Received: 22 June 2021 | Revised: 2 February 2022 | Accepted: 22 June 2022

DOI: 10.1002/zoo.21721

RESEARCH ARTICLE

ZOOBIOLOGY WILEY

American alligator (*Alligator mississippiensis*) weight gain in captivity and implications for captive reptile body condition

Faith Kruis[1] | **Madison Wallwork**[1] | **Marisa Spain**[1,2] | **Adam E. Rosenblatt**[1]

[1]Biology Department, University of North Florida, Jacksonville, Florida, USA

[2]Jacksonville Zoo and Gardens, Jacksonville, Florida, USA

Correspondence

Adam E. Rosenblatt, Biology Department, University of North Florida, Jacksonville, FL 32224, USA.
Email: adam.rosenblatt@unf.edu

Funding information

University of North Florida

Abstract

The body condition of an animal is an indicator of health status and is dependent upon many factors, some of which can vary between wild and captive settings. Despite this, there have not been many studies on how captivity affects body condition relative to wild animal populations. This study explores the body condition of captive and wild American alligators (*Alligator mississippiensis*) because reptiles are frequently overlooked in studies of captive animal health and because alligators are well-represented in captivity. We collected body condition data from 209 captive alligators and 935 wild alligators throughout Florida and southeastern Georgia and compared the relationships between body condition and body length for each group. We found that captive alligators exhibited significantly higher body condition values as they aged, and that this result was driven by the difference between captive and wild males. Body condition values for captive juveniles did not differ from wild juveniles, but they differed when comparing adults. Our results suggest that factors such as diet and movement rates play major roles in determining alligator body condition and that body condition may be an important metric for monitoring captive alligator health, especially for older adult males.

KEYWORDS

body condition, crocodylian, Florida

1 | INTRODUCTION

An animal's body condition (the ratio of mass to size) is a key indicator of health because body condition is responsive to a wide range of factors, including diet type, resource availability, environmental changes, disease status, and population density. Captivity can affect all of these variables and potentially lead to unhealthy body condition for some species, but what constitutes "healthy" body condition has not been established for many animal species. As a result, it is unclear if care protocols are currently adequate for some species in captivity or if such protocols would benefit from updates informed by species-specific research.

To assess whether or not a captive animal's body condition is potentially unhealthy requires comparative studies of captive and wild populations. For example, Mellor et al. (2020) assessed 13 species of lemurs and discovered that some, such as the red bellied (*Eulemur rubriventer*) and greater bamboo (*Prolemur simus*) lemurs, had healthy body conditions in captivity. However, other lemur species, such as the black and white ruffed (*Varecia variegate*) and red ruffed (*Varecia rubra*) lemurs, were found to be obese in captivity. The factors influencing weight gain in captivity included the design of climbing structures and differences in feeding habits between wild and captive individuals. To counteract these factors and benefit physical wellbeing for lemurs, it was recommended that facilities practice proper weight management for the lemurs and incorporate a mixture of fixed and flexible climbing structures with enrichment scattered throughout the enclosure. In contrast, for some species body condition does not strongly vary across wild and captive individuals. A study of Montagu's harrier nestlings (*Circus pygargus*) found that body condition varied predictably when prey abundance was low or high regardless of where an individual lived (Sternalski et al., 2010).

Since it can be difficult to assess body condition for some large animals in the wild, some studies have used semicaptive animals for comparison instead. For example, body condition scores for captive Asian (*Elephas maximus)* and African (*Loxodonta africana*) elephants have been compared with those of semicaptive Asian elephants that spend the day working in Myanmar's timber industry but are able to forage and mate without human intervention during the night (Morfeld et al., 2016; Santos et al., 2020). The results indicated that body condition scores were lower (less body mass per unit size) for semicaptive elephants relative to captive elephants because in captivity elephants did not exercise as much and had a more structured, predictable diet.

Comparisons of wild and captive animal body condition have focused mostly on birds and mammals; in fact, to our knowledge only one study directly measured the effect of captivity on reptile body condition. It found that captive Otago skinks (*Oligosoma otagense*) had more body mass and faster rates of growth than wild individuals (Connolly & Cree, 2008). Despite their ubiquity in captivity, there is a clear lack of research on the effects of captivity on reptile body condition, so it is unknown if reptile management and care protocols are in need of updating.

