Chelonian Conservation and Biology, 2023, 22(2): 165–174
doi:10.2744/CCB-1563.1

Eastern Box Turtle (*Terrapene carolina carolina*) Shell Damage and Health in an Urban Landscape

Anna Thonis[1], **Christopher Werni**[2], **Cosku Ozcelik**[3], **Zhen Ye Pan**[3], **Kristi Fung**[3], **Brittany Ford**[3], **Melissa Hunter**[3], **and Lisa Prowant**[4,*]

[1]*Department of Ecology and Evolution, Stony Brook University, Stony Brook, New York 11790 USA [anna.thonis@stonybrook.edu];*
[2]*School of Marine and Atmospheric Sciences, Stony Brook University, Stony Brook, New York 11790 USA [chriswerni1999@gmail.com];*
[3]*College of Arts and Sciences, Stony Brook University, Stony Brook, New York USA 11790 [coskuxx@gmail.com; williampan713@gmail.com; kristileefung@gmail.com; brittanyford40@gmail.com; mhunter209@gmail.com];*
[4]*Department of Biology, Culver-Stockton College, Canton, Missouri 63435 USA [lprowant@culver.edu]*
[*]*Corresponding author*

Abstract. – Eastern box turtles (*Terrapene carolina*) are becoming increasingly threatened by the rate of urbanization and habitat fragmentation. The high population density and heavy urbanization of Long Island, New York, provide an ideal system to examine possible drivers of differences in eastern box turtle shell damage and health in an urban landscape, as well as possible differences in sex and stage ratios. Over the course of our 2-yr study, we captured a total of 189 unique individual eastern box turtles across 20 sites on Long Island. Shell damage was evaluated according to a 5-level ranking system based on the amount and type of damage an individual turtle exhibited. To study eastern box turtle health, we calculated a body condition index using each turtle's body weight and straight-line carapace width. All damage and health data were compared by site, sex, and life stage using generalized linear models. These relationships were also analyzed against a set of land cover and land use variables. Across all comparative analyses performed, only the US Geological Survey land cover variable Dryland Cropland and Pasture showed a significant relationship to shell damage. Additionally, Long Island's eastern box turtles appear to exhibit greater rates of shell damage when compared with turtles in more rural parts of their range. We found male-biased sex ratios across the island; however, no definitive driver was identified. Our study underscores the need for future work on the long-term viability of eastern box turtle populations, specifically those inhabiting areas of high human population density.

Key Words. – body condition; sex ratio; shell damage; stage ratio; urbanization

The eastern box turtle (*Terrapene carolina*) is a long-lived species inhabiting a combination of mixed and open forests, riparian habitat, and fields (Dolbeer 1969). The species is found throughout the eastern and southern United States, from southern Maine and New Hampshire to Florida, and west to Texas, and also occurs in parts of Mexico (Kiester and Willey 2015). When last assessed by the International Union for Conservation of Nature (IUCN) in 2010, van Dijk (2011) noted widespread and continuing decline of the species, estimated to exceed 30% over 3 generations. The survival of eastern box turtles is threatened by habitat loss and fragmentation, roads and heavy traffic, the pet trade, and diseases (Steen et al. 2006; Northeast Partners in Amphibian and Reptile Conservation 2010; van Dijk 2011; Kiester and Willey 2015). The New York State Department of Environmental Conservation (NYDEC) lists the eastern box turtle as a high-priority Species of Greatest Conservation Need, while the IUCN Red List classifies the eastern box turtle as Vulnerable (van Dijk 2011; NYDEC 2013). Under the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES), eastern box turtles are listed under Appendix II to curb the high volume of box turtle species involved in the pet trade (CITES 1994). Although these protections and listings can ameliorate the impact of some of the threats faced by eastern box turtles, populations of the species throughout their range still appear to be declining (Kiester and Willey 2015). In a Maryland population, Stickel (1978) found that the population of eastern box turtle declined by ~50% between 1965 and 1975 alone, while a 40-yr study at the Patuxent Wildlife Research Center in Maryland found a 77% decline in the species between 1955 and 1995 (Hall et al. 1999). Similarly, Nazdrowicz et al. (2008) found a 75% decline in a Delaware population of the species between 1968 and 2002 and Kemp et al. (2022) found a 71%–74% decline in a southeastern Pennsylvania population between 1978 and 2020.

