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Growth in Common Snapping Turtles, *Chelydra serpentina* (Testudines: Chelydridae), in northern Indiana

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The Common Snapping Turtle, *Chelydra serpentina* (Linnaeus, 1758), is the most widely distributed turtle species in North America and fourth in that category in the world (Turtle Taxonomy Working Group, 2021). It is also one of the most frequently encountered turtles in its range (Ernst and Lovich, 2009). However, despite these facts, geographic variation in many of its life history traits remains understudied. For example, growth data are available for nine (mostly northern) populations (Table 1), but geographic patterns in juvenile growth are not yet clear. We collected growth data from a population in Indiana, expecting to identify a latitudinal pattern.

Between 1980 and 2016, we made 262 total captures of *Chelydra serpentina* in the southeastern bay of Dewart Lake, Kosciusko County, Indiana (41.3652°N, 85.7806°W), following the methods outlined in Smith et al. (2006, 2018). We captured 142 males, 50 females, and 22 probable subadult males (based on tail morphology), 16 probable subadult females, and 32 unsexed juveniles. Of these, 182 were individually marked, and of those, 36 were recaptured only once, 19 were recaptured twice, three were recaptured three times, and one was recaptured six times (59 total recaptures). For each turtle we measured maximum carapace length (CL in mm). We also attempted to count growth rings on costal scutes, but found those counts to be unreliable because of the confusion between secondary (seasonal) and primary (annual) annuli (see also Brooks et al., 1997; Wilson et al., 2003). For example, JBI counted five annuli on a 66.5 mm CL juvenile, and only six annuli on a 241 mm CL adult male. Furthermore, upon recapture the annuli counts of some turtles did not reflect actual time intervals. Therefore, we employed a von Bertalanffy (vB) growth analysis (after Fabens, 1965) to estimate growth in this population of snapping turtles.

For our vB analysis we compared body size data from the first to the last capture. We ignored intermediate captures, except for three males and three females recaptured while still juveniles (< 200 mm CL) and then later recaptured 6–10 years later as presumed adults (263–375 mm CL). For these six individuals, juvenile growth and adult growth were each included separately, because including the entire span between first and last capture (7–17 yrs; mean 11.5 yrs) would have inappropriately skewed their growth rates by diluting

Table 1. Estimated body size (carapace length, CL, in mm) of Snapping Turtles (*Chelydra serpentina*) at age 10 yrs across the species' range. Populations are arranged in order of declining latitude and samples include males (M), females (F), mixed (X), and unsexed (U) samples. Note that the first three studies refer to the same population.

Location	Latitude	Sample	CL	Source
Ontario	45.6	24 X	160[1]	Armstrong and Brooks, 2013
Ontario	45.6	317 X	210[2]	Armstrong and Brooks, 2013
Ontario	45.6	19 F	175	Galbraith et al., 1989
South Dakota	43.1	27 X	305[3]	Hammer, 1969
Michigan	42.5	6 X	324[4]	Gibbons, 1968
Michigan	42.5	41 U	197	Congdon et al., 1992
Massachusetts	42.5	8 X	239[5]	Graham and Perkins, 1976
Nebraska	41.8	50 F	253	Iverson and Lewis, 2019
Iowa	41.8	34 F	248[6]	Christiansen and Burken, 1979
Indiana	41.5	23 F	250	This study
Indiana	41.5	51 M	254	This study
Pennsylvania	40.2	43 X	195[7]	Hughes and Meshaka, 2020
Florida	30.5	21 X	250[8]	Aresco and Gunzberger, 2007

[1] estimated from their Fig. 2.
[2] estimated from their Figs. 1C, 4.
[3] estimated from their Fig. 5.
[4] extrapolated from log-transformed data in their Table 1.
[5] extrapolated from log-transformed data in their Table 2.
[6] extrapolated from log-transformed data in their Table 3 for ages 1–11 (omitting CL = 230, presumably a typographical error).
[7] estimated from their Fig 6.
[8] estimated from their Fig 2.

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the faster juvenile rate with the slower subadult/adult rate. We also assumed that CL at age zero for males and females was 29.1 mm after Congdon et al. (1987), which agreed with our smallest capture at 31.4 mm CL on 25 May 1985 (i.e., when the individual was just beginning its first full growth season). For the male analysis, we included adult males, probable subadult males, and unsexed juveniles, and for the female analysis, we included adult females, probable subadult females, and unsexed juveniles.

