

Increases in Capture Rates of an Aquatic Snake (*Seminatrix pygaea*) Using Naturally Baited Minnow Traps: Evidence for Aquatic Funnel Trapping as a Measure of Foraging Activity

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The secretive nature of most snake species can hinder efforts to understand aspects of their ecology and population biology unless systematic capture techniques are employed and potential sampling biases are recognized (Parker and Plummer 1987). For herpetofauna other than snakes (e.g., amphibians, lizards, and turtles) numerous studies of collecting methods and sampling regimes have resulted in standardized methods, with well-elucidated biases (e.g., Dodd 1991; Dunham et al. 1994; Gibbons 1990; Heyer et al. 1994; Willson and Dorcas 2004; Willson et al. 2005). Several collection techniques have been used successfully for terrestrial snakes (reviewed in Fitch 1987, 1992), such as terrestrial drift fences with pitfall and funnel traps (Gibbons and Semlitsch 1981), road cruising (Dodd et al. 1989; Mendelson and Jennings 1992; Seigel and Pilgrim 2002), visual encounter surveys (Sun et al. 2001), and artificial cover objects (Fitch 1992; Grant et al. 1992). For capturing snakes in aquatic habitats most studies have relied upon visual encounter surveys, opportunistic captures, or aquatic funnel traps (Casazza et al. 2000; Gibbons and Dorcas 2004; Madsen and Shine 2000; Seigel et al. 1995a; Seigel et al. 2000), but the effectiveness and biases of these methods have seldom been examined experimentally (e.g., Willson et al. 2005).

Keck (1994) demonstrated that aquatic funnel traps can be used to successfully capture snakes in aquatic habitats and that baiting funnel traps with dead prey items (e.g., fish and amphibians) can increase capture rates. Here I chose a blocked experimental design that would allow a further, more powerful test of whether baiting traps increases capture rates of aquatic snakes. By design this experiment also examines whether aquatic snakes randomly enter funnel traps during movements or if they seek out funnel traps due to foraging behavior, thereby providing insight into some of the potential biases of aquatic trapping.

This experiment was conducted from 4–25 June 2003 at Ellenton Bay, a protected Carolina bay wetland located on the U.S. Department of Energy's Savannah River Site in South Carolina. Ellenton Bay is an ideal locality for aquatic trapping experiments because (1) it generally supports large populations of aquatic snakes, including the focal study species, *Seminatrix pygaea* (Black Swamp Snakes; Winne et al. 2005) and (2) it is dominated by shallow water (< 1 m deep) and relatively uniform distributions of emergent grasses (predominantly *Panicum* spp.), water lilies (*Nymphaea odorata*), and water shields (*Brasenia schreberi*), thus reducing variability in capture success attributable to heterogeneous habitat distributions. Traps were set in shallow water with approximately 3–5 cm of the trap above water to reduce the possibility of drowning captured snakes. Two varieties of commercially avail-

able cylindrical funnel traps, designed to capture minnows (i.e., minnow traps), were used during the study: steel (model G-40; Cuba Specialty Manufacturing Company, Fillmore, New York) and plastic (model 700; N.A.S Incorporated, Marblehead, Ohio). Steel funnel traps were 42 cm long and 19 cm in diameter, and constructed of galvanized steel mesh (mesh openings = 0.6 cm wide). Plastic funnel traps were 43 cm long and 16 cm in diameter, and had slightly smaller mesh openings (0.4 cm wide). All of the funnel traps had two funnels, one on each end of the trap (openings 2.5 cm in diameter), that extended 11 cm inwards towards the center of the trap. Throughout most of the study a total of 36 plastic and 30 steel funnel traps was used (i.e., 18 and 15 pairs, respectively); however, some pairs were not used during the first few days of the study.

Aquatic funnel traps were set in pairs (traps within a pair < 1 m apart) and within pairs each trap was randomly assigned to serve as either a "baited" or an "unbaited trap." This blocked design removed any variation in trap success that could be due to microhabitat differences. Rather than actively baiting traps with dead prey items, baited traps were allowed to naturally accumulate (i.e., self-bait) live larval amphibians (e.g., tadpoles and salamander larvae) throughout the study. In contrast, the unbaited traps were emptied of their contents daily. At Ellenton Bay aquatic funnel traps rapidly accumulate amphibian larvae; as a result, unbaited traps were not always truly unbaited. However, because all snakes were captured after the second trap night, baited traps always contained substantially more larval amphibians than unbaited traps. Traps were checked daily and all snakes were taken to the lab, where sex (presence or absence of hemipenes), snout-vent length, mass, and reproductive state (determined by palpation, Seigel et al. 1995b) were recorded. All snakes were individually marked (branding) and released at their point of capture. All predatory aquatic insects were removed daily from both baited and unbaited traps.