One method for studying potential drivers of decline in eastern box turtles focuses on box turtle health and shell damage. By using body condition index (BCI) as a first-level indicator of box turtle health, we can investigate if turtle health varies with land cover and/or land use and thereby study the contribution of land cover to the long-term viability of the species. BCI serves as a metric to quantify the physical state of an individual by evaluating the amount of fat it possesses (dePersio et al. 2019). An individual's fat content represents its amount of energy reserves and also provides information on the individual's general health and nutritional state (dePersio et al. 2019). Because we did not conduct a comprehensive health evaluation of each turtle—e.g., like that conducted by Adamovicz et al. (2015)—we are using BCI only as a first-level indicator of eastern box turtle health. A more complete health evaluation would have included information on a turtles' vital rates, an oral examination, bloodwork, and screening for pathogens and parasites. In addition to BCI, by studying nonlethal levels of shell damage in eastern box turtles, we can improve our understanding of which factors contribute most to box turtle injury and damage. Certain causes of injury and damage in the species may result in death; however, mortality in the species is infrequently reported. Although not a direct measure of mortality, Brown and Sleeman (2002) found that impacts with motor vehicles was the most common cause of trauma in eastern box turtles admitted to the Wildlife Center of Virginia between 1991 and 2000. They suggested that the apparent increase in reptiles brought into the Wildlife Center through time may indicate an increase in reptile mortality in the region over the course of the study. In one of the few studies investigating natural eastern box turtle mortality events, researchers found over 50 individuals killed by a necrotizing bacterial infection in August 2013 and identified ranavirus outbreaks in July 2014 and 2015 (Adamovicz et al. 2018). Therefore, in addition to understanding eastern box turtle mortality caused by diseases and pathogens, research focused on identifying the most important drivers of nonlethal injury and damage could prove useful for future conservation initiatives.

Sex and stage ratios may also provide insight into eastern box turtle declines. Many studies have already explored the demography of eastern box turtles and found that populations frequently exhibit even to heavily male-biased sex ratios (Dodd 1997; Hall et al. 1999; Nazdrowicz et al. 2008; Dodd et al. 2012). Male-biased sex ratios could be indicative of higher rates of female mortality, or other external forces impacting the species. Gibbs and Steen (2005) showed that sex ratios in turtles have become more male-biased in states with higher road densities, with freshwater turtle species having higher rates of male-bias compared to semiaquatic and terrestrial species. Regarding stage ratios, juveniles may account for between 26.5% and 46% of a given population; however, they are often underrepresented in surveys as they are often more difficult to find (Kiester and Willey 2015). Skewed stage ratios could be linked to higher rates of either adult or juvenile mortality which, if found, warrants further study. High annual survival rates (81%–96%) are reported in adults; however, no studies at this time have explored annual survival rates for juveniles (Nazdrowicz et al. 2008; Currylow et al. 2010). Population densities appear to vary extensively throughout the species' range, with more fragmented areas having lower population densities (1 adult/ha) compared with more contiguous areas ($>$ 10 adults/ha) (Willey 2010; Kiester and Willey 2015). Like many turtle species, eastern box turtles can live to be very old and there is evidence of individuals living to over 100 yrs of age (Kiester and Willey 2015).

To investigate health, shell damage, and sex and stage ratios in the eastern box turtle, we focused on the woodland box turtle subspecies (*Terrapene carolina carolina*) on Long Island, New York. Although studies of eastern box turtles on Long Island have been conducted (Latham 1916; Nichols 1939; Burke and Capitano 2011a, 2011b; Figueras et al. 2021), an island-wide study in which multiple variables are measured has not been conducted. Our study evaluates the influence of human and landscape factors on shell damage and injury, health, sex ratios, and stage ratios across 20 sites on Long Island over 2 yrs. Results of our study have implications for the conservation management of Long Island's eastern box turtles, as well as for populations of the species occurring in other areas of high human population density.

METHODS

Study Region. — Long Island, New York—the easternmost part of New York State—measures approximately 3626 km^2 and is bounded by New York City on its westernmost edge, the Long Island Sound on its northern shore, and the Atlantic Ocean on its eastern and southern coastlines (US Geological Survey [USGS] 2017). As of 2010, 7.56 million people lived on Long Island, with the amount of developed land cover and human population density decreasing as one moves from west to east (USGS 2017). Long Island exemplifies an urbanization gradient and is therefore a suitable location for studies interested in assessing the impacts of urbanization and high human population density of wildlife.

