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Research article

Body mass and growth rate of zoo-housed eastern massasauga rattlesnakes *Sistrurus catenatus*: implications for ex situ conservation programs

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Abstract

The eastern massasauga *Sistrurus catenatus* is an at-risk pygmy rattlesnake species experiencing decreasing populations in the wild. These declines have led to the establishment of ex situ conservation programs in accredited zoos. Information related to body size and growth are critical for the success of ex situ conservation programs, but there is a lack of physiological research into zoo-housed massasauga populations. This study aimed to: 1) determine average body mass and growth rate across growth windows, and 2) determine which factors (sex, institution, origin) influence the size and growth of eastern massasaugas in zoos. A total of 76 females and 94 males (N=170) born between 2000-2021 across 18 institutions were analysed from the Species360 Zoological Information Management System (ZIMS). Results indicated that average body mass was not different between the sexes in any of the growth windows. The average mass of neonates at birth was not different between females and males. The growth rate was highest during the 12-35 month period of life, where females experienced a higher growth rate than males. Institution significantly affected both mass and growth rate. The origin of snakes (wild vs. zoo) affected birth mass and early growth rate, but not overall body mass in any window. Comparison to the literature indicated zoo-housed adult eastern massasaugas are heavier than wild individuals. These findings reveal important allometric information about the eastern massasauga rattlesnake that can inform zoo husbandry practices to improve animal health and wellbeing, and contribute to breeding success.

Introduction

Over one in five species of reptile are listed as threatened with extinction by the International Union for the Conservation of Nature (Cox et al. 2022). Snakes, an evolutionarily unique branch of Reptilia, serve important ecological roles across continents as both predator and prey (Virgin and King 2019; Knight and Erickson 2024), contributors to disease control (Martinez et al. 2024), and even seed dispersers (Reiserer et al. 2018). The snake family Viperidae includes a diverse group of species found on all continents except Antarctica, with individuals reaching the highest altitudes and latitudes of any snake clade (Maritz et al. 2016). Despite providing valuable ecosystem services, around 25% of all viper species are threatened with extinction due to a myriad of factors including persecution (IUCN 2025). Rattlesnakes, a group of pitvipers, are one of the most persecuted snakes in North America largely due to misinformation, fear, and cultural norms (Allison et al. 2024). Furthermore, rattlesnakes face threats such as habitat loss, disease, and climate change pressures that are negatively impacting populations (Clark et al. 2011; Dovčiak et al. 2013).

The eastern massasauga *Sistrurus catenatus* is a pygmy rattlesnake typically ranging from 50-70 cm in length (Dreslik et al. 2017a). The species currently ranges from the midwestern

to eastern United States northward to Ontario, Canada. The eastern massasauga is listed as threatened in the United States (USFWS 2016) and is at-risk of extinction in Ontario, with the Great Lakes-St. Lawrence population listed as threatened and the Carolinian population listed as endangered due to land conversion, road mortality, and persecution by humans (MECP 2023). These population declines have led to the establishment of an Association of Zoos and Aquariums (AZA) Species Survival Plan (SSP) that was recently updated to a Saving Animals From Extinction (SAFE) program (AZA 2025). The SAFE program includes field studies, conservation breeding, and translocation efforts to protect the eastern massasauga from further population declines. For example, the Toronto Zoo is actively breeding eastern massasaugas with the goal of translocating snakes in Ontario to reestablish wild population numbers (Toronto Zoo 2020; AZA 2025).

Accredited zoos serve as critical population assurance colonies for many at-risk species and are increasingly implementing conservation activities such as breeding and translocations (Olive and Jansen 2017). Reintroduction and population reinforcement projects with zoo animals can lead to effective conservation outcomes, with animal quality (e.g. health) being a key driver in post-translocation success (Blais et al. 2025). As such, it is important that these conservation efforts are informed with relevant longitudinal data regarding animal body condition, which can serve as a proxy for health. Furthermore, conservation breeding programs need to have consistent reproductive success and healthy individuals for long-term conservation to be viable (Che-Castaldo et al. 2019). Understanding typical body mass in various life stages and establishing a target growth rate for neonates can benefit both the health and welfare of animals in zoos (Krebs et al. 2018; Curry et al. 2023). Information on these and other major physiological factors are lacking for snakes in zoos, including the eastern massasauga.

