and Ephemeroptera Plecoptera Trichoptera Index) and increases in conductivity and phosphorus levels from 2011–2016 have occurred as development of the surrounding land progressed (University of Lynchburg. 2016. Water Quality Analysis of Streams in the City of Lynchburg. University of Lynchburg. Available from https://www.lynchburg.edu/academics/academic-community-centers/center-for-water-quality/stream-ecology-management/blackwater-creek-management [Accessed 20 October 2019]). If environmental degradation increases and subsequently leads to crayfish declines (Richman et al. 2015), this local population of Queensnakes could be extirpated. Ernst (2003) observed extirpation in a snake community in southeastern Pennsylvania, USA, downstream of a dam. People were intentionally killing basking snakes (Queensnakes, Northern Watersnakes, and Common Gartersnakes) and changes made to the dam along with a 3-m wall of floodwater that swept over the dam caused degradation to the crayfish habitat. After these events, Ernst (2003) did not find any Queensnakes at the dam or in the creek below the dam.

Overall, it appears that Queensnakes may be relatively resilient to habitat loss through fragmentation as evidenced by the persistence of this urban population in a habitat fragment. Given the isolated nature of the small patch of suitable habitat surrounded by an inhospitable landscape and the increased development-related threats, the future of this population is precarious. Currently though, this population has persisted over at least 12 y, despite being in a less-than-pristine urban environment.

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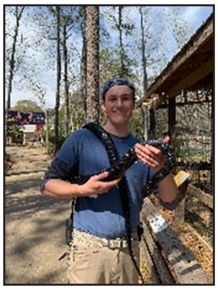

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