Amphibia-Reptilia 31 (2010): 169-174

Ecology of juvenile Northern watersnakes (*Nerodia sipedon*) inhabiting low-order streams

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Abstract. The juvenile stage for many reptiles is considered "the lost years" because of low capture probabilities, however understanding factors impacting juvenile survivorship and recruitment is critical for conservation of populations. We studied the ecology of juvenile Northern watersnakes, *Nerodia sipedon*, by intensively sampling a first-order stream and determined the occupancy of juveniles in 30 low-order streams in the Piedmont of North Carolina. Juveniles were relatively abundant within a single stream ($n = 62 \pm 9$), and their capture probabilities were positively related to increasing stream-water temperatures. We also found that juveniles had high survivorship ($\varphi = 0.87 \pm 0.017$). Occupancy of juvenile *N. sipedon* in low-order, Piedmont streams may be greater at streams that have confluences with high order streams or lakes, which potentially support adult *N. sipedon* populations. This study provides important information regarding the natural history of juvenile reptiles and indicates the importance of low order streams as habitat for *N. sipedon* populations.

Keywords: abiotic variables, capture probabilities, occupancy, survivorship.

Introduction

In recent years, scientists have become increasingly interested in modeling population parameters of secretive and difficult to detect organisms such as reptiles (Pike et al., 2008; Dorcas and Willson, 2009). Understanding the ecology of juvenile reptiles is critical when attempting to understand population dynamics (Cole, 1954; Sterns, 1992; Frederiksen, Wanless and Harris, 2004), however the secretive nature (i.e., low detectability) of juvenile reptiles has resulted in only limited investigations (Carr, 1967; Morafka, 1994; Pike et al., 2008). As conservation and management issues increase in prominence, researchers must understand the basic ecology and population parameters of juveniles to determine how juvenile survival and ultimately recruitment may be affected by current and future anthropogenic disturbances (Brown et al., 2005).

Northern watersnakes (*Nerodia sipedon*) are a wide-ranging and locally abundant snake found throughout much of eastern North America (Bauman and Metter, 1975; Gibbons and Dorcas, 2004). Adult *N. sipedon* are associated with a variety of aquatic habitats, such as man-made impoundments, natural lakes, ponds, streams, rivers, and large and small wetlands (Gibbons and Dorcas, 2004). They are dietary generalists foraging primarily on amphibians, crayfish, fish, and occasionally rodents (Gibbons and Dorcas, 2004). They forage diurnally and nocturnally employing both sit-and-wait and active foraging strategies (Balent and Andreadis, 1998). Although attributes of adult *N. sipedon* ecology have been well described, little information exists regarding the natural history of *N. sipedon* juveniles or juveniles of other natricines (Gibbons and Dorcas, 2004). In this study, we describe various aspects of the ecology of juvenile *N. sipedon* in the western Piedmont of North Carolina. Specifically, we examine size, growth, distribution, prey, survival, and abundance. Secondly, because adult *N. sipedon* typically inhabit habitat (i.e., lakes, rivers) that may be dangerous to juvenile *N. sipedon*, we

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hypothesized that streams adjacent to high order rivers or lakes may have higher juvenile occupancy than streams further from areas potentially supporting adult populations. This study sheds light on aspects of the juvenile ecology of a common and widely distributed snake and provides information important to consider when addressing conservation issues related to semi-aquatic reptiles.

Methods

We intensively studied juvenile *N. sipedon* in and adjacent to a first-order stream in the western Piedmont of North Carolina located within the Cowan's Ford Wildlife Refuge (hereafter referred to as the CFWR stream; Zone 17, N3914855 E0503106; Cecala, Price and Dorcas, 2009). Our study stream had an intact mixed-hardwood forest catchment bisected by a single power-line right-of-way, which resulted in an open canopy at the headwaters of the stream. The stream was 150 m long, extending from a seep near the power-line right-of-way until its confluence with the Catawba River. Several smaller seeps joined the stream. Approximately 20 m from the confluence with the Catawba River, the flow decreased and the stream widened (approximately 10 m wide) and contained various species of emergent wetland vegetation and relatively low canopy cover. We used a temperature-sensitive data-logger (Tidbit Stowaway, Onset Computer Inc., Bourne, Massachusetts) to record stream-water temperature at 30 minute intervals throughout the duration of our study approximately halfway between the confluence and seep (65 m from confluence).