Using zoological records of eastern massasaugas, this research aimed to: 1) determine average body mass (including birth mass) and growth rate across growth windows (0-11, 12-35, 36-71, 72+ months), and 2) determine which factors (sex, institution, origin) influence size and growth of eastern massasaugas in zoos. It was hypothesized that body mass and growth would vary: 1) between females and males due to differences in reproductive strategies, with females growing faster but males reaching larger sizes as is seen in wild individuals, 2) between housing institutions due to differences in husbandry that can affect body condition, and 3) between origins (wild vs. zoo) due to differences in environmental conditions potentially impacting early life development. This information can be utilized to better inform eastern massasauga conservation breeding programs in accredited zoos and conservation partner institutions, resulting in enhanced overall understanding of the body size and growth of this species under managed care. Additionally, this research can be applied to enhance reptile welfare, an area that has been lacking compared to mammals.

Materials and Methods

The Species360 Zoological Information System (ZIMS) database was used to collect data on eastern massasaugas housed in zoos (Species360 2025). The "Animals" database within ZIMS was utilized to find eastern massasaugas born in the years 2000-2021. The year 2000 was chosen as the starting date because this is when consistent annual births started in zoos (AZA Eastern Massasauga Rattlesnake SSP 2023). To be included in the study, individuals needed to have a known birth date and known biological sex. A total of 76 females and 94 males (N=170) were found across 18 institutions. Of these, 57 females and 59 males had sufficient data for growth analyses. Data including individual ID, date of birth, sex, mass, date of mass measurements, housing institution, and animal origin (wild or zoo) were collected. Animals with wild origin were either sourced from the wild or were born from wild mothers that were temporarily under managed care to give birth, while zoo origin individuals were born in zoos from zoo-housed mothers. Growth windows were separated and defined as: 0-11 months (first year of life), 12-35 months (rapid growth), 36-71 months (entering sexual maturity), and ≥72 months (fully mature) to account for differences in physiology at important life stages. The average mass of females and males each month from 0-177 months (the range of life span of the study animals) was calculated to visualize growth across all life stages. Body mass was compared across growth periods, where the average of ≥6 mass measurements in a window for each individual was recorded. Female body mass measurements recorded within three months prior to a birth were removed to eliminate higher mass bias associated with gravidity. The body mass of neonates within five days of birth was recorded to represent birth mass. Growth rate (g/month) was calculated by finding the slope of the best fit line consisting of ≥6 mass measurements in a growth window for each individual. Housing institution was reported as the location where a majority of measurements were recorded for mass and growth analyses, and as the location the individual was born for birth mass analysis. Additionally, we noted the proportion of females in the study that had given birth, and the average age that first births occurred within the study population.

Generalized additive models in the package 'gamlss' (Rigby and Stasinopoulos 2025) were used to analyse the data in the software, R (R Core Team 2025). Growth window, sex, institution, and origin were used as fixed effects to analyze body mass and growth rate. The institution variable was set to 'Other' if there were less than four data points from an institution to avoid overdispersion in models. Birth mass was also analyzed using sex, institution, and origin as fixed effects. Models were built where fixed effects were tested singularly to avoid overfitting due to small sample sizes for certain groups. Different data families were used depending on the distribution of the variables. Models were analysed for proper fit by checking the normality of the residuals and utilizing Q-Q plots as well as worm plots. The alpha value was set to 0.05 for all significance testing. Data are represented as means and standard deviations.

Results

Body mass

The average body mass of zoo-housed eastern massasaugas varied across time, with both females and males exhibiting a similar pattern (Figure 1). Average body mass was significantly different ($P<0.05$) between each of the growth windows, where mass was lowest in the 0-11 months window (25.2±6.2 g) and highest in the 72+ months window (324.7±61.3 g). There was no difference ($P>0.05$) between the sexes in any of the time periods for body mass (Table 1). Institution significantly ($P<0.05$) impacted average mass during all time periods (Figure 2). There was no difference ($P>0.05$) between wild and zoo origin body mass between any of the time periods (Figure 3). A post hoc review of the literature found that adult zoo individuals on average (females: mean=291 g, range=209-396 g; males: mean=312 g, range=222-407 g) have higher mass than wild adult individuals (females: mean=204 g, range=140-251 g; males: mean=271 g, range=217-329 g) based on the sources found (Table 2).