The American alligator (*Alligator mississippiensis)* is an ideal model species for assessing the effects of captivity on reptile body condition because alligators have been studied intensively in the wild for 60 years and are also commonly found in captivity. This is especially true in states such as Florida, where there are many tourist attractions, zoos, aquariums, and museums that house alligators. Research on wild alligators has shown that their body condition can be influenced by water depth (Brandt, Beauchamp, et al., 2016; Fujisaki et al., 2009), habitat type (Brandt, Nestler, et al., 2016; Dalrymple, 1996), diet (Delany et al., 1999; Gabrey, 2010), and temperature (Herbert et al., 2002). Our objective was to compare morphometric data collected from wild and captive alligators throughout Florida (and some from southeast Georgia) and determine why body condition might vary between the two groups. We hypothesized that captive alligators would exhibit higher body condition scores (i.e., more body mass per unit length) on average than their wild counterparts, potentially because of differences in diet and movement rates.

2 | METHODS

2.1 | Data collection

To calculate body condition, we used Fulton's condition factor, a metric commonly used in studies of wild alligators (Fujisaki et al., 2009; Rice et al., 2007). The equation for Fulton's condition factor is

$$K = M/SLV^3 \times 10^5,$$

where K is body condition, M is body mass in kg, and SVL is snout-vent length in cm (Fujisaki et al., 2009). To make valid comparisons between wild and captive alligators we gathered mass, SVL, and sex data for both groups. Wild alligator data came from many published studies of alligator biology in Florida and southeast Georgia (Delany & Abercrombie, 1986; Delany et al., 1988, 1999; Rice et al., 2007; Rosenblatt & Heithaus, 2011; Rosenblatt et al., 2013; Nifong et al., 2015) as well as some recent data from Jekyll Island, GA (A. Rosenblatt, unpublished data). The wild alligators resided in a wide array of habitats, including lakes, ponds, estuaries, and barrier islands, spanning from the tip of southwest Florida to southeast Georgia (25°18′ N to 31°31′ N). In total, we aggregated data from 935 wild alligators with measurements taken between 1977 and 2020.

To acquire captive alligator data, we contacted 279 businesses in Florida that possessed active permits for captive alligators (as of 2020) from the Florida Fish and Wildlife Conservation Commission. We requested mass, SVL, and sex data for as many alligators as possible from each business, and received data from 22 businesses including zoos, aquariums, museums, and a variety of other tourist attractions. The businesses spanned from south to north Florida (24°43′ N to 30°30′ N). In total, we received data for 209 captive alligators with measurements taken between 1999 and 2021. Some of the captive alligator data was undated, so we are unsure how long ago some of the measurements may have been taken.

2.2 | Data analysis

We used the statistical program R (version 4.0.3; R Core Team 2020) for all analyses. Before data analysis, we identified and removed outliers using the interquartile range method (Dovoedo & Chakraborti, 2015). This led us to remove one alligator from the captive data set and four alligators from the wild data set. For the remaining data, we used linear regression to model the relationship between K and SVL for wild and captive alligators separately. We then tested for significant differences between regression slopes using the “pairs” function within the lsmeans package. We performed multiple comparisons between subsets of both the wild and captive alligator data sets to help identify if certain segments of each population were driving the observed differences.

3 | RESULTS

We analyzed measurements of 208 captive alligators from 21 facilities. Of these, 30% were female ($n = 63$), 38% were male ($n = 79$), and 32% were unknown ($n = 66$). Adults, classified as SVL ≥ 90 cm, made up 20% of the data set ($n = 42$) while 80% of the data set consisted of juveniles (SVL ≤ 90 cm; $n = 166$). We analyzed measurements of 931 wild alligators from 14 locations in Florida and Georgia. Of these, 36% were females ($n = 338$), 62% were male ($n = 574$), and 2% were unknown ($n = 19$). Adults made up 73% of the data set ($n = 686$) while 27% of the data set consisted of juveniles ($n = 245$). Overall, the highest K value in the wild data set was 4.43 and 99.6% of the K values were below 4 (Figure 1).

