Population decline in gray ratsnakes *(Pantherophis spiloides)* at Murphys Point Provincial Park

Calvin Elisen[1]

[1]Student number: 300296822

Email: celis027@uottawa.ca

Supervisor: Gabriel Blouin-Demers

Email : gabriel.blouin-demers@uottawa.ca

Abstract

As biodiversity and wildlife populations continue to decline globally, population monitoring and modelling is a crucial first step in countering these trends. Informed conservation action depends on first describing which populations are under threat and why. To this end, capture-recapture techniques are widely used to analyze trends in population size and demography. Unfortunately, these methods can be resource intensive, making small scale monitoring efforts difficult. Here I investigate the long-term population dynamics of the gray ratsnake *(Pantherophis spiloides)* at Murphys Point Provincial Park in Ontario, using opportunistic capture-recapture data. While abundance estimates are confounded by variable sampling effort, significant declines in mean snout-to-vent length (SVL) indicate a downward shift in the population age structure. With at least five instance of road moratlity annually in the last decade, this demographic trend likely reflects the hazards posed to snakes by park roads. These results demonstrate that non-standardized or low-effort sampling can successfully identify demographic threats, acting as an informative alternative when structured abundance monitoring is unfeasible. Furthermore, the continuing negative impacts of road mortality in a large, protected area bodes poorly for the success of the species in the surrounding fragmented landscape.

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Introduction

Biodiversity has been declining at an alarming rate globally, with wildlife populations falling 71% since 1970 (World Wide Fund for Nature, 2024). As the number of species threatened with extinction continues to grow, informed and specific conservation actions must be taken to combat biodiversity loss. The often-limited resources designated to these efforts require that blind or ineffectual management decisions be avoided by first thoroughly understanding the population under threat. This makes monitoring and modelling the population dynamics of species at risk a crucial step in the conservation process.

Population monitoring is carried out in a variety of ways, depending on available funding and work hours, the monitored species' biology, and the unique requirements of monitoring organizations. The monitoring methods employed in a study have implications for the nature and quality of the data gathered, thus determining which population estimates can be made and how well. For example, formal surveys involving transect or quadrat sampling standardize data collection practices, allowing for straightforward estimation of population parameters that are comparable across study years and locations (Jolly, 1965; Schwarz & Arnason, 1996). Monitoring techniques like these work well for abundant or conspicuous taxa, but they can often be resource intensive.

For rare, elusive, or difficult to catch species, it is often more pragmatic to use traps for standardized data collection. Like area surveys, traps create a consistent, easily defined detection process, but without relying on the detection capability of surveyors. Camera traps or similar passive detection regimes further reduce resource requirements by eliminating processing time.. To limit both effort and invasiveness, passive detection forgoes the capture and handling of individuals, often sacrificing unique identification, and the measurement of individual traits. Similar challenges are met with the use of citizen science data such as those sourced from eBird or iNaturalist. While they can provide helpful information on occurrence patterns, they are inadequate for estimating true population parameters and prone to several biases.

Opportunistic sampling functions as a less resource intensive sampling process that can still involve the identification of unique individuals and the measurement of individual traits (Boys et. al., 2019). Capturing individuals whenever they are encountered by chance can still introduce sampling biases but may also permit the analysis of demographic trends, and possibly the use of capture-recapture models to estimate population size (Boys et.al., 2019). These factors can be essential to population monitoring, as early warning metrics perform poorly when ignoring changes in demographic traits (Clements & Ozgul, 2016). Modelling traits like sex ratios, age distribution, individual health or body condition, and age-specific survival and reproduction can mitigate bias in population projections that would otherwise misinform management decisions, leading to adverse conservation outcomes. Changes in demography also typically precede population decline and can thus act as an early indicator of decline (Clements & Ozgul, 2016). As with other less formal monitoring procedures, opportunistic sampling can increase sample sizes when monitoring elusive species like the gray ratsnake, but can additionally provide valuable individual-level data.