Survey Methods. — Sampling for eastern box turtles took place on Long Island, New York, from June to August 2016 and June to July 2017. We sampled 12 sites in 2016, 15 new sites in 2017, and resampled 2 sites from 2016 in 2017, for a total of 27 unique sites (Fig. 1). Although 27 sites were sampled, box turtles were found at only 20 of the sites. Survey sites varied in size from 5.1 to 65.5 ha. Between 2 and 16 field assistants walked 5 m apart along parallel transect lines in opposite directions for 1–10 hrs to complete the visual encounter surveys. These survey methods are consistent with those used in previous studies (Stickel 1978; Hall et al. 1999). When

Figure 1. Location of all sites surveyed for eastern box turtles (*Terrapene carolina carolina*) in 2016 (•), 2017 (+), and in both years (◊).

field assistants encountered an individual eastern box turtle, it was sexed, weighed (to the nearest gram) using a hanging scale, measured (height, carapace length and width, plastron length and width) using a digital caliper, and photographed (plastron and carapace), and the age of the individual was estimated. Carapace length was measured from the midline of the nuchal scute to the notch where the 2 most posterior marginal scutes of the carapace met. Each turtle was also given a temporary tag with a silver Sharpie marker, where a star was drawn onto a turtle's shell the first time it was captured, and a circle was drawn around the star if the turtle was captured a second time. The Sharpie marker remained on a turtle's shell for approximately 2 yrs. This tagging method did not allow for individual identification of a turtle.

Sex and Stage Ratios. — We estimated an individual turtle's age using the number of annuli (growth rings) on 2 or more scutes on the turtle's carapace and plastron, assuming 1 growth ring equates to 1 yr (Ewing 1939). Due to increased crowding of growth rings as a turtle ages, a turtle's age could only be accurately determined for turtles 15 yrs of age and younger. Individuals older than 15 yrs were categorized as adults and were not assigned a specific age. Individuals with 10 or fewer annuli on the scutes of the carapace were categorized as juveniles (Hall et al. 1999). Eastern box turtles are sexually dimorphic, with males often possessing concave plastrons and red irises as compared to the flat plastrons and brown irises of females. However, iris color alone is not a consistently valid method for sexual identification because some males may display brown irises like those of females (Kiester and Willey 2015). Due to possible within-sex variation, we used secondary sexual characteristics such as eye color, plastron and carapace shape, rear claw shape, and tail morphology, to sex captured turtles (Stickel 1950; Evans 1951; Ernst et al. 1994). Furthermore, only adult ($>$ 15 yrs) eastern box turtles were sexed.

We compared sex and stage ratios by site using a Pearson's χ^2 test. We used Welch's 2-sample *t*-test to analyze sex and stage data against shell damage and BCI data for sites that contained $>$ 10 turtles. All statistical analyses were performed in R (version 3.6.3, R Core Team 2020).

Model Covariates. — ArcGIS (version 10.4.1; ESRI 2011) was used to process all covariates so they could be used in subsequent analyses. To create the land cover and land use layers, we reclassed the Land Use/Land Cover System Modified Level 2 categorical raster layer to create individual binary layers for each land cover category, calculating the percentage of each land cover category within a 15-km radius (USGS 2018). A 15-km radius was selected as this distance likely represents the full breadth of environmental conditions a turtle will experience within its lifespan, including transient individuals (Stickel 1950; Dodd 2002). To create the covariates Road Density and Distance to Roads, we used the Global Roads Open Access Data Set (Center for International Earth Science Information Network [CIESIN] et al. 2013). Road density represents the density of roads within a 15-km radius, while distance to roads represents the Euclidean distance from each pixel centroid to the closest road. To create the Distance to Water covariate, we used the Global River Bankfull Width and Depth Database (Andreadis et al. 2013). Given that this database contained 2 separate files for lakes and rivers, we created 2 separate 1-km^2 resolution rasters in which the value of each pixel represented the distance of that pixel to either a lake or a river. The minimum value for each pixel was used to combine the 2 rasters, thereby producing the Distance to Water covariate. Postprocessing, all covariates matched in extent, had a resolution of 1 km^2, and were in the WGS84 coordinate reference system.

Following covariate processing, we used generalized linear models of box turtle health (i.e., BCI), damage, sex ratio, and stage ratio, and a set of land cover and land use covariates to identify possible drivers of any observed differences found across sites. To assess collinearity, we calculated a Pearson correlation matrix and removed covariates that had a correlation of 0.62 or greater. All covariates and their original data sources are listed in Table 1.

Damage Assessment. — We considered damage to a box turtle as any physical trauma or microbial infection caused by an external force. We recorded chipped

Table 1. List of all covariates used in the generalized linear models and the source of the covariate.