We sampled snakes at CFWR from May 2006 until April 2007. Our primary sampling periods occurred once per month except for June and July 2006, when our primary periods occurred twice per month yielding 14 primary sampling periods. Our secondary sampling periods were four consecutive trapping days from May–July 2006, and three consecutive trapping days from August 2006–April 2007. Snakes were captured using three methods. First, we used two soda-bottle funnel traps placed within each meter of the stream, a 2 l and 0.5 l in each 1 m section facing in opposing directions (Willson and Dorcas, 2003; Cecala, Price and Dorcas, 2009) to captures snakes within each meter of the stream (total trap number = 300). Second, we placed seven coverboards in the floodplain adjacent to the stream channel in the lower 30 m of the stream. Lastly, we checked under all cover objects (e.g., logs) greater than six cm in diameter within the stream and along the stream bank. The coverboards, natural cover objects, and traps were checked each day of our sampling periods.

When snakes were captured, we returned them to the laboratory where they were measured (snout-vent [SVL] and total length [TL]), weighed (to nearest 0.1 g), sexed, palpated for food items, and individually marked using a cauterizing technique (Winne et al., 2006). Snakes were retained in the lab until the end of each three or four day sampling period at which time, they were released at their capture locations.

We used program MARK to estimate recapture probability and survivorship for all juvenile *N. sipedon* captured (White and Burnham, 2001). We pooled all captures for each secondary sampling period to yield capture histories from the primary sampling periods only for use with an open population model, the Cormack-Jolly-Seber model. We were interested in examining the relationship between capture probability and environmental conditions; therefore, we used mean stream-water temperature for each capture period to examine this relationship. Because mean water temperature of capture periods was strongly correlated with time, we removed time from our analysis and examined the effects of water temperature on recapture probabilities. We tested models to evaluate if survivorship varied temporally and if recapture probabilities varied with mean water temperature during the primary capture periods. Model fit was evaluated using 1000 bootstraps. If the global model had evidence of lack-of-fit, the $\hat{c}$ (χ/df) was adjusted and model testing proceeded. We compared models using Akaike's Information Criteria (AIC) and weights were adjusted for small sample sizes ($\mathrm{AIC_c}$; Burnham and Anderson, 1998). Model-weighted parameter estimates were provided by program MARK. Lastly, using the mean detection probability for months when juvenile *N. sipedon* were active, we estimated the population size and linear density of the population per m^2 of stream.

To determine the applicability of information obtained at this site to other sites in the area and to determine if occupancy was higher at sites closer to adult habitat, we also sampled *N. sipedon* juveniles in 30 streams in the Charlotte, North Carolina metropolitan area in 2005, 2006, and 2007. We used soda-bottle funnel traps and cover object surveys at 30 streams. Twelve traps were set within a ten-meter transect in each stream. We repeated this process once in March and sampled a different ten meter transect in April. We used these data to calculate naïve occupancy estimates of *N. sipedon* juveniles in first-order streams. We did not capture enough individuals at all of these sites to allow us to conduct a full occupancy analysis (Pollock et al., 2002). Therefore, we obtained naive occupancy estimates for the two groups (see below) by assuming that the only differences among these stream groups were the stream order or size of their confluence. Streams were grouped based on (1) if streams had confluences with other first-order streams or (2) streams had confluences with higher-order water bodies including lakes, ponds, or rivers. We classified 13 streams as having confluences with low-order streams similar in size (low-order confluences group). We classified the remaining 17 sites as having confluences with higher-order water bodies including rivers such as the Rocky River, wetlands, and reservoirs such as the Mountain Lake Reservoir (high-order confluences group).

Results

We captured 23 juvenile *N. sipedon* represented by 37 captures at the CFWR stream, which yielded an approximately equal sex ratio with 11 females and 12 males. Snakes were captured 2 m from the stream confluence with the Catawba River upstream to 133 m from this confluence. The highest number of captures was found between 20 and 30 m upstream from the confluence, but individuals were found throughout the stream (fig. 1). Bottle funnel traps proved to be the most effective sampling technique accounting for 26 of 37 captures. The remaining captures were by hand ($n = 7$) and cover boards ($n = 4$).

Overall measurements at first capture ranged from 150-311 mm SVL and 203-411 mm TL. Individuals were first captured in May 2006, and our last capture of 2006 was in September. Following the winter months, we recaptured an individual in March 2007 (fig. 2). Of the 7 recaptured juveniles (males, $n = 4$; females, $n = 3$), male SVL increased by 0.99 ± 0.29 mm per day, but females grew only 0.25 ± 0.04 mm per day (SVL $\pm$ 1 SE). Five of the 37 captured *N. sipedon* were found with gut contents. Two snakes consumed crayfish and three consumed red salamander larvae (*Pseudotriton ruber*), which were abundant throughout the stream.