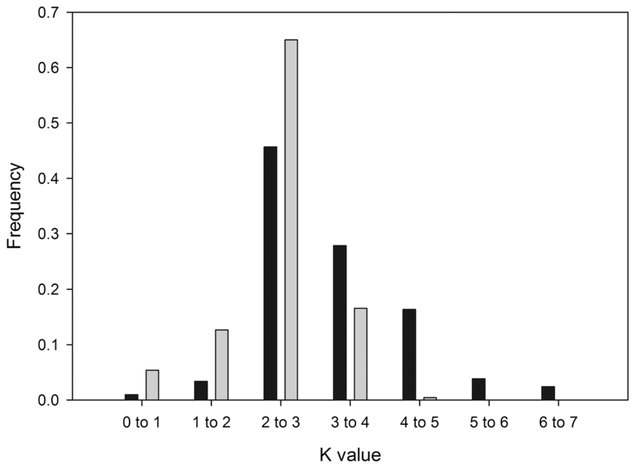

FIGURE 1 Frequency histogram of body condition values (*K*) for wild alligators (gray) and captive alligators (black). Higher *K* values indicate more mass per unit size.

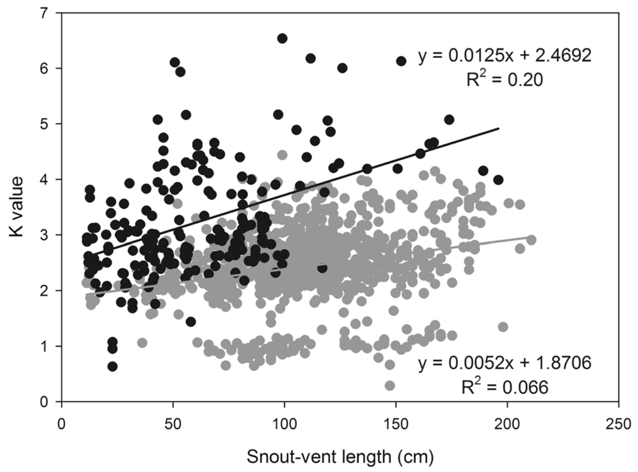

FIGURE 2 Body condition values (*K*) versus snout-vent length (SVL) for the full data sets of wild alligators (gray) and captive alligators (black). Lines represent linear regression best fit equations. Higher *K* values indicate more mass per unit size.

TABLE 1 Pairwise comparisons between subsets of wild and captive American alligator populations

Comparison	Sample size	Slopes	*p* value
All wild and all captive	931, 208	0.0052*x*, 0.013*x*	3.0×10^{-6}***
Balanced wild and balanced captive	490, 84	0.0054*x*, 0.015*x*	2.8 × 10−6***
Wild males and captive males	574, 79	0.0055*x*, 0.0102*x*	.036*
Wild females and captive females	338, 63	0.0081*x*, 0.0053*x*	.52
Wild adults and captive adults	686, 42	0.0044*x*, 0.0168*x*	.0011**
Wild juveniles and captive juveniles	245, 166	0.0031*x*, 0.0098*x*	.063

$^*p < .05$; $^{**}p < .01$ $^{***}p < .001$.

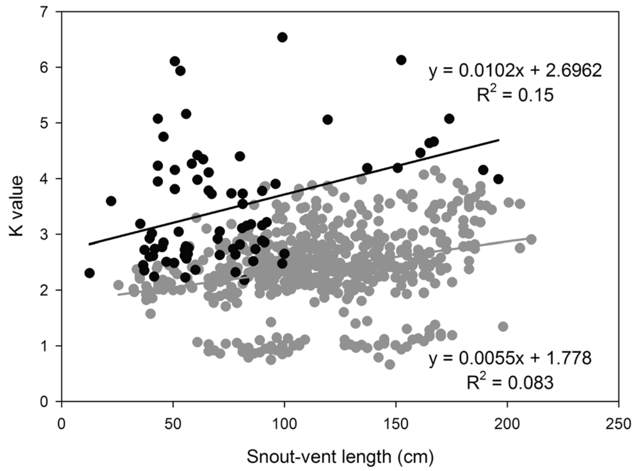

FIGURE 3 Body condition values (K) versus snout-vent length (SVL) of male wild alligators (gray) and male captive alligators (black). Lines represent linear regression best fit equations. Higher *K* values indicate more mass per unit size.

In contrast, the highest *K* value in the captive data set was 6.53 and only 77.9% of the *K* values were below 4 (Figure 1).