We anchored our vB curves (following Jones, 2017) by including three juveniles (58.8–66.5 mm CL) that were captured in late July and estimated by scute growth (i.e., only exhibiting the annulus from the first winter of life) to be near the end of their first full growing season (age = 0.83 years, assuming a growing season of 1 May–30 October). None of those three were recaptures, but we assumed that they had grown from a hatching size of 29.1 mm CL in the prior year. These three sets of measurements were included in both the male and female vB analyses.

For both males and females, we found growth rate to be highly correlated with body size (Figs. 1, 2). Our vB growth model for males and juveniles was $CL = 380.156 * 1\text{-}0.9235e^{-0.1024t}$ (n = 51; mean interval = 3.54 yrs; range, 1–11 yrs). Our model for females and juveniles was $CL = 317.402 * 1\text{-}0.90843^{-0.1447t}$ (n = 23; mean interval = 3.28 yrs; range, 1–9 yrs). Although these models revealed little difference in growth rate between males and females for the first decade of life (see Table 1), males subsequently grew faster than females and reached larger sizes (as has been reported for all studied populations of snapping turtles (review in Iverson et al., 1997).

Our analysis suggests an asymptotic CL for males of 380.2 mm in Indiana, although our largest males were 429 and 427 mm CL. Estimated asymptotic CL for females in Indiana was 317.4 mm, and our largest females were 342 and 339 mm CL.

Including our new data, juvenile growth trajectories are now available for ten populations across the species' range. However, despite a total species range from ca. 25°N to 52°N latitude, data from only a single population outside the band between 40°N and 46°N are available. With this narrow sampling, no clear geographic pattern in juvenile growth rate is evident (Fig. 3).

The broad range of habitats occupied by snapping turtles, from highly eutrophic to oligotrophic, and from locally hyperthermic to hypothermic, are known to impact their growth (Steyermark, 2008) and this complicates our understanding of geographic patterns,

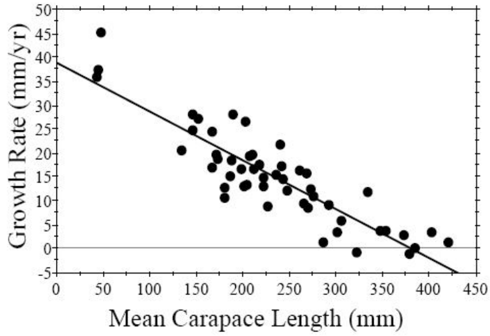

Figure 1. Relationship between carapace growth rate (GR; mm/yr) and mean carapace length (MNCL, in mm) at first and last capture for male and three small unsexed juvenile *Chelydra serpentina* in northern Indiana. GR = -0.1024MNCL + 38.928; $r^2 = 0.79$; $p < 0.0001$; $n = 51$.

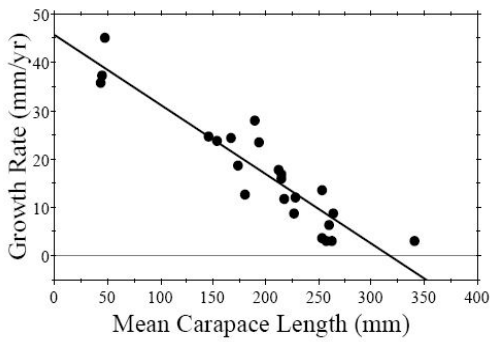

Figure 2. Relationship between carapace growth rate (GR; mm/yr) and mean carapace length (MNCL; in mm) at first and last capture for female and three small unsexed juvenile *Chelydra serpentina* in northern Indiana. GR = -0.1447MNCL + 45.928; $r^2 = 0.86$; $p < 0.0001$; $n = 23$.

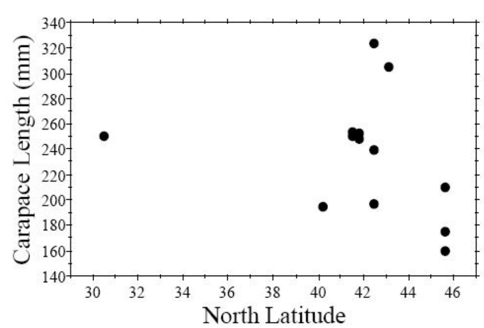

Figure 3. Estimated carapace length (in mm) of *Chelydra serpentina* at age ten years plotted by latitude of study site (see Table 1). Relationship is not significant ($r = 0.27$; $p = 0.37$).

as does the lack of data from most of the species' range, especially the warmer southern portion of the range. However, it is possible that juvenile growth has a substantial genetic component with little geographic variation, except that resulting from local thermal conditions and/or food resources. Future research should close the geographic gap in growth data, and also employ common garden experiments to evaluate the genetic contribution to juvenile growth in snapping turtles.

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