Birth mass

Sex did not have an effect ($P>0.05$) on eastern massasauga birth mass, with females (11.5±2.2 g) having similar mass to males

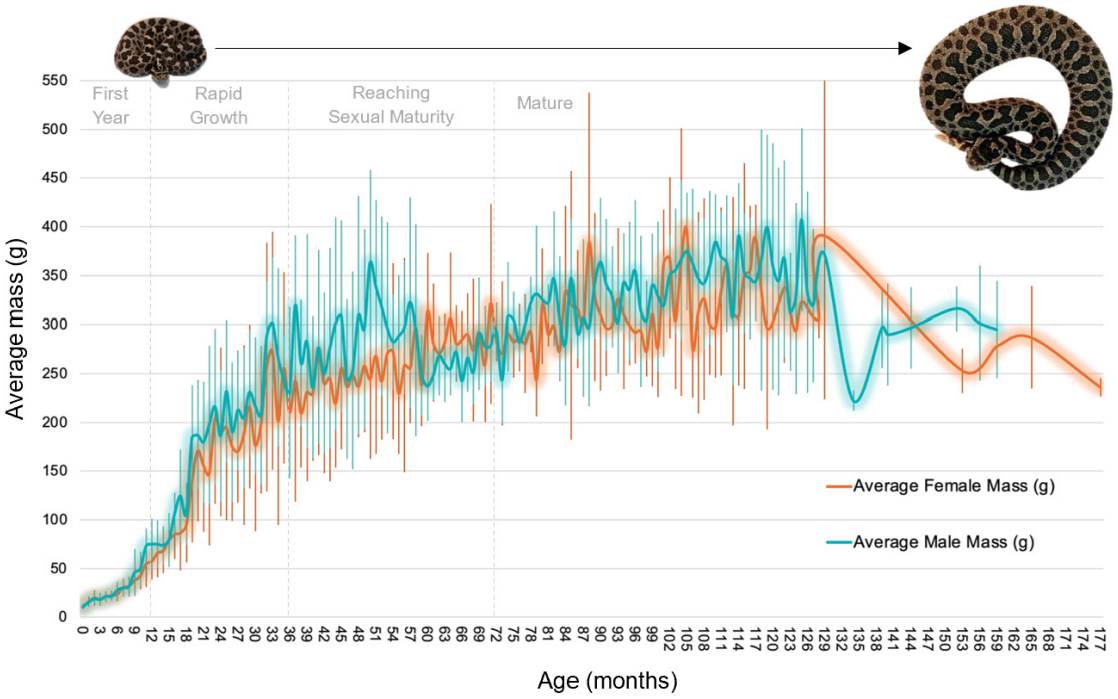

Figure 1. Average body mass over time of zoo-housed eastern massasauga rattlesnakes (n=75 females; n=92 males) born between 2000-2021. The four growth windows are defined as first year of life (0-11 months), rapid growth (12-35 months), reaching sexual maturity (35-71 months), and fully mature (72+ months). Data are shown as mean ± standard deviation. Photos by the Toronto Zoo.

Table 1. Comparison of average body mass and growth rate between male and female zoo-housed eastern massasauga rattlesnakes across different time periods. Growth rate (g/month) was calculated by finding the slope of the best fit line consisting of ≥6 body mass measurements in a growth window for each individual. Data are shown as the mean ± standard deviation. F represents females and M represents males. Asterisks indicate significant difference (P<0.05) between sexes.

Age	Mass (g)	Growth rate (g/month)	n
Birth	F: 11.5±2.2 M: 10.5±2.8	-	F: 35 M: 40
0-11 months	F: 24.9±6.0 M: 25.6±6.5	F: 3.0±1.2 M: 3.2±1.3	F: 41 M: 33
12-35 months	F: 141.7±54.7 M: 156.9±51.2	F: 9.1±3.9* M: 8.1±2.6	F: 21 M: 12
36-71 months	F: 259.0±66.3 M: 295.0±86.2	F: 2.9±4.1 M: 2.2±4.8	F: 22 M: 20
72+ months	F: 311.0±51.5 M: 335.2±67.2	F: 0.5±1.7 M: 0.3±2.2	F: 16 M: 21

(10.5±2.8 g). There was a significant effect (P<0.05) of institution on birth mass for snakes. Additionally, there was a significant (P<0.0001) effect of origin, where zoo origin neonates (11.6±2.5 g) had a higher body mass than wild origin neonates (8.9±1.3 g), though the sample size was limited for wild individuals (Figure 4).

Growth rate

There was a significant difference (P<0.05) between growth windows for growth rate, where the 12-35 months window (8.7±3.5 g/month) exhibited the highest growth rate, and the 72+ months window (0.4±1.9 g/month) contained the lowest (Figure 2). Females (9.1±3.9 g/month) experienced a higher (P<0.01) growth rate than males (8.1±2.6 g/month) during the fastest growth period (12-35 months) (Table 1), though the sample size for males was limited in this period. Housing institution significantly (P<0.05) affected growth rate across all growth windows (Figure 2). The growth rate of individuals with wild origin (2.9±1.0 g/month) was less than (P<0.05) zoo origin individuals (3.6±1.5 g/month) during the 0-11mo time period but was the same (P>0.05) across all other time periods (Figure 3).