The gray ratsnake has been formally recognized as a species at risk in Ontario since 2001, but despite conservation work, the outlook for the population's status has not improved with subsequent assessments (COSEWIC, 2018). The Ontario population is divided into the Carolinian and St. Laurence/Great Lakes subpopulations, listed as endangered and threatened respectively (COSEWIC, 2018). The Carolinian subpopulation formerly ranged across north shore of Lake Erie; however, the most recent estimates place the <250 remaining individuals dispersed across the southern parts of Elgin, Norfolk and Haldimand counties (COSEWIC, 2018). The St. Lawrence/Great Lakes population has an estimated 25,000-67,000 remaining individuals, but remains under threat from continuing development of the Frontenac Arch (COSEWIC, 2018).

Both populations have seen significant decreases in both range and abundance, as the life history of gray ratsnakes makes them particularly susceptible to anthropogenic disturbance (Bohm et. al., 2016). They are a long-lived species that is faithful to its home ranges and overwintering sites. Disruption of traditional hibernacula is expected to reduce subsequent overwinter survival, and habitat degradation by human development can elevate mortality rates during the active season (Row et. al., 2007) . Due to the outsized reproductive value of large adult snakes, even low levels of excess mortality (e.g. habitat loss, road mortality) can cause populations to decline inevitably (Row et. al., 2007) .

Despite ongoing threats, monitoring and conservation efforts for this species have declined in recent years as conservation authorities have focused their efforts elsewhere. A long-term research program on gray ratsnakes at the Queens University Biological Station recently ended, and two Ontario Parks (Frontenac and Charleston Provincial Parks) that formerly had similar monitoring programs to Murphys Point have also discontinued this work. Camera traps are employed intermittently at hibernaculum sites in Thousand Islands National Park, but this program no longer involves tagging individual snakes at scale. Research in the Carolinian DU has been limited, with sporadic efforts confirming the persistence of the population but little more (COSEWIC, 2018). For these reasons, the ongoing, long-term capture-recapture program at Murphys Point will provide important insight into the state of gray ratsnake populations in Ontario.

Objectives:

My objectives are to describe the long-term demographic trends of gray ratsnakes at Murphys Point Provincial Park and to examine possible drivers of demographic change. I will apply linear mixed effect models to investigate trends in snout-to-vent length (SVL) and body condition. My other objective is to evaluate the efficacy of informal sampling methods in monitoring this species, to inform future monitoring and conservation efforts of this species in Ontario Parks.

Methods

Sampling Process

Gray ratsnake observations were collected from 1994-2025 by a combination of opportunistic captures and formalized hibernaculum monitoring. Data from hibernaculum monitoring was collected at five of eight known hibernaculum sites, with regular surveys from 2003-2010, and in 2014 (*n* = 217). Two sites were monitored extensively (**Figure 1**), with drift fences and funnel traps checked daily from late April to early May, and with transect surveys also performed daily in the surrounding areas. Only four hibernaculum observations were not recorded at these two sites. Hibernaculum monitoring methodology is described in detail by Brdar (2005). Opportunistic data (*n* = 1009) (**Figure 1**) includes gray ratsnake encounters by both park staff and campers, with calls being directed to staff trained in processing snakes. These staff also performed semi-regular foot and vehicle surveys of park roads to record road mortalities (*n* = 97) (**Figure 1**), as well as frequent checks of known shedding sites at historic buildings in the park (included in opportunistic data). Sampling effort of opportunistic data varies widely from year to year without records, therefore; it cannot be quantified outside of the number of captures made.