Covariate	Data source[a]
% Canopy cover	USGS: Global tree canopy cover circa 2010 (Hansen et al. 2013)
Human population density	NASA: 2015 gridded population of the world v4 (CIESIN et al. 2018)
Human influence index	Wildlife Conservation Society, Wild Data v2 (WCS et al. 2005)
Road density	NASA: Global Roads Open Access Data Set Version 1 (CIESIN et al. 2013)
Distance to roads	NASA: Global Roads Open Access Data Set Version 1 (CIESIN et al. 2013)
Distance to water	Global River Bankfull Width and Depth Database (Andreadis et al. 2013)
% Mixed forest	USGS: Land Use/Land Cover System Modified Level 2
% Evergreen needleleaf forest	USGS: Land Use/Land Cover System Modified Level 2
% Deciduous broadleaf forest	USGS: Land Use/Land Cover System Modified Level 2
% Cropland/woodland mosaic	USGS: Land Use/Land Cover System Modified Level 2
% Cropland/grassland mosaic	USGS: Land Use/Land Cover System Modified Level 2
% Savanna	USGS: Land Use/Land Cover System Modified Level 2
% Shrubland	USGS: Land Use/Land Cover System Modified Level 2
% Urban and built-up land	USGS: Land Use/Land Cover System Modified Level 2
% Irrigated cropland and pasture	USGS: Land Use/Land Cover System Modified Level 2
% Dryland cropland and pasture	USGS: Land Use/Land Cover System Modified Level 2

[a] USGS indicates US Geological Survey; NASA, National Aeronautics and Space Agency; CIESIN, Center for International Earth Science Information Network; WCS, Wildlife Conservation Society.

marginals by estimating whether the marginal area was more or less than 50% chipped. Other damage recorded included damaged scutes, missing limbs, tail, and/or digits, the presence of bite marks or holes, the presence of exposed bone, bleeding, scarring, missing enamel, and/or cracking. Split scutes and shell anomalies were not included because they are the result of abnormalities in development (Cherepanov 2014). We also conducted a supplemental damage analysis in which we excluded chipped marginals to compare our results more accurately with those of Boucher and Ernst (2004), who also quantified rates of damage in their study.

To assess damage, 3 research assistants independently scored the level of damage to a turtle's shell captured in photographs taken of the turtle while in the field. We developed a 5-level ranking system where level 1 represented a turtle exhibiting no damage and level 5 represented a turtle exhibiting substantial damage (Table 2; Fig. 2). To assign damage levels, 3 research assistants independently analyzed the photographs for any damage to the carapace or plastron of an individual turtle. Following a discussion of each photograph and the turtle's damage level, these same 3 research assistants jointly agreed on the damage level for an individual turtle.

Body Condition Index (BCI). — The BCI, a measure of fat volume or body fat percentage in an individual turtle, was used as a first-level indicator of an eastern box turtle's health. We calculated a BCI for each captured turtle using its recorded body weight and straight-line carapace width (SCW). We used the BCI model provided in dePersio et al. (2019) to calculate a BCI for each eastern box turtle captured for this study. To determine the best-fit model for BCI, dePersio et al. (2019) evaluated 23 models using the corrected Akaike information criterion (AIC_c). Using this best-fit model, we can determine how an individual turtles' body condition or the mean body condition of turtles at a given site compares to that of age-matched conspecifics (dePersio et al. 2019). The equation taken from dePersio et al. (2019) is as follows:

$$Fat\ Volume\,(BCI) = e^{\ln((weight) \times 0.400336) + \left(\ln\left(\frac{SCW}{10}\right) \times 0.985831\right)} - 2.26447$$

BCI values were compared by sex, stage, and site using generalized linear models. For analyses of BCI vs. sex, we used only individuals 11 yrs and older (classified as adults). Turtles with undetermined age were not used in these analyses. For each site, we computed the mean male BCI, mean female BCI, mean adult BCI, and mean juvenile BCI. We also performed these analyses for all sites together to identify any island-wide sex-based or stage-based trends with respect to BCI. Additionally, to

Table 2. Characteristics for each of the 5 shell damage levels used in shell damage assessment of the eastern box turtle (*Terrapene carolina carolina*).

Damage level	Characteristics
1	No damaged scutes
2	No marginals damaged $\geq 50\%$
	1–2 marginals damaged $< 50\%$
	1–3 scutes with carapace and/or plastron damage
	1–2 holes consistent with bite marks
	No missing digits
	Split scutes and scute anomalies
	Damaged tail with no cloacal damage
3	1–2 marginals damaged $\geq 50\%$
	3–4 marginals damaged $< 50\%$
	≥ 4 scutes with carapace and/or plastron damage
	≥ 3 holes consistent with bite marks
	Missing digits on ≤ 2 limbs
4	3–5 marginals damaged $\geq 50\%$
	≥ 5 marginals damaged < 50 %
	Missing digits on > 3 limbs
	Exposed bone on $< 50\%$ of carapace
5	≥ 6 marginals damaged ≥ 50 %
	Exposed bone on $\geq 50\%$ of carapace
	Damaged tail and vent
	Infection, missing limb, and/or bleeding