I captured 47 adult *S. pygaea* over 1758 trap nights. I used Chi-squared tests to test the null hypothesis that there were equal numbers of captures in baited and unbaited traps. There was an obvious bias in captures towards baited funnel traps: 79% of all snakes ($\chi^2 = 15.51$, $p < 0.001$) and 88% ($\chi^2 = 9.94$, $p = 0.002$) of all pregnant females were captured in the baited traps (Fig. 1). Capture rates (trap nights/captures) were over 3 times higher in baited traps (4.2% vs. 1.3%).

The majority of *S. pygaea* were captured in baited funnel traps despite having an equal chance of encountering the unbaited funnel traps located less than 1 m away. This result confirms Keck's (1994) finding that baiting increases capture rates of aquatic snakes and demonstrates the benefits of allowing traps to self-bait (e.g., Seigel et al. 1995; Winne et al. 2005). The strong bias in capture rates of baited funnel traps suggests that the majority of the aquatic trap captures were due to foraging behavior rather than random entry into traps. Indeed, Seigel et al. (2000) noted that another natricine snake, *Thamnophis marcianus*, often feeds on tadpoles inside aquatic funnel traps. Consequently, captures of snakes in aquatic funnel traps may be biased towards foraging individuals, a result which has important implications for inter- and intraspecific comparisons of relative abundance within snake communities.

There are at least four reasons why inter- or intraspecific differ-

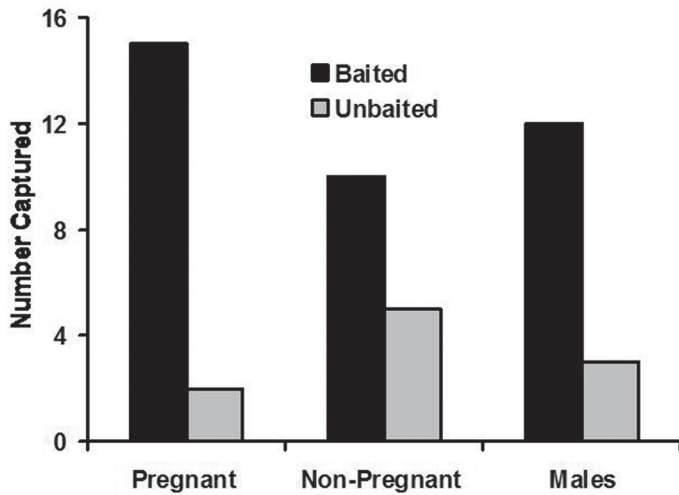


FIG. 1. Number of pregnant and non-pregnant female and male *Seminatrix pygaea* captured in baited vs. unbaited aquatic funnel traps at Ellenton Bay in June 2003. Overall, 79% of snakes ($\chi^2=15.51$, $p < 0.001$) were captured in baited traps.

ences in foraging ecology could lead to biased estimates of relative species abundance or sex ratios in aquatic funnel traps. First, if species/sexes differ in foraging mode (i.e., active vs. sit-and-wait foragers) funnel trap captures may be biased towards the species/sex that is a more active forager. Second, if species/sexes differ in their diet any potential capture biases of funnel traps towards certain prey species/sizes could translate into biases towards the species/sex that forages for that particular prey species/size. Third, in studies specifically comparing capture rates over time or among sites, capture rates may differ because of differences in accumulated bait. Lastly, if species/sexes differ in seasonal patterns of active foraging funnel traps might result in biased estimates of relative abundance during some seasons.

The current study species, *S. pygaea*, may serve as one example of how intraspecific differences in foraging ecology might translate into biased estimates of relative abundance using baited minnow traps. Based on aquatic funnel captures, the Ellenton Bay population of *S. pygaea* is significantly female biased during May and June, but the sex ratio is equal during other parts of the year (Winne et al. 2005). This seasonal change in sex ratio is strongly correlated with sexual differences in foraging ecology. During May and June pregnant *S. pygaea* contain food items significantly more frequently than adult males (unpublished data), presumably because males are searching for mates instead of foraging for prey. In contrast, in other months of the year, when the sex ratio at Ellenton Bay is equal, males are frequently found with food items (unpublished data), indicating that they have resumed foraging.