Lastly, it was observed that of the 76 females in this study (all over three years old at time of analysis), only 18 females (24% of the study animals) have successfully reproduced (i.e. given birth to offspring), with the average age of first reproduction being 58±3 months (range=35-86 months).

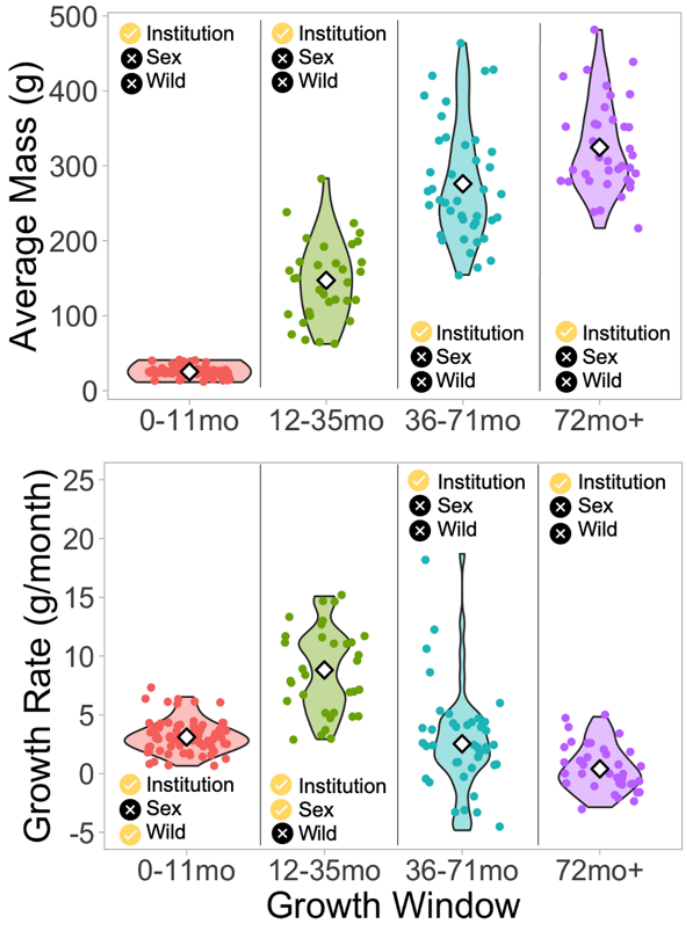

Figure 2. Comparison between growth windows (0-11, 12-35, 36-71, 72+ months [mo]) of zoo-housed eastern massasauga rattlesnake average body mass (top panel) and growth rate (bottom panel). Terms with a yellow check mark symbol next to it indicate there was a significant (P<0.05) effect of the variable (institution, sex, wild origin) on mass or growth rate. The white diamonds indicate the mean, while the thickness of the shapes represents the distribution of the data.