Capture Procedure

Live snakes were captured, processed and returned to the site of their capture typically within one hour, with no snakes being held overnight. Snakes were only processed once per season, although secondary encounters were also noted. When possible, approximate GPS coordinates of the capture were recorded or copied from previous captures nearby. Two measurements of SVL were taken, and the mean of these was recorded. Mass was recorded using a spring scale. For first captures of a new snake, an area of skin approximately 10 cm above the vent was sanitized using ethanol, and a PIT tag was inserted subcutaneously using a needle. The area was then sealed against infection using glue. Sex was identified by inserting a lubricated probe into the vent, until there was slight resistance. If the probe could be inserted more than two ventral scales from the vent, sex was identified as male. Juveniles under 80cm were not always processed, depending on the comfort levels of park staff. All these guidelines were generally followed, the specific products, tools, and techniques that were used varied between years and between captures. Due to constraints on staff training, available time, and resources, incomplete observations missing one or more fields were also frequently recorded.

Statistical analysis

I used linear mixed effect models to evaluate trends in SVL over time. Initial models included fixed effects of year, sex, day of year, live/dead status, and sampling method (two level factor of hibernaculum or opportunistic), as well as all two-way interactions. SVL was log-transformed to meet assumptions of homoscedasticity, and year and day of year were both zeroed to simplify interpretation of the intercept. I used backwards elimination based on significance and the Bayesian Information Criterion (BIC) to compare fixed effect structure of the models. Parameter estimates were made by maximum likelihood (ML) in the model selection process, but restricted maximum likelihood (REML) was used once the optimal fixed effect structure was identified. In all models I included Individual ID as a random intercept, and a first-order autoregressive correlation structure (AR1) to account for the nonindependence of repeatedly observed snakes. Variance was weighted as an exponential function of year to account for heteroscedasticity. The final selected model included year, sex, day of year, and sampling method, as well as the interaction between day of year and sampling method. Data for which any variable was unknown were excluded from the model.

I then analyzed how body condition is changing in the population. I used a standardized major axis regression of log-transformed mass on log-transformed SVL to generate a universal slope describing size-weight allometry. Scaled Mass Index (SMI) was calculated as described by Peig and Green (2009), using the population mean SVL and the previously estimated allometric scaling slope. I then evaluated trends of SMI over time, once again using linear mixed effects models. The variance weight structure, random intercepts, and AR1 structure, as well as the model selection process was identical to that described above for SVL, but fixed effects differed slightly. Initial models included fixed effects of zeroed year, zeroed day of year, sampling method, sex, status, and mean-centered SVL to capture any residual allometry not absorbed by the calculation of SMI. Additionally, all two-way interactions were included as fixed effects in initial models. The final selected model included year, SVL, sampling method, and the interaction between year and SVL.

Finally, working in Program MARK, I used the POPAN formulation of the Jolly-Seber model to generate annual estimates of abundance, survivorship, recruitment, and detection probability (Jolly, 1965; Schwarz & Arnason, 1996). Sampling method, and number of observations were used as annual covariates on abundance and on detection probability.

Results

The models successfully identified population level changes in both SVL and SMI through time when controlling for other effects. Mean SVL is decreasing by 0.282% annually, or a

7.34% decrease over the 28 years of size data (**Table 1; Figure 2**). SVL additionally varies with day of year, sampling method, and their interaction, with a near significant effect of sex as well (**Table 1**). Repeated measurements of SVL in the same snake were found to be highly correlated ($\varphi = 0.876$) (**Table 1**).

From the SMI models, most of the size distribution of gray ratsnakes at Murphys Point is increasing in body condition over time, while the longest snakes in the population weigh less for their length in later years (**Table 2; Figure 3A-B**). The equilibrium point is 140.4 cm, so snakes at this SVL have approximately the same SMI as 28 years ago, while the directional trend across time is opposite for snakes above and below this SVL (**Figure 3B**). Significant effects on SMI were also found in sampling method, sex, and the main effect of year (**Table 2**). Repeated SMI measurements of the same snake were correlated, but less strongly than repeat measurements of SVL ($\varphi = 0.299$) (**Table 2**).