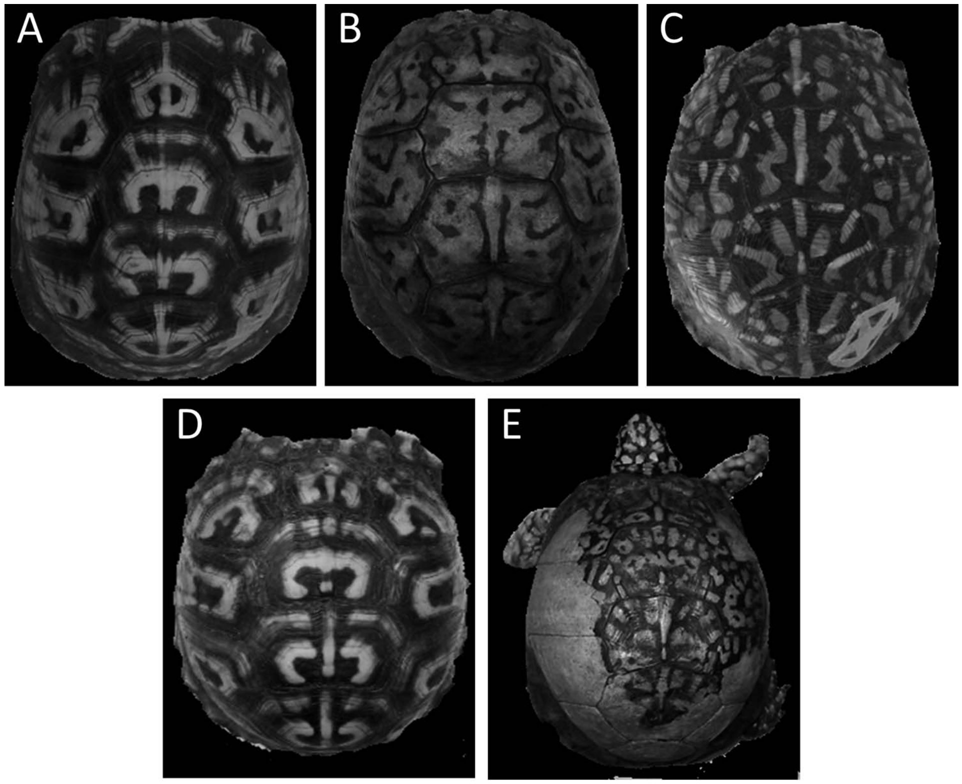

Figure 2. Representative photographs of each of the 5 shell damage levels used in damage assessment for eastern box turtles (*Terrapene carolina carolina*) on Long Island, New York. (A) Level 1, (B) level 2, (C) Level 3, (D) level 4, and (E) level 5. All photographs by L. Prowant.

compare BCI between rural and suburban eastern box turtle populations, we quantified BCI for eastern box turtles found in rural Vermilion County, Illinois, and for Long Island's eastern box turtles, using data taken from dePersio et al. (2019). As of 2010, the human population densities of Long Island, New York, and Vermilion County, Illinois, were 2086 people/km^2 and 35.1 people/km^2, respectively (US Census Bureau 2010).

RESULTS

A total of 199 eastern box turtles were captured over the 2-yr study period across 20 study sites, with 10 recaptures. We recorded 163 adults (101 males, 62 females) and 30 juveniles (Fig. 3). The sex of 6 individuals could not be determined.

Sex and Stage Ratios. — All sites except for Site F exhibited male-biased sex ratios with a mean sex ratio of 2.14:1 (95% confidence interval [CI]: 1.02–3.26:1) for sites with > 10 captured individuals (Fig. 3). Although the sex ratios at most sites were male-biased, only Site M had a significant deviation from 1:1 ($\chi^2_1 = 10.29$, $p = 0.0013$). With respect to juveniles, we found a significant difference in the ratio of adults to juveniles captured when compared across all sites ($\chi^2_7 = 98.00$, $p < 0.0001$). Juveniles accounted for an average of only 12% of captured individuals across all sites with > 10 captured individuals.