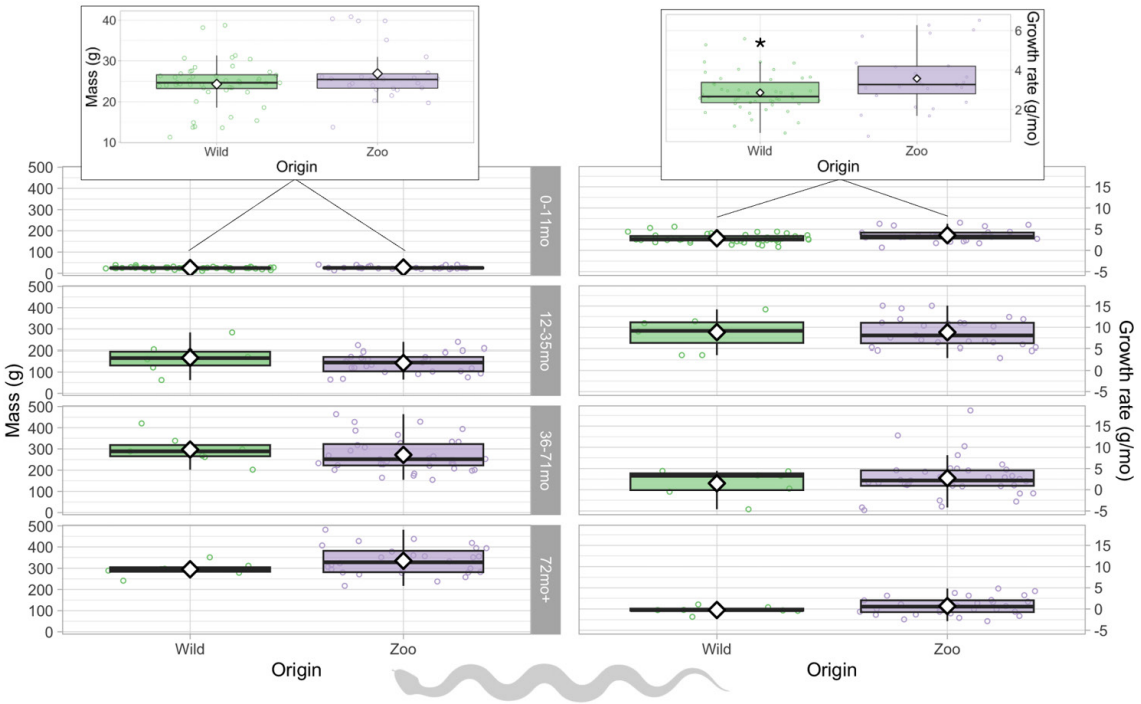

Figure 3. Comparison of average left: body mass (g) and right: growth rate (g/month [mo]) between zoo-housed eastern massasauga rattlesnakes with wild and zoo origins across different growth windows. Asterisks indicate significant difference (P< 0.05) between origins. The white diamonds indicate the mean, the black horizontal lines represent the median, and the whiskers represent the range of the data.

Table 2. Comparison of average adult body mass of female and male eastern massasauga rattlesnakes between wild-living individuals (sourced from the literature) and zoo-housed individuals in this study. The locations of the wild studies are indicated. Masses of zoo-housed individuals from the current study include females and males three years of age and older and removes mass measurements of females within three months of a birthing event. Data from wild-living individuals include adult non-gravid females and males.

Source	Location	Average Female Mass (g)	Average Male Mass (g)
Dreslik (2004)	Illinois	197	253
Jellen et al. (2007)	Illinois	-	265
Slater et al. (2017)	Michigan	181	248
Lee (2019)	Michigan	140*	217
Shoemaker (2007)	New York	239	316
Yagi, pers. comm.	Ontario	251	329
Moxley & Hathaway, pers. comm.	Ontario	213	266
Average (± SD) of above wild studies		204 ± 40	271 ± 39
Average (± SD) of zoo population in current study		291 ± 41 (43% increase)	312 ± 42 (15% increase)

*Included females with spring egress follicle development

Discussion

The goal of this research was to compare the body mass and growth of zoo-housed eastern massasaugas using historical zoological records. The main findings were that: 1) birth mass was influenced by institution and origin, 2) body mass was affected by institution, and 3) growth rate was affected by sex, institution, and origin. The hypothesis that growth rate would vary between males and females was partially supported, with females growing faster than males initially, but adult males and females reached similar body masses after 36 months of age as opposed to showing sexual size dimorphism. The hypothesis that housing institution would affect body condition was fully supported, with housing institution significantly affecting all response variables. The hypothesis that origin would impact early development was partially supported since wild origin neonates had lower masses and grew more

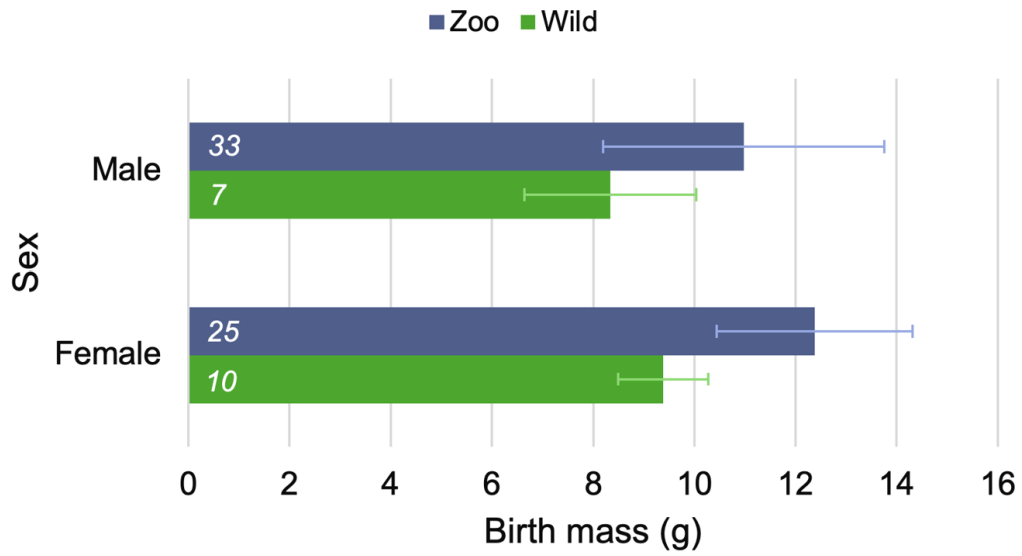

Figure 4. Comparison of average birth mass (g) between zoo-housed male and female eastern massasaugas with zoo and wild origins. Error bars represent the standard deviation, and white numbers indicate the sample size. Zoo origin individuals were significantly ($P<0.05$) heavier than wild origin neonates.