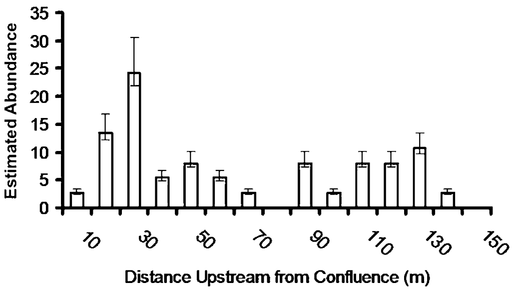

Figure 1. Estimated abundance of juvenile *N. sipedon* per 10 m stream reach along the length of the CFWR stream. Error bars represent 95% confidence intervals.

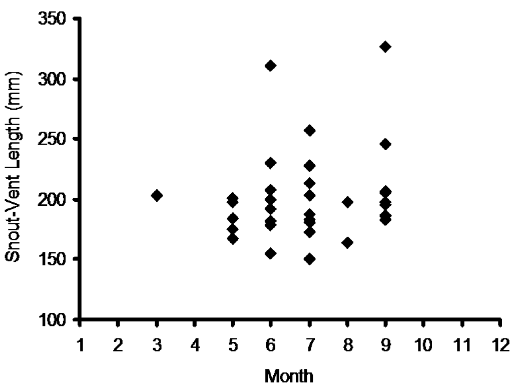

Figure 2. Size of all captured juvenile *N. sipedon* found in monthly capture periods. The first capture occurred in March (month 3) and the last captures occurred in September (month 9).

To estimate population parameters for juvenile *N. sipedon*, we first found evidence of the global model's fit using 1000 bootstraps ($P = 0.15$). Therefore, we corrected for this small dataset's overdispersion by adjusting the $\hat{c}$ (χ/df) to 1.875 before proceeding with model evaluation. Our model comparisons indicated that temperature strongly affected detection of juvenile *N. sipedon* (table 1). Further analysis of this relationship showed a strongly positive association between stream water temperature and recapture probability (fig. 3). We found that monthly survivorship of juvenile *N. sipedon* ap-

Table 1. Results of Cormack-Jolly-Seber model testing. φ represents survivorship, P represents capture probability, t represents time, and "Temperature" represents the mean stream-water temperature during the sampling period.

Model	Number of parameters	$QAIC_c$	$\Delta QAIC_c$	$QAIC_c w$
$\varphi P^{\text{Temperature}}$	3	32.07	0.00	0.79
$\varphi^t P^{\text{Temperature}}$	5	35.08	3.00	0.18
φP	2	38.13	6.05	0.04
φP^t	12	63.98	31.90	0.00
$\varphi^t P$	12	68.72	36.65	0.00
Global	16	97.72	65.64	0.00

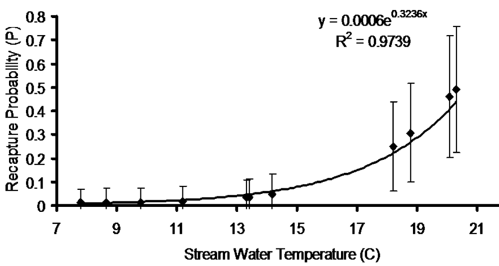

Figure 3. Recapture probabilities (P) increase exponentially with mean stream water temperature correlated with time of year. Although our data suggest an exponential relationship, this curve is most likely a portion of a logistic curve.

pears to have remained constant throughout the year (table 1) and appeared to be high within this stream at 0.87 ± 0.017. Snakes were captured most frequently in June, July, and August (mean capture probability was 0.37 ± 0.05 for this time period). The estimated population size of juvenile *N. sipedon* within this stream was 62 ± 9 individuals, and the population estimate yielded a density of approximately 0.4 individuals per linear meter of stream.

In our occupancy evaluation of juvenile *N. sipedon* occupancy, we detected 32 juvenile *N. sipedon* from 12 different streams. No adult *N. sipedon* were found in any of the surveyed stream reaches. In our low-order confluences group, juvenile *N. sipedon* occupied approximately 23% of these stream reaches. Alternatively, in our high-order confluences group, juvenile *N. sipedon* occupied approximately 53% of these stream reaches.

Discussion

Our results provide important baseline information, including survivorship, feeding, growth rates, and factors affecting occupancy of the juvenile ecology of *N. sipedon*. Juvenile *N. sipedon* appear to inhabit and forage within low-order streams, where population densities may exceed 0.4 individuals per linear meter, and are found more frequently adjacent to larger-order waterways. Our estimates of juvenile snake survival (0.87 ± 0.017) are higher than survivorship estimates reported by Pike et al. (2008) for other juvenile reptiles. We also found juveniles were more detectable at higher mean water temperatures. Our survey describes the importance of low-order streams as juvenile *N. sipedon* habitat.