Damage Assessment. — When including chipped marginals in our assessment, 63% of Long Island's eastern box turtles exhibited some degree of shell damage. Omitting chipped marginals, 21% of Long Island eastern box turtles exhibited some form of damage. No significant difference was observed between eastern box turtle males and females in the severity of damage ($t_{130.7} = -1.06$, $p = 0.29$), with mean shell damage levels of 2.12 for males and 1.94 for females. Similarly, we did not observe a significant difference between juveniles and adults in damage severity ($t_{26.6} = -0.178$, $p = 0.86$), with mean shell damage levels of 1.96 for juveniles and 2.05 for adults. When regressed against the set of land cover and land use covariates, mean shell damage at a site exhibited a statistically significant relationship only to the Dryland Cropland and Pasture variable ($r^2 = 0.54$, $p = 0.038$, $y = 17.36x + 1.96$), a single variable generated by the USGS.

BCI. — A mean BCI of 12.26 (95% CI: 9.69–14.83) was calculated for all captured individuals. Across all sites, we calculated a mean male BCI of 13.16 (95% CI: 11.55–14.77), a mean female BCI of 12.94 (95% CI: 11.41–14.46), a mean adult BCI of 13.08 (95% CI: 11.54–14.62), and a mean juvenile BCI of 7.78 (95% CI: 5.39–10.35). A significant difference in BCI was found only between adult and juvenile turtles ($t_{33.4} = 11.07$, $p < 0.0001$). There were no significant relationships between BCI and any of the land cover

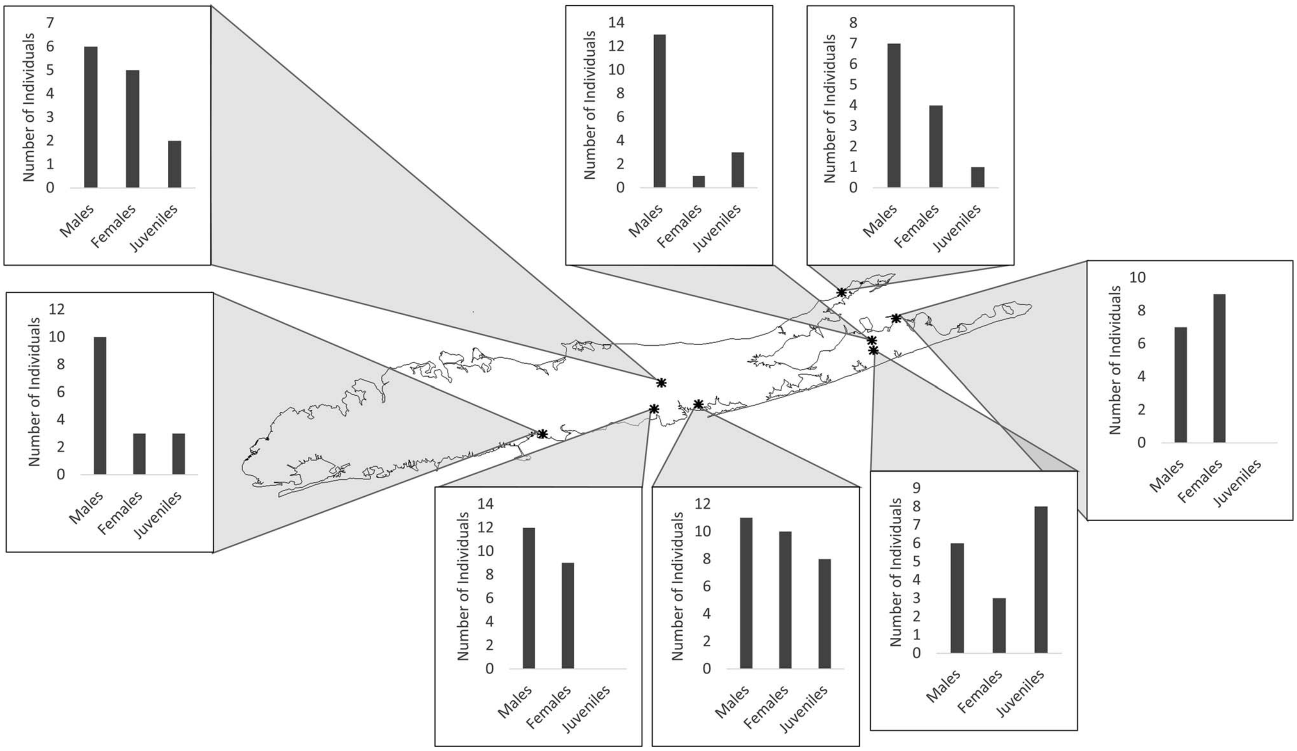

Figure 3. Sex and stage structure of eastern box turtles at 8 survey sites across Long Island, New York, with > 10 eastern box turtles (*Terrapene carolina carolina*) captured. If an individual exhibited 10 or fewer annuli (growth rings), it was classified as a juvenile. If an individual was an adult, it was sexed using secondary sexual characteristics.

and land use covariates when compared by site, stage, or sex. BCI data for all sites are summarized in Table 3.