slowly during the first year of life compared to zoo origin neonates; however, wild and zoo origin individuals eventually grew to similar sizes after 12 months of age. Finally, a review of the literature revealed that wild populations of adult eastern massasaugas trend towards lower body masses on average compared to zoo individuals in this study. These findings indicate that eastern massasaugas may be born larger in zoos and retain larger body mass compared to wild-living counterparts due to factors such as consistent feeding or low mobility conditions under managed care. Further, snakes with wild origin that are raised in zoos reach a larger body mass that is sustained throughout their lives. Certain zoos exhibited markedly higher eastern massasauga growth and mass, indicating the need for standardization in husbandry protocols.

Body mass

We found a lack of sexual dimorphism in terms of mass across time periods. Within wild populations of viperids, males are typically larger than females (Shine 1994). For example, age-dependent sexual dimorphism has been observed in other pygmy rattlesnakes (e.g. *Sistrurus miliarius barbouri*) where males are heavier than females (May and Farrell 2012). This could be evolutionarily advantageous, as male eastern massasaugas with higher mass have been found to gain more access to females for mating opportunities as a result of advantages obtained during male-male combat (Jellen et al. 2007; Perelman et al. 2022). However, past research has found that there was no sexual size dimorphism in terms of body mass in wild massasaugas (Seigel 1986), and some suggest this trait may be dependent on population (Marshall et al. 2006). More recently, eastern massasaugas were found to have age-specific sexual dimorphism where males eventually become the larger sex (Dreslik et al. 2017a). Within the zoo population, our results indicate that sexual dimorphism based on body mass is not present, with females exhibiting a higher mass similar to males.

The AZA reports that sexually mature adults range from 180-400 g, with body masses over 400 g common for animals of great lengths (>75 cm) (AZA Eastern Massasauga Rattlesnake SSP 2013). This aligns with the current study that shows adults three years and older ranged from 209 to 407 g. This large range can be partially explained by differences in life stages and housing institutions. All growth response variables were significantly impacted by institution. This is likely because various zoos have differing husbandry practices and habitats (e.g. enclosure sizes). Previous research has similarly shown that differences in housing institutions can affect body mass and growth rate in mammals (Curry et al. 2023; Kleinlugtenbelt et al. 2023). Changes in factors such as diet, temperature, humidity, and opportunity to hibernate have been shown to affect animal health (Lorenzon et al. 1999; McCain et al. 2013; Mellor et al. 2020). For example, temperature during development and exposure to brumation conditions have been shown to influence behaviour, body mass, and growth in snakes (Aïdam et al. 2013; Sacerdote-Velat et al. 2014). Emphasis should be placed on sharing the most effective methods for enhancing massasauga health and wellbeing that can be incorporated into the species care manual to ensure institutions follow consistent protocols to achieve more predictable outcomes (AZA Eastern Massasauga Rattlesnake SSP 2013).

When examining zoo-housed eastern massasauga rattlesnakes three years of age and older in our study, we found that female body mass was 291 g and male body mass was 312 g on average, which is generally higher than the body mass of wild adult individuals described in the literature. For example, a study surveying a population of eastern massasaugas in Michigan found that adult females had an average body mass of 140 g, while males were 217 g on average (Lee 2019). Examining the mean body mass reported in literature on wild populations, wild adult females are typically 204 g, while adult males are 271 g on average (Table 2). This indicates that zoo-housed adult females have 43% higher body mass on average compared to wild adult females, and zoo-housed adult males have 15% higher body mass than wild eastern massasauga males. We acknowledge that zoo-housed female body masses may be higher due to the presence of unfertilized retained ova, which was not readily available information in the dataset but has been known to occur in *Sistrurus* in zoos (Kaye and Valitutto 2022; Choquette et al. 2025). Additionally, the definition of adult varies among the literature. Regardless, both sexes are likely heavier under managed care relative to their wild counterparts for reasons described.