No single collection method is without biases (Fitch 1992), including aquatic funnel trapping. Despite some inherent biases, aquatic funnel traps are effective at capturing large numbers of highly secretive aquatic snakes (*Farancia* spp., *S. pygaea*, and *Regina rigida*; Willson et al. 2005), which are particularly difficult to collect using other conventional methods (e.g., visual encounter surveys, terrestrial sampling; Gibbons and Semlitsch 1991). Further, aquatic funnel traps provide an excellent method for systematically tracking demographic changes in aquatic snake popu-

lations (e.g., Madsen and Shine 2000; Seigel et al. 1995a) because they allow for highly repeatable sampling regimes and greatly reduce observer biases associated with visual observation and hand collecting techniques (Casazza et al. 2000; Keck 1994). The results of this study clearly demonstrate that aquatic funnel traps are most effective when baited and highlight the importance of considering some of the potential sampling biases inherent to this technique.

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Detectability of a Large-bodied Snake (*Sistrurus c. catenatus*) by Time-constrained Searching

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Detectability of vagile species is an important consideration when surveying populations. Without an approximation of the proportion of individuals present that are detected by a given method, it is difficult to determine how well relative measures represent true population values (Boulinier et al. 1998; Burnham and Overton 1979; Hyde and Simmons 2001; Norvell et al. 2003). This difficulty can be compounded if detectability varies by time (Bonnet et al. 2002), temperature (Royle 2004), habitat (Hyde and Simmons 2001; Prior et al. 2001; Weatherhead and Charland 1985; Weatherhead and Prior 1992), or segment of the population (Martin 1993; Prior et al. 2001). For cryptic taxa such as snakes, detectability should be a particularly important factor because most individuals in a given area may not be seen. Despite its importance, detectability is generally not considered in field studies that estimate abundance of snakes (e.g., Mendelson and Jennings 1992; Seigel 1998; Stevenson et al. 2003; Sullivan 2000).

Large-bodied, sedentary snakes (e.g., rattlesnakes) tend to avoid traps and artificial shelters (Fitch 1992; Ryan et al. 2002). For these species, time-constrained searches (searching a set area in a

given amount of time) may be the most efficient method of surveying the population. Rattlesnakes can be detected both visually and by hearing the rattle. Determining the detectability of snakes in time-constrained searches will provide an empirical foundation for population estimates, and a standard with which to evaluate alternative methods of detection. Using snakes equipped with radio transmitters, I tested how often, and under what conditions, individual Eastern Massasauga rattlesnakes (*Sistrurus c. catenatus*) were found by time-constrained searches when the snake was known to be present.

Methods.—I opportunistically captured Massasauga rattlesnakes for use in the study by searching suitable habitat on the Bruce Peninsula, Ontario (Weatherhead and Prior 1992). I implanted 7 adult snakes (2 non-gravid females, 5 males) with temperature-sensitive radio transmitters (Model SI-2T, Holohil Systems Inc., Ontario) in 2002 and 2003 as part of a separate study. Surgical procedures generally followed Reinert and Cundall (1982). Post-surgery, snakes were held for three days and then released at their point of capture. Snakes carrying implanted transmitters in this and other studies appeared to behave normally over extended time periods, although there is little comparative data from non-implanted snakes or experimental evaluation of the impact of implanted transmitters on behavior (Harvey, pers. obs.; Lutterschmidt and Reinert 1990).

Each detectability trial was conducted by two individuals, a tracker and a searcher. After locating a snake with a transmitter, the tracker established a 50 x 50 m square around the snake using string. The snake's position within the square was randomly determined for each trial using coordinates derived from a random number generator (Excel 2002). The searcher, naïve to the snake's location other than it was somewhere within the square, was given 20 min to find the snake. Based on preliminary trials this was considered sufficient time to search the entire area at a steady pace. Upon completion of each trial, the temperature of the snake was determined from the transmitter pulse rate, and the percent of the snake that was visible from above was recorded to the nearest 25%. If a snake was located by the searcher, the time required to find the snake and method of detection (audible, visual) were noted.

Of the 61 trials conducted in June and July 2004, no more than two trials were conducted per snake per week, with each snake used in an equal number of trials overall (8 or 9 each). Trials were conducted during the day (0930–1600 h) in fields, marshes, and forests, and in a range of weather conditions. Trials were split equally between two experienced and fourteen inexperienced searchers. Experienced searchers had observed massasauga rattlesnakes in the wild more than 500 times each, whereas inexperienced searchers had fewer than 20 observations each prior to the trials. To avoid inexperienced searchers improving at finding snakes over the course of trials, no individual conducted more than four trials. To estimate variance in detection rates I applied the bootstrap technique with 1000 replications (Efron and Tibshirani 1993).

Results.—Snakes were successfully located in 9 of 61 trials (14.8%, SD = 4.6%). Searchers usually passed near snakes during trials but the snakes did not respond by movement or rattling. Only in 3 cases was the snake completely hidden during the trial. Neither the experience of the searcher nor the habitat the snake was in affected whether a snake was found (Table 1). Snakes were found most often at intermediate temperatures (20–30°C; Table 1). No