While demographic trends were successfully identified from size data, mark-recapture models failed to produce meaningful results and so no results are reported here. Estimates of abundance, survivorship, recruitment and detection probability were all unstable. The parameters generated by POPAN varied widely and nonsensically, regardless of which covariates were introduced to stabilize the model. Road mortality numbers are also confounded with sampling effort, however mean annual road mortality loss is at least 2.97 across the study period, and at least 5.4 over the last 10 years.

Discussion

The changing demographic profile of gray ratsnakes at Murphys Point Provincial Park over the last three decades is a strong indicator that this population has been destabilized by human activity. A 7.34% decline in SVL over time means the relative frequency of large snakes compared to small ones is decreasing. This change in proportions can be explained either by an influx of juvenile snakes in the population, or a truncation of the age distribution. While sampling effort fluctuates too widely from year to year in this dataset to compare true abundance estimates of different age classes, the number of captures each year has generally increased. Despite more thorough sampling, the largest size classes of ratsnakes have disappeared from the data in recent years.

The loss of large adult snakes in the population is consistent with the high rates of road mortality observed in this study. Row et. al. (2007) proposed that road mortality may selectively kill large snakes based on the smaller portion of the road that a vehicle can safely pass them by as they cross. While this may be true, elevated incidental mortality rates across the size distribution would also decrease the probability that an individual lives long enough to grow to the longest SVLs. In either scenario, road mortality provides a likely mechanism by which population mean SVL is decreasing.

Juvenile influx, however, cannot be ruled out definitively. The absolute number of small individuals observed each year has increased over time (**Figure 2**), and trends in population size were not estimable, precluding inferences from the overall success of the population. A healthy population with high recruitment rates would also be consistent with the observed increase in body condition. Body condition indices and other proxies for individual health often precede changes in population size (Clements & Ozgul, 2016), and in snakes, body condition correlates to reproductive success (Naulleau & Bonnet, 1996). However, gray ratsnake populations can be highly sensitive to increases in road mortality rates (Row et. al., 2007), so with road mortality rates of 5.4 deaths/year in the last 10 years, which is a minimum estimate of total road mortality in the population., truncation of the right tail of the size distribution better explains the decline in SVL over time, while an alternative explanation is still required for trends in body condition.

One possibility is the competitive release of the remaining gray ratsnakes (Waye & Mason, 2007). If resources are limited, a decline in population density may allow the surviving individuals to secure more resources and build body condition more quickly. However, gray rat snakes are typically limited by factors related to thermoregulation, rather than space or food resources (Blouin-Demers & Weatherhead, 2002). Competitive release has been observed once in snakes, in a population of brown tree snakes in Guam (Waye & Mason, 2007). However these snakes are invasive and are found at remarkably high population densities, which is not true of gray ratsnakes at Murphys Point.

Alternatively, changes in body condition may indicate an adaptive response in life history to elevated mortality rates . If the decline in SVL represents a reduction in expected longevity, the optimal pace-of-life may be accelerated. Specifically, greater investment in reproduction in early life would be favoured, rather than distributing reproductive effort across a longer lifespan (Shine & Shwarzkopf, 1992). Since threshold body condition is required for reproductive success in snakes (Naulleau & Bonnet, 1996), smaller gray ratsnakes may be investing heavily in building body condition earlier in their life relative to previous generations (Shine & Shwarzkopf, 1992). Importantly, this also explains the effect of the interaction between SVL and year on SMI. As some few individuals that invested heavily in reproduction still live to older age classes, they experience the cost of that investment as reduced body condition (Brown & Shine, 2025). While this hypothesis will require reproductive and cohort studies to be tested definitively, a combination of road mortality and accelerating life history would parsimoniously explain both the decline in population mean SVL and the size-dependent changes in SMI in gray ratsnakes at Murphys Point over the last three decades.

In addition to the population trends described, this study additionally supports the value of opportunistic or hybrid sampling protocols for small-scale conservation efforts.