Zoo-housed snakes may be larger than wild individuals due to consistent feedings that are not typical in stochastic, wild settings; for example, research with managed diamond-backed rattlesnakes found that juveniles fed higher intake diets gained more mass than snakes fed a low intake diet (Taylor and DeNardo 2005). This could be due to the "silver-spoon effect" that describes how individuals under favourable conditions (e.g. increased food availability) have higher growth later in life and reach larger sizes (Madsen and Shine 2000). Additionally, sedentary situations where animals are not exposed to regular stimuli, such as exercise, can result in increased body mass (Alexa et al. 2023). From a physiological standpoint, animals in ex situ settings can be prone to chronic stress due to factors such as higher proximity to humans, incompatible substrate microclimates, movement limitations, among others (Morgan and Tromborg 2007), although adaptation to managed care is highly species-specific (Fischer and Romero 2019). Chronic stress can cause increased corticosterone (i.e. the main reptilian glucocorticoid) produced via the hypothalamic-pituitary-adrenal axis, having downstream negative effects on immune function, reproduction, and body condition (Moore and Jessop 2003; Schulte-Hostedde and Mastromonaco 2015). Elevated adrenal activity and corresponding decrease in thyroid function can impact body mass; for example, research in birds has found that increased corticosterone depresses triiodothyronine (i.e. thyroid hormone T3) levels and results in mass gain (Buyse et al. 1987). It is also possible zoo-housed snakes live longer than wild counterparts due to veterinary care and lack of predators, resulting in more individuals reaching a higher mass. However, even when only considering measurements of zoo-housed massasaugas below eight years old in our dataset, body mass was still larger compared to wild populations. Interestingly, we found that zoo-housed individuals of wild origin eventually grew to similar sizes as zoo origin individuals despite having initially lower birth mass and growth rate. It is likely that proximate resources more strongly impact growth and mass for this species via phenotypic plasticity, rather than genetic predetermination (Tanaka 2011). Animals that are smaller in size relative to counterparts and then fed a high quality diet have been shown to exhibit "catch-up" growth associated with increased energy efficiency (Miller and Wise 2008), which could explain how wild origin eastern massasaugas reached similar body mass to zoo origin individuals.

There could be conservation impacts of larger sized individuals in zoos, as adaptation in ex situ settings can have effects on later efforts such as breeding and translocations (Schulte-Hostedde and Mastromonaco 2015). The phenotypic plasticity of eastern massasaugas to reach larger sizes in zoos could lead to benefits for reintroductions and population reinforcement projects, as recent work found that translocated garter snakes with a higher body mass at the start of hibernation had higher survival rates (Choquette et al. 2024). However, excessively higher masses could also cause detrimental health issues such as predisposition to sequalae including liver dysfunction (Mitchell 2004). Furthermore, it has been speculated that obesity/unfitness in female herpetofauna under managed care is linked with egg retention

(DeNardo et al. 2000; Roth et al. 2010; Pimm 2013; Hunter 2023), a prevalent issue in reptiles under managed care (Rivera 2008; Kummrow et al. 2025). An official body condition score or index is not currently established for zoo-housed eastern massasaugas (AZA Eastern Massasauga Rattlesnake SSP 2013), a valuable metric to ensure consistent and healthy body masses are reached for conservation efforts (see Gibbs and Chiucchi 2012). Snakes in zoos are often fed monotypic rodent diets that can be higher in fat than more diverse, wild diets (Jackson et al. 2024); this, combined with limited physical activity could potentially predispose snakes to high body mass-related health issues (Peeling and Recchio 2016). Research has found that eastern massasauga rattlesnake mean daily movement in the wild ranges from 12-50m (Weatherhead and Prior 1992; Dreslik et al. 2017b), though daily movement in zoos is not well documented for this species. Future research into the potential impacts of diet, habitat use and movement, and body mass on health, reproduction, and welfare in zoo-housed eastern massasauga rattlesnakes is necessary to ensure whole life care for this species.

Birth mass

There was no difference between males and females for birth mass. In another crotalid species *Crotalus triseriatus*, birth mass was higher for males compared to females (Jaramillo Alba et al. 2021). Within eastern massasaugas, field research found that female neonate body mass did not differ from male neonate body mass (Jellen and Kowalski 2007; Hileman et al. 2018), which aligns with our findings. We also found that wild origin individuals had lower birth masses on average compared to zoo neonates, though results should be taken with caution due to the skewed sample size between groups. Research covering eastern massasaugas in New York found that neonate body mass was on average 10.8 g (Johnson 2013), while mean neonate body mass ranged from 8.3-11.6 g across several other regions (Jellen and Kowalski 2007; Hileman et al. 2017, 2018), with an overall average of 10.3 g. We found that average birth mass was slightly higher at 11.5 g for eastern massasaugas of zoo origin, which could result from zoo-housed female mothers being heavier; for instance, research has found that larger female snakes produced heavier offspring and laid heavier egg clutches (Madsen and Shine 1992; Guo et al. 2022). Within massasaugas specifically, higher prepartum female mass has been found to correlate with increased brood mass (Aldridge et al. 2008). It is important to note that the wild birth mass sample size from ZIMS data in our study is limited, and a larger sample size would lend to more definite results in the future.