Although *N. sipedon* juveniles were distributed throughout the CFWR stream, they were found most frequently at the lower confluence of this stream with the Catawba River and far from that confluence where the stream enters the power-line right-of-way. These open canopy areas may have provided juvenile *N. sipedon* more basking opportunities than areas of higher canopy cover. King (1939) demonstrated altitudinal shifts in the range of *N. sipedon* adults following disturbance that may have afforded basking locations in previously unused habitat of high canopy cover. Furthermore, smaller water bodies (low-order streams) may contain a more appropriately sized prey base such as salamanders and small crayfish (MacCallum, 1995; Gibbons and Dorcas, 2004). Although only a single individual was found between years, small streams could provide important locations for overwintering by juvenile *N. sipedon.*

Survivorship of *N. sipedon* juveniles found within CFWR stream was relatively high compared to many other studies of similar snake species or juveniles of other species. Previous studies examining the survivorship of adults of *N. sipedon* have yielded annual survivorship estimates of 0.63 (*N. sipedon insularum*; King, Queral-Regil and Stanford, 2006) or 0.16 for juvenile *Thamnophis radix* (King and Stanford, 2006; table 2). We found that juvenile *N. sipedon* in the CFWR stream appeared to have much higher survivorship estimates than juveniles of other species and also have higher survivorship than adults of many other reptile species (table 2).

Use of low-order streams by juvenile *N. sipedon* may demonstrate ontogenetic shifts in habitat use and diet within this species as found in other *Nerodia* species. (Plummer and Goy, 1984) but more importantly, may also provide juveniles a refuge from potential predators. Although we acknowledge that our occupancy estimates may be biased, our study demonstrates that streams directly adjacent to larger water bodies may be more likely to be occupied by juvenile *N. sipedon* than streams that do not flow directly into larger-order streams or lakes. Large water bodies that provide habitat for adult *N. sipedon* may contain higher predator abundances (e.g., predatory fish, birds, turtles) that may reduce survivorship of juveniles (Mitchell, 1994; Gibbons and Dorcas, 2004). Furthermore, large waterbodies may expose small snakes to

Table 2. Previously estimated survivorship estimates of snake and other juvenile reptile populations.

Genus	Species	Life stage	Survivorship	Study
Coluber	*constrictor*	Juvenile	0.12	Rosen, 1991
Coluber	*constrictor*	Adult	0.53	Rosen, 1991
Nerodia	*sipedon insularum*	Adult	0.63	King, Queral-Regil and Stanford, 2006
Nerodia	*sipedon sipedon*	Juvenile	0.87	Present Study
Thamnophis	*atratus*	Adult	0.64	Lind, Welsh and Tallmon, 2005
Thamnophis	*atratus*	Adult	0.56	Lind, Welsh and Tallmon, 2005
Thamnophis	*radix*	Juvenile	0.16	King and Stanford, 2006
Thamnophis	*sirtalis*	Adult	0.83	Larsen and Gregory, 1989
Ctenotus	spp.	Juvenile	0.18	James, 1991
Gopherus	*polyphemus*	Juvenile	0.04	Pike and Seigel, 2006

additional terrestrial predators such as raccoons and birds as a result of limited refugia and open canopies adjacent to banks where juveniles would be found (Mitchell, 1994).

Our understanding of the ecology of juvenile reptiles is limited but is critical for a more comprehensive understanding of their ecology and for addressing issues related to reptilian conservation (Pike et al., 2008). Juvenile *N. sipedon* appear to have relatively high survivorship within small streams indicating that recruitment into adult populations may be high for *N. sipedon* populations in areas with high levels of habitat diversity. Lastly, our study demonstrates that juvenile *N. sipedon* commonly occupy low-order streams, and low-order streams may provide critical habitat for the successful recruitment of *N. sipedon.* Our study suggests that future conservation efforts to improve juvenile reptile survival may need to investigate alternate habitats that may provide juveniles refuge and/or other resources unavailable to adults.

Acknowledgements. We thank the Davidson College Herpetology Laboratory for assistance with animal collection and processing, and Mecklenburg Country Parks and Recreation particularly K. Coffey and D. Serriff, Cabarrus County Soil and Water Conservation District, and local landowners for access to our study sites. All procedures were approved by the Davidson College IACUC, and all necessary permits were obtained. The Maerz Herpetology Lab provided important comments that improved the manuscript. Manuscript preparation was aided by the Environmental Remediation Sciences Division of the Office of Biological and Environmental Research, U.S. Department of Energy through Financial Assistance Award number DE-FC09-96SR18546 to the University of Georgia Research Foundation. Funding was provided by: Davidson College Department of Biology; a Grant-in-Aid-of-Research from the National Academy of Sciences, administered by Sigma Xi, The Scientific Research Society; a Yarbrough Research Grant administered by the Collegiate Academy, North Carolina Academy of Science; Duke Power; and National Science Foundation grants (DEB-0347326 and DBI-1039153) to MED.

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Received: June 27, 2009. Accepted: September 3, 2009.