While standardized sampling is typically preferred for population monitoring, less resource intensive strategies can still provide valuable demographic data to inform decision-making and conservation action (Boys et. al., 2019). While this informal data collection protocol made standard mark-recapture models inadequate for estimating population size, the detection of decline indicators in SVL road mortality rates suggest that these methods can act as a viable alternative for conservation organizations with limited resources. Furthermore, the application more complex state-space or integrated population models may yet make abundance estimates feasible (Boys et. al., 2019). For the gray ratsnake, the long-term capture-recapture program at Murphys Point has implications for the conservation of the species across its range in Ontario. The decline indicators described here present evidence that the gray ratsnake population is unstable, even in a large protected area. Murphys Point is at least in theory meant to be an area in which the species can thrive, and so its continuing decline here bodes poorly for the species as a whole. The landscape surrounding the park is largely fragmented for agricultural use, and bifurcated by busier road networks than those found inside park boundaries. As road mortality threatens the gray ratsnake even in a provincial park, further monitoring, research, and conservation action will be necessary for the long term protection of this species.

Contributions

I performed formal analyses and wrote this report. My supervisor, Gabriel Blouin-Demers, provided guidance on methodology, and insight and feedback on writing throughout the creation of this report. Murphys Point staff collected the data used for these analyses and provided relevant background information about the data collection process, with notable contributions from Tobi Kiesewalter and Rachel Needham.

Statement of AI use

None of the contents of this report were conceived of or generated by AI.

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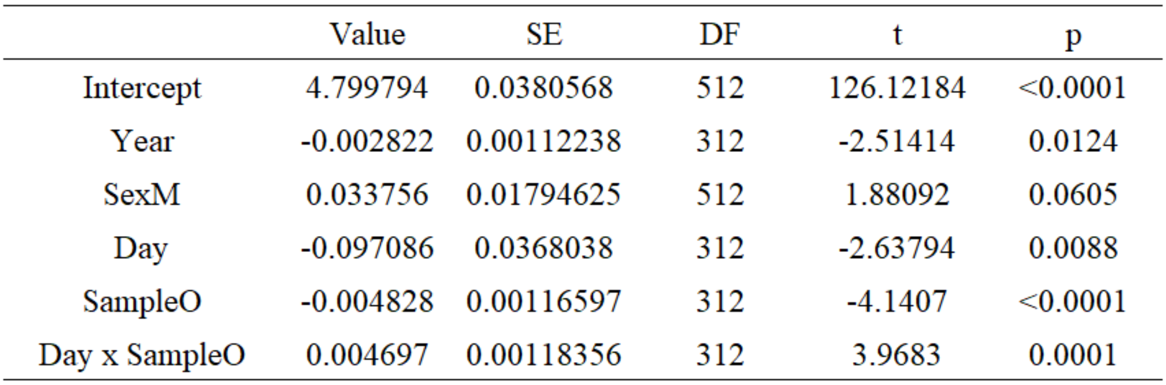
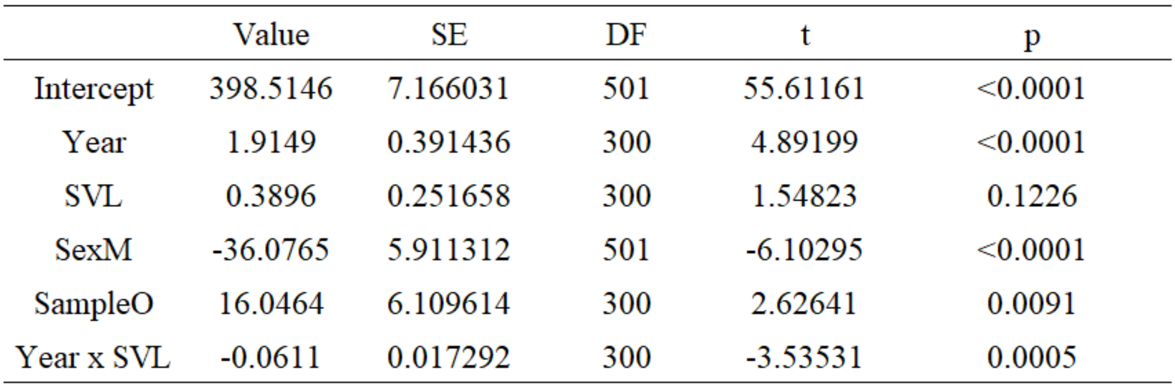
Table 1. Linear mixed effect model of log-transformed snout-to-vent length (SVL). SVL is decreasing over time, is higher in males (near significant), decreases throughout the season for snakes captured opportunistically, and increases across the hibernaculum monitoring season. Intercept is the predicted log-transformed SVL for a female snake captured at a hibernaculum on the earliest recorded emergence April 9th, and the first year of SVL observations in 1998. Individual ID was also included as a random intercept (*sd* <0.0001) with a residual standard deviation of 0.1746. $N_{obs} = 830$; $N_{groups} = 514$; $BIC = -490.470$; $\varphi = 0.875$; exponential variance covariate = 0.0122.