Knowing reproductive factors including age of first reproduction can be useful for zoo animal management, including completing more informed population viability analyses (Scott et al. 2023). The average age of first reproduction for zoo-housed female eastern massasauga rattlesnakes in this study was approximately five years old (58 months). In the wild, eastern massasauga sexual maturity is dependent on latitude. Snakes in the more southern extent of their range mature at 2-3 years old, while individuals in the north can take 4-6 years to mature (Hileman et al. 2017). Another interesting finding was that among all the females in the study (all of which were three years or older at time of analysis), only 18 of 76 individuals (24%) had ever successfully reproduced. This study was limited to zoo-housed individuals with known birth dates between 2000-2021, so there are likely many females missing from the dataset that have bred successfully. Additionally, it is a possibility that some zoos do not report reproductive events that do not result in viable offspring. Nevertheless, over 75% of females in this study have not reproduced, some of which could have valuable genetics. Focusing on breeding underrepresented individuals is an important target to increase the genetic diversity and longevity of the assurance population (AZA Eastern Massasauga Rattlesnake SSP 2023). Furthermore, space and resources are limited in zoo conservation breeding programs, so it is critical that a high proportion of the population is actively participating in reproduction to ensure sustainability (Che-Castaldo et al. 2018).

Growth rate

Eastern massasaugas displayed a variable growth rate across time, which is expected through different life stages where animals exhibit lag phases and rapid periods of growth (Vázquez et al. 2012). The data presented here follow the pattern of a logistic or von Bertanlaffy growth curve, where growth is initially rapid for maintenance and allocation toward reproduction, and eventually plateaus and later declines during geriatric years (Shine and Charnov 1992). We found that eastern massasauga females grew faster than males, which aligns with data from the wild (Dreslik et al. 2017a; Helferich et al. 2025), and could be evolutionarily advantageous for increased fecundity (Madsen and Shine 1992). Our research found that the 12-35 months period of life showed the fastest growth rate, which differs slightly from research in a similar rattlesnake species where the first year of life also exhibited a rapid growth rate (May and Farrell 2012). Research focusing on the growth rate of wild massasaugas using SVL indicated rapid growth during the first year of life as well (Ernst and Ernst 2003; Dreslik et al. 2017a). It is possible differences in diet, feeding behaviour, temperature, and space use between zoo and wild populations could be affecting growth. Alternatively, wild massasaugas could have undergone a rapid increase in SVL in their first year and then a more rapid mass accrual at a later time period.

The current AZA care manual for eastern massasaugas states that individuals less than one year old can optionally be fed weekly for a fast growth rate if desired for breeding purposes (AZA Eastern Massasauga Rattlesnake SSP 2013), as a faster growth rate can lead to potentially earlier sexual maturity in snakes (Ford and Seigel 1994; Taylor and DeNardo 2005), which may be beneficial for reaching larger population numbers for releases to the wild. While the first year of life is important for growth, the time from one to three years of age is also critical for developmental factors such as reproduction. For example, we found that the institution with the highest growth rates in the 12-35 month period had females that reproduced for the first time at a younger age than all other institutions on average (51 months vs. 66 months). Data from wild populations indicate that females can become sexually mature by their second year, and most likely reproduce annually or biannually (Goldberg and Holycross 1999; Keenlyne 1978). However, there are potential detriments to enhanced feeding to accelerate growth and time to sexual maturity. Research has indicated that increased growth rate early in life can lead to a shortened lifespan and decreased sexual responsiveness (Lee et al. 2013; Yuan et al. 2023), as well as potential impacts on female reproductive health (Di Giuseppe et al. 2017). We recommend a more consistent feeding schedule across institutions for neonates, though more research is needed into the optimal amount, type, and frequency of food items.

Overall, this research compiled and analysed eastern massasauga data covering over 20 years from 18 institutions. Imperative information about the body mass and growth of this threatened snake species was revealed. Housing institution affected body mass, growth rate, and birth mass, suggesting that husbandry practices could benefit from a higher level of standardization for more predictable outcomes. Based on wild population literature, zoo-housed eastern massasaugas, especially females, have higher body mass than their wild counterparts, indicating an effect of living under managed care. Potential husbandry modifications in diet, space use, and body condition indices should be carefully

considered to better correlate the size of zoo-housed eastern massasaugas to wild individuals. These results lend a valuable lens on the state of body mass and growth of eastern massasaugas in zoos from the last two decades and can inform conservation breeding and translocation programs for more effective outcomes.

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Data Availability

Data are available under reasonable request from the corresponding author.

Conflict of Interest Disclosure

There is no conflict of interest to declare.

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