The regression slopes of the full wild and captive data sets were significantly different ($p < .0001$; Table 1), with captive alligator *K* values increasing more quickly than wild alligators as they aged (Figure 2). However, the two data sets were dissimilar in that the captive data set was dominated by juveniles while the wild data set was dominated by adults. To correct for this potential source of bias we randomly removed 124 captive juveniles and 441 wild adults to produce two data sets with a balanced distribution across size classes, then re-ran the analysis. The results were the same: captive alligator *K* values increased significantly more quickly than wild alligators ($p < .0001$; Table 1). When comparing within sex, there was a significant difference between the regression slopes for the wild and captive males ($p = .036$; Table 1; Figure 3), but no significant difference between the slopes for females ($p = .52$; Table 1). When comparing within age class, there was a significant difference between the regression slopes for the wild and captive adults ($p = .0011$; Table 1), but no significant difference between the slopes for wild and captive juveniles ($p = .063$; Table 1).

4 | DISCUSSION

Our study is the first to focus on quantifying the effect of captivity on American alligator body condition. The results support our hypothesis that captive alligators exhibit higher body condition scores than their wild counterparts as they age. There are multiple factors that could have caused this result with diet type as a major one. Previous studies on wild alligators have found that diet influences alligator body condition due to the variation of nutrient content in different prey (Delany et al., 1999; Gabrey, 2010). Alligators in captivity tend to have structured, predictable diets that consist of high quality food (vertebrates, e.g., chickens, pigs, cows, deer, and rodents) in addition to food specifically formulated to meet their nutritional needs (e.g., Mazuri Exotic Animal Nutrition), while those in the wild have diets based on availability that fluctuate due to environmental changes (Rosenblatt & Nifong, 2018). In addition, many of the prey that wild alligators consume are of lower quality (invertebrates, e.g., *Callinectes sapidus*), containing small amounts of meat and large amounts of indigestible structures (Nifong et al., 2012).

Another important factor is the difference in activity levels between wild and captive alligators. Some wild alligators, especially males during the spring courtship and breeding period, move extensively to find mates, burning calories and presumably decreasing their *K* values in the process. In a south Florida estuary, adult male alligators averaged movement rates of 37.5 m/h, with a maximum of 233.3 m/h (Rosenblatt et al., 2013), while in a Louisiana coastal marsh adult male alligators averaged movement rates of 30.6 m/h, with a maximum of 352.4 m/h (Joanen & McNease, 1972). In contrast, an adult male alligator at Jacksonville Zoo and Gardens exhibited an average movement rate of only 13.5 m/h during summer 2019 (M. Spain, unpublished data). This male was housed with four other alligators, all females; males housed with other males or in higher density situations may exhibit different movement rates.

Differences in movement rates between wild and captive females appear to be much smaller: in a Louisiana coastal marsh adult female alligators averaged movement rates of 1.0 m/h with a maximum of 19.1 m/h (Joanen & McNease, 1970), while four adult female alligators at Jacksonville Zoo and Gardens exhibited an average movement rate of 6.0 m/h with a maximum of 18.9 m/h (M. Spain, unpublished data). These divergent movement rate patterns between males and females may explain the sex-specific differences in *K* values we observed. Our data show that *K* value slopes for wild versus captive males differ significantly, but no such difference exists for wild versus captive females. If movement rates are much lower for captive males relative to wild males, while movement rates are similar for captive females relative to wild females, then this sex-dependent pattern is exactly the result we would expect to see.

Our results also suggest that differences in *K* values between wild and captive alligators only manifest in larger size classes. We found that slopes for wild and captive juveniles did not differ significantly, while slopes for wild and captive adults did differ significantly. This is likely because even though juvenile alligators in captivity are eating higher quality food on a consistent schedule relative to wild juveniles, most of the consumed food is directed toward growth and body elongation. Though it has long been assumed that alligator body length growth is indeterminate, it has recently been shown that alligator growth is in fact determinate with males ceasing body length growth around 43 years old and females around 31 years old (Wilkinson et al., 2016). As adults, body elongation slows and as very large adults, body elongation stops. Thus, for the longest individuals most consumed food generates weight gain, leading *K* values to increase substantially for the oldest captive alligators. Old wild alligators may not exhibit similar weight gain because of inconsistent food supplies, access to only low-quality food, and faster movement rates. Testing this hypothesis would require comparing the growth rates of captive and wild juvenile alligators.