Using the BCIs for eastern box turtles collected between 2014 and 2016 by dePersio et al. (2019), we found that the BCI of turtles in the Illinois study ($\bar{x} = 12.18 \pm 3.06$ SD, $n = 63$; dePersio, pers. comm.) was not significantly different from the BCI of turtles in our study ($\bar{x} = 12.26 \pm 2.56$ SD, $n = 199$), $t_{90.6} = 0.31$, $p = 0.76$). Similarly, there were no significant differences when comparing BCI by sex between the 2 studies. Illinois male turtles had a mean BCI of 12.31 ± 3.19 SD ($n = 41$), while male turtles in our study had a mean BCI of 13.16 ± 1.6 SD ($n = 101$), a nonsignificant difference ($t_{48.4} = 1.625$, $p = 0.11$). Illinois female turtles had a mean BCI of 11.95 ± 2.93 SD ($n = 22$), while female turtles in our study had a mean BCI of 12.94 ± 1.52 SD ($n = 62$), also a nonsignificant difference ($t_{25.15} = 1.51$, $p = 0.14$). The Illinois study did not provide data on turtle life stage and therefore comparisons could not be made at the life stage level.

DISCUSSION

A globally declining species, the eastern box turtle is threatened by habitat loss and fragmentation due to residential and commercial development, collection, diseases, pollution, and road mortality (van Dijk 2011; Kiester and Willey 2015; Howell and Seigel 2019). In addition to these threats, Nazdrowicz et al. (2008) found mowing activities in agricultural fields to be the most significant source of human-induced mortality for the species. On Long Island, New York, several of these threats are elevated by the high human population density and fragmented landscape of the region. Although not a direct measure of population decline, we studied potential drivers of differences in box turtle health (i.e., BCI) and shell damage, as well as sex and stage ratios across the island, to provide insight into potential threats facing Long Island eastern box turtle populations. Our study found that eastern box turtles have higher levels of damage in areas classified as dryland, cropland, or pasture—a single land cover variable that experiences greater rates of mowing and agricultural activities. Additionally, our results provide a valuable demographic summary of Long Island's eastern box turtle population. Our findings can be used to inform conservation planning and management for eastern box turtles on Long Island, as well as for other populations of the species located in areas with high human population density.

Numerous studies cite encounters between turtles and agricultural machinery as a major source of damage, and possible mortality, to various turtle species (Dodd et al. 1997; Saumure et al. 2007; Erb and Jones 2011; Parren 2013). Of the 16 land cover and land use covariates analyzed, shell damage in Long Island's eastern box turtles exhibited a significant relationship only with the percentage of Dryland Cropland and Pasture covariate. When compared to other sites outside of Long Island that have lesser degrees of urbanization, shell damage rates in these

Table 3. The mean body condition index (BCI) for males, females, adults, and juveniles at each site, as well as the overall site mean BCI, for the eastern box turtle (*Terrapene carolina carolina*). Each cell in the table is formatted as mean ± SD (*n*) where SD is standard deviation and *n* is the number of individuals in that sample. Official site names are not provided to prevent potential illegal capture of the species.