	Value	SE	DF	t	p
Intercept	4.799794	0.0380568	512	126.12184	<0.0001
Year	-0.002822	0.00112238	312	-2.51414	0.0124
SexM	0.033756	0.01794625	512	1.88092	0.0605
Day	-0.097086	0.0368038	312	-2.63794	0.0088
SampleO	-0.004828	0.00116597	312	-4.1407	<0.0001
Day x SampleO	0.004697	0.00118356	312	3.9683	0.0001

Table 2. Linear mixed effect model of scaled mass index (SMI). SMI is increasing over time for most of the size distribution, although it is decreasing the right tail of the size distribution. Body condition is higher in longer snakes, female vs. male snakes, and in opportunistically captured vs. hibernaculum sampled snakes. Intercept is the predicted SMI for a female snake of mean SVL (109.099 cm) if captured at a hibernaculum in the first year of SMI observations in 1998. Random intercept of ID (*sd* = 32.098) is also included. N_{obs} = 807; N_{group} = 503; BIC = 9233.025, φ = 0.299, exponential variance covariate = 0.0323.



	Value	SE	DF	t	p
Intercept	398.5146	7.166031	501	55.61161	<0.0001
Year	1.9149	0.391436	300	4.89199	<0.0001
SVL	0.3896	0.251658	300	1.54823	0.1226
SexM	-36.0765	5.911312	501	-6.10295	<0.0001
SampleO	16.0464	6.109614	300	2.62641	0.0091
Year x SVL	-0.0611	0.017292	300	-3.53531	0.0005