We have shown that adult alligators, and especially males, held in captivity tend to exhibit higher *K* values than their wild counterparts. Lowering these *K* values for captive adult alligators may require modifying feeding schedules and food type and/or increasing movement rates through enrichment techniques. However, it is unknown if having a high *K* value impacts alligator health. We do not know of any studies that have focused on obesity in alligators or the effects of excessive weight gain on alligator health and functioning. Studies of blood chemistry and anatomy in alligators with high K values would thus be important for determining whether or not changes in alligator care protocols should be made.

In our study there were several factors that we could not control for yet could have influenced our results. First, an alligator's body condition may vary across seasons and if they are reproductively active or not (Brandt, Beauchamp, et al., 2016), so the timing of body measurements for each individual as well as their reproductive status would ideally be factored into analyses. Second, the origin of captive individuals (wild caught vs. bred in captivity) as well as their size when entering captivity could affect their body condition. Third, housing density can affect alligator stress levels and ultimately growth, with high housing densities causing more stress and slower growth than lower housing densities (Elsey et al., 1990). Unfortunately, the exact measurement date for each alligator in our study, their reproductive status at the time of measurement, precise origin information for captive alligators, and housing density for captive alligators at the time of measurement were not available for most individuals. Future targeted studies that are able to account for all of these factors would certainly improve our understanding of the determinants of alligator body condition in captivity.

Knowledge of the effects captivity can have on alligators is vital for ensuring proper care of the species. Our study provides a baseline for the range of body condition values that can be expected in captivity and what body condition values can be targeted if institutions are attempting to recreate more “wild” alligator exhibits and stimulate natural behaviors. However, further research must be done to fully understand the factors that affect alligators in captivity. It would be worthwhile for future studies to focus on the role of competition and housing density in determining captive alligator body condition, and researchers should gather more detailed data on the foods that captive alligators are fed as well as feeding frequency.

ACKNOWLEDGMENTS

We are indebted to St. Augustine Alligator Farm Zoological Park and Jacksonville Zoo and Gardens for their support of this project and to all the institutions that contributed data. We also thank Gen

Anderson and Cayle Pearson for reading a draft of the manuscript and providing useful feedback. This study was funded by a grant to F. K. from the University of North Florida.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Marisa Spain http://orcid.org/0000-0001-6899-9744

REFERENCES

Brandt, L. A., Beauchamp, J. S., Jeffery, B. M., Cherkiss, M. S., & Mazzotti, F. J. (2016). Fluctuating water depths affect American alligator (*Alligator mississippiensis*) body condition in the Everglades, Florida, USA. *Ecological Indicators*, *67*, 441–450.

Brandt, L. A., Nestler, J. H., Brunell, A. M., Beauchamp, J. S., & Mazzotti, F. J. (2016). Variation in body condition of *Alligator mississippiensis* in Florida. *Bulletin of the Florida Museum of Natural History*, *54*, 1–12.

Connolly, J. D., & Cree, A. (2008). Phenotypic differences between wild and captive individuals of a viviparous endangered skink (*Oligosoma otagense). Biological Conservation*, *141*, 1283–1292.

Dalrymple, G. H. (1996). Growth of American alligators in the Shark Valley region of Everglades National Park. *Copeia*, *1996*, 212–216.

Delany, M. F., & Abercrombie, C. L. (1986). American alligator food habits in Northcentral Florida. *Journal of Wildlife Management*, *50*, 348–353.

Delany, M. F., Linda, S. B., & Moore, C. T. (1999). Diet and condition of American alligators in 4 Florida lakes. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies*, *53*, 375–389.

Delany, M. F., Woodward, A. R., & Kochel, I. H. (1988). Nuisance alligator food habits in Florida. *Florida Field Naturalist*, *16*, 90–96.

Dovoedo, Y. H., & Chakraborti, S. (2015). Boxplot-based outlier detection for the location-scale family. *Communications in Statistics-Simulation and Computation*, *44*, 1492–1513.

Elsey, R. M., Joanen, T., McNease, L., & Lance, V. (1990). Stress and plasma corticosterone levels in the American alligator—Relationships with stocking density and nesting success. *Comparative Biochemistry and Physiology*, *95*, 55–63.