Figures

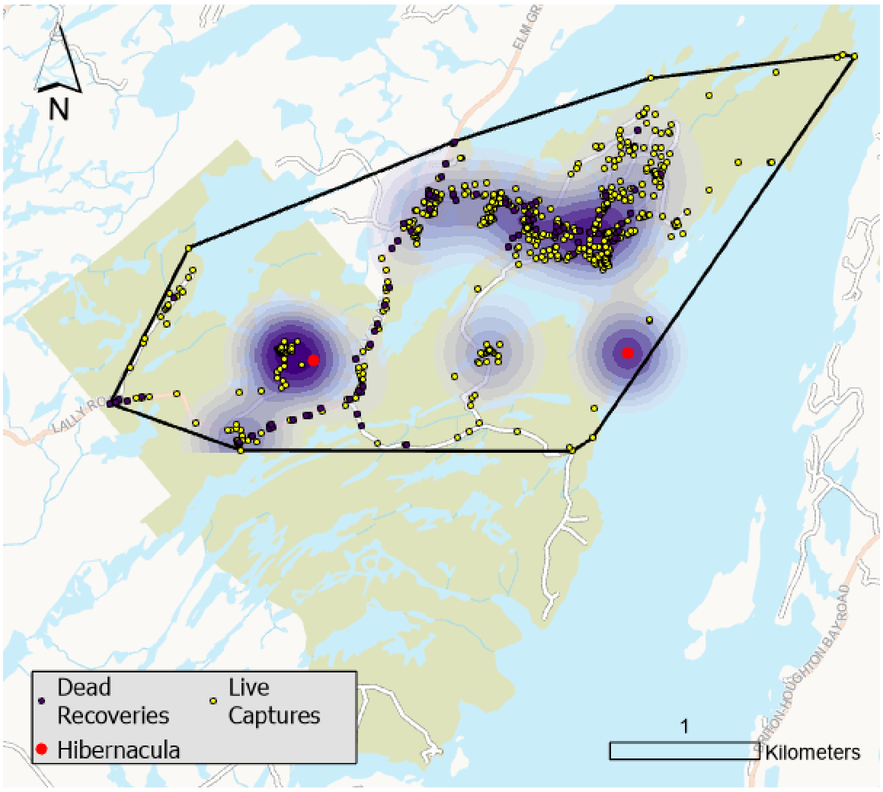


Figure 1. Spatial distribution of gray ratsnake observations. Sampling process included road mortality surveys, opportunistic captures, and formalized hibernaculum monitoring. Kernel density estimate generated using a 500 m search radius. Within-hotspot recapture probability is maximized at a 500 m search radius. Minimum convex polygon approximates the upper limit of study area size at 7.43 km^2.

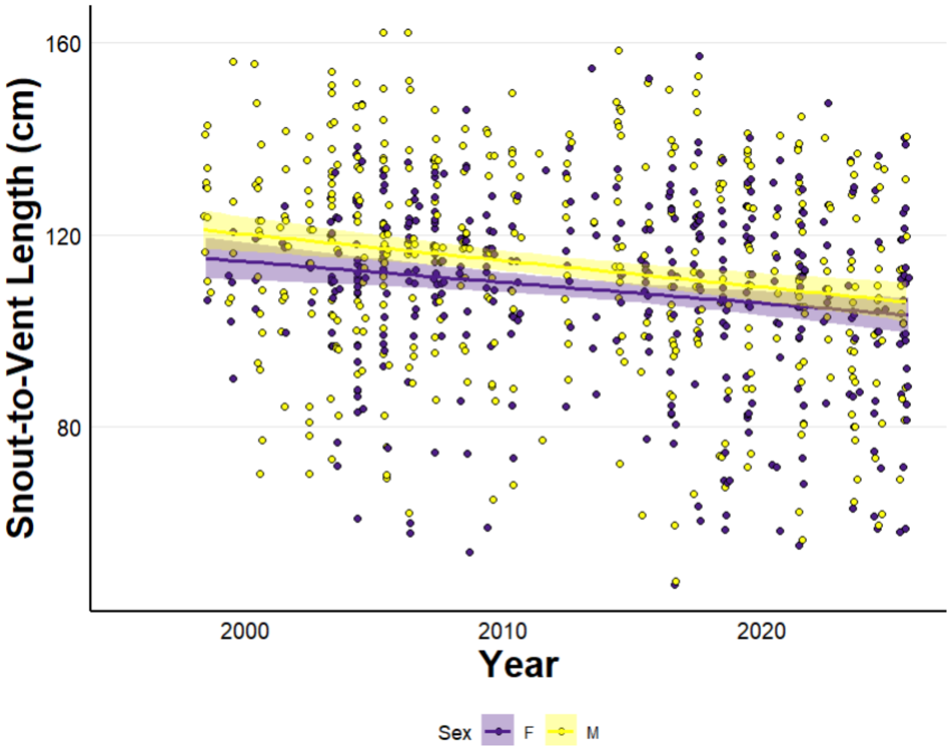


Figure 2. Change in snout-to-vent length (SVL) over time. The linear model is fitted on raw SVL data, grouped by sex, with 95% confidence intervals. The trendlines illustrate the decrease in the relative frequency of large snakes over time, while the point distribution depicts temporal changes in the absolute numbers of observations of very large and very small snakes.