Fujisaki, I., Rice, K. G., Pearlstine, L. G., & Mazzotti, F. J. (2009). Relationship between body condition of American alligators and water depth in the Everglades, Florida. *Hydrobiologia*, *635*, 329–338.

Gabrey, S. W. (2010). Demographic and geographic variation in food habits of American alligators (*Alligator mississippiensis*) in Louisiana. *Herpetological Conservation and Biology*, *5*, 241–250.

Herbert, J., Coulson, T., & Coulson, R. (2002). Growth rates of Chinese and American alligators. *Comparative Biochemistry and Physiology Part A*, *131*, 909–916.

Joanen, T., & McNease, L. (1970). A telemetric study of nesting female alligators on Rockefeller Refuge, Louisiana. *Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners*, *24*, 175–193.

Joanen, T., & McNease, L. (1972). A telemetric study of adult male alligators on Rockefeller Refuge, Louisiana. *Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners*, *25*, 252–275.

Mellor, E. L., Cuthill, I. C., Schwitzer, C., Mason, G. J., & Mendl, M. (2020). Large lemurs: Ecological, demographic and environmental risk factors for weight gain in captivity. *Animals: An Open Access Journal from MDPI*, *10*, 1443.

Morfeld, K. A., Meehan, C. L., Hogan, J. N., & Brown, J. L. (2016). Assessment of body condition in African (*Loxodonta africana*) and Asian (*Elephas maximus*) elephants in North American zoos and management practices associated with high body condition scores. *PLoS One*, *11*, e0155146.

Nifong, J. C., Layman, C. A., & Silliman, B. R. (2015). Size, sex and individual-level behavior drive intrapopulation variation in cross-ecosystem foraging of a top-predator. *Journal of Animal Ecology*, *84*, 35–48.

Nifong, J. C., Rosenblatt, A. E., Johnson, N. A., Barichivich, W., Silliman, B. R., & Heithaus, M. R. (2012). American alligator digestion rate of blue crabs and its implications for stomach contents analysis. *Copeia*, *2012*, 419–423.

Rice, A. N., Ross, J. P., Woodward, A. R., Carbonneau, D. A., & Percival, H. F. (2007). Alligator diet in relation to alligator mortality on Lake Griffin, FL. *Southeastern Naturalist*, *6*, 97–110.

Rosenblatt, A. E., & Heithaus, M. R. (2011). Does variation in movement tactics and trophic interactions among American alligators create habitat linkages? *Journal of Animal Ecology*, *80*, 786–798.

Rosenblatt, A. E., Heithaus, M. R., Mazzotti, F. J., Cherkiss, M., & Jeffery, B. M. (2013). Intra-population variation in activity ranges, diel patterns, movement rates, and habitat use of American alligators in a subtropical estuary. *Estuarine, Coastal and Shelf Science*, *135*, 182–190.

Rosenblatt, A. E., & Nifong, J. C. (2018). Understanding alligator feeding patterns: historical and modern perspectives. In C. B. Eversole, & S. E. Henke (Eds.), *American alligators: Habitats, behaviors, and threats* (pp. 155–174). Nova Science Publishers.

Santos, D. J., Jackson, J., Phil, M., Aung, H. H., Nyein, U. K., Htut, W., & Lummaa, V. (2020). Sex differences in the reference intervals of health parameters in semicaptive Asian elephants (*Elephas maximus*) from Myanmar. *Journal of Zoo and Wildlife Medicine*, *51*, 25–38.

Sternalski, A., Mougeot, F., Eraud, C., Gangloff, B., Villers, A., & Bretagnolle, V. (2010). Carotenoids in nestling Montagu's harriers: Variations according to age, sex, body condition and evidence for diet-related limitations. *Comparative Biochemistry and Physiology Part B*, *180*, 33–43.

Wilkinson, P. M., Rainwater, T. R., Woodward, A. R., Leone, E. H., & Carter, C. (2016). Determinate growth and reproductive lifespan in the American alligator (*Alligator mississippiensis*): Evidence from long-term recaptures. *Copeia*, *104*, 843–852.

How to cite this article: Kruis, F., Wallwork, M., Spain, M., & Rosenblatt, A. E. (2023). American alligator (*Alligator mississippiensis*) weight gain in captivity and implications for captive reptile body condition. *Zoo Biology*, 42, 107–111. https://doi.org/10.1002/zoo.21721