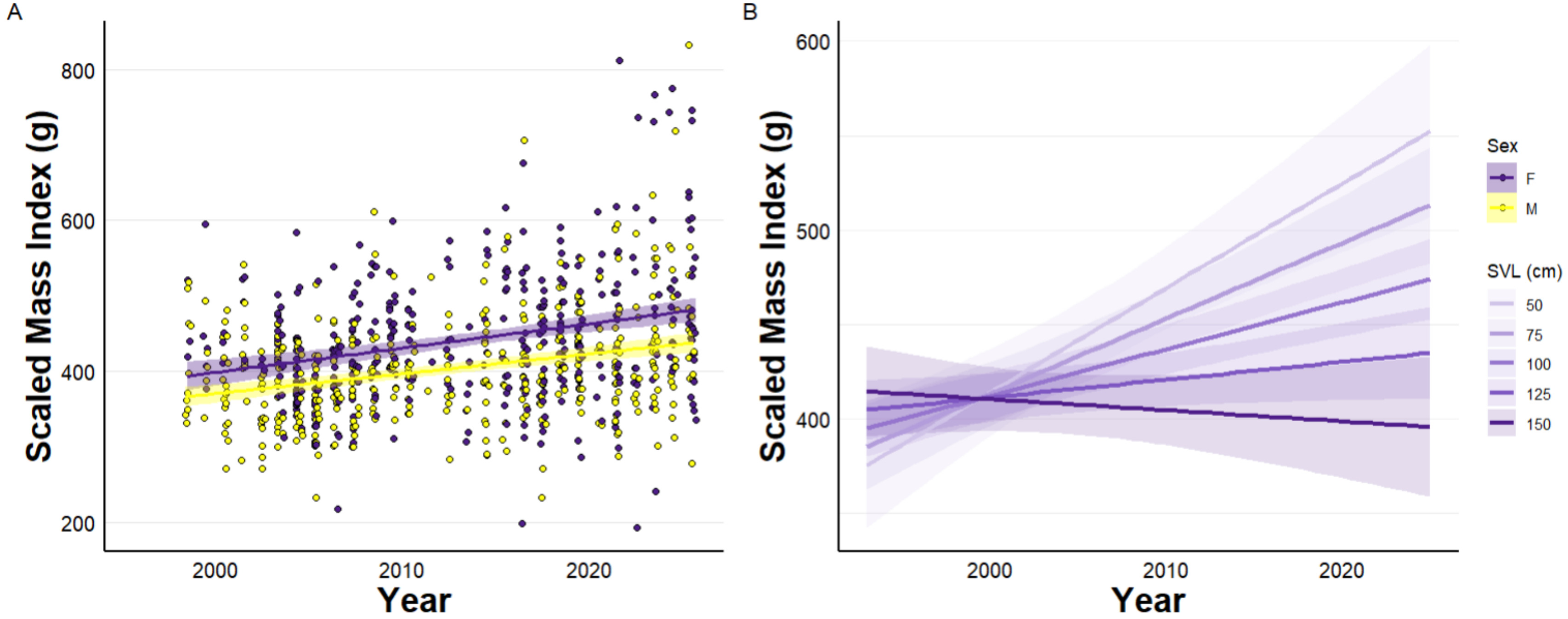


Figure 3. Change in Scaled Mass Index (SMI) over time. (A) Observed change in SMI over time, grouped by sex. The linear model is fitted on raw scaled mass index data with 95% confidence intervals. Visualization of the average increase in body condition over time. SMI represents observed mass, scaled to the mean SVL of the population. **(B)** Modelled interaction of Snout-to-Vent Length (SVL) and year on SMI. Predicted SMI over time of representative snakes with SVLs in intervals of 25 cm, from 50 cm to 150 cm, with 95% confidence intervals. Ratsnakes of SVL < 140.4 cm in 2025 have greater SMI than individuals of the same length in previous years.