Site	Male	Female	Adult	Juvenile	All individuals
A	14.1 ± 0.64 (2)	13.7 (1)	13.9 ± 0.50 (3)	—	13.9 ± 0.50 (3)
B	13.9 ± 0.80 (2)	—	13.9 ± 0.80 (2)	—	13.9 ± 0.80 (2)
C	13.9 (1)	13.5 ± 0.60 (2)	13.7 ± 0.48 (3)	—	13.7 ± 0.48 (3)
D	13.0 ± 1.50 (9)	13.0 ± 0.87 (5)	13.0 ± 1.27 (14)	10.7 ± 1.58 (2)	12.7 ± 1.48 (16)
E	15.5 ± 5.04 (4)	11.8 (1)	14.8 ± 4.66 (5)	6.46 (1)	13.4 ± 5.37 (6)
F	12.9 ± 1.52 (7)	14.3 ± 2.05 (10)	13.7 ± 1.93 (17)	—	13.7 ± 1.93 (17)
G	13.0 ± 0.43 (2)	13.4 ± 0.80 (5)	13.3 ± 0.70 (7)	—	13.3 ± 0.70 (7)
H	14.02 (1)	—	14.0 (1)	—	14.0 (1)
I	11.1 (1)	13.6 ± 0.01 (2)	12.8 ± 1.43 (3)	5.62 (1)	11.0 ± 3.77 (4)
J	14.2 ± 0.03 (2)	13.4 ± 1.35 (2)	13.8 ± 0.90 (4)	7.44 (1)	12.5 ± 2.94 (5)
K	13.8 ± 0.73 (9)	12.5 ± 0.45 (4)	13.4 ± 0.88 (13)	5.65 (1)	12.8 ± 2.23 (14)
L	13.4 ± 0.18 (2)	11.8 ± 0.16 (2)	12.6 ± 0.90 (4)	4.64 (1)	11.0 ± 3.64 (5)
M	12.9 ± 1.21 (15)	11.9 (1)	12.9 ± 1.20 (16)	8.45 ± 0.77 (3)	12.2 ± 2.00 (19)
N	12.1 ± 1.54 (6)	11.7 ± 1.03 (3)	12.0 ± 1.34 (9)	7.33 ± 2.55 (8)	9.8 ± 3.08 (17)
O	—	17.2 (1)	17.2 (1)	—	17.2 (1)
P	13.3 (1)	12.6 (1)	12,9 ± 0.45 (2)	—	12.9 ± 0.45 (2)
Q	13.1 ± 1.74 (11)	12.0 ± 1.64 (3)	12.9 ± 1.72 (14)	7.70 ± 3.49 (3)	12.0 ± 2.84 (17)
R	—	—	—	9.31 (1)	9.31 (1)
S	13.0 ± 1.32 (14)	12.5 ± 1.44 (10)	12.7 ± 1.42 (24)	8.32 ± 2.99 (7)	11.7 ± 2.60 (31)
T	12.8 ± 1.16 (13)	12.2 ± 1.17 (9)	12.6 ± 1.18 (22)	—	12.6 ± 1.18 (22)
All	13.16 ± 1.61 (101)	12.94 ± 1.52 (62)	13.06 ± 1.58 (163)	7.78 ± 2.48 (29)	12.26 ± 2.57 (193)

other sites appear to be lower. Egmont Key, Florida, and Mason Neck Wildlife Refuge, Virginia, had damage rates of 18% and 10%, respectively (Dodd et al. 1997; Boucher and Ernst 2004), compared to our Long Island damage rate of 63%. The Egmont Key eastern box turtle population has no native terrestrial mammals depredating them, although there have been cases of raccoons washing ashore and causing moderate damage to the turtles. In addition to occasional damage by raccoons, the Tampa Bay Pilot's Association (TBPA) is located on Egmont Key and grounds personnel maintaining the TBPA compound with lawn-mowing activities can cause extensive damage to the turtles (Dodd et al. 1997). However, the overall damage rate reported by Dodd et al. (1997) remains substantially lower than that found for Long Island turtles (when including chipped marginals). The Mason Neck Wildlife Refuge study omitted chipped marginals as a form of unnatural physical damage to an individual's shell, stating these could occur due to a turtle's natural movements or falls (Boucher and Ernst 2004). When we omitted chipped marginals from our assessment, we found that 21% of Long Island eastern box turtles exhibit some form of damage—a rate still greater than those of Egmont Key and the Mason Neck Wildlife Refuge. Therefore, we believe that these higher rates of shell damage in Long Island eastern box turtles are driven by the high human population density and heavy urbanization characteristic of the area.

With respect to eastern box turtle health, our study found relatively constant body condition in eastern box turtles across Long Island regardless of study site. Although turtles were found at 20 sites across the island, Long Island's relatively uniform environmental characteristics, as well as consistently high human population density, may mask any potential impacts that Long Island's urban landscape has on the species' health. When comparing rural and suburban populations of eastern box turtles, the similarity in mean BCI for eastern box turtles surveyed on Long Island compared to those surveyed in Vermilion County, Illinois, suggests that high human population density and heavy urbanization may not play a role in eastern box turtle health. However, it is also possible that human population density and urbanization had an effect on a turtles' health, but not an effect that we were able to measure given the data collected. Because we only calculated the BCI for an individual turtle and did not conduct oral examinations, bloodwork, or parasite/pathogen screenings, a turtle's BCI is likely not painting the complete picture of an individual turtles' health. Similarly, there may be other species characteristics, such as population density, survival, or fecundity, that are impacted by human population density and urbanization that our first-level measure of turtle health did not capture.

When comparing BCI by life stage, we found that juvenile eastern box turtles have lower body condition on average than adults. Despite slight differences in adult classification criteria between our study and the dePersio et al. (2019) study, juveniles in both studies consistently exhibited lower body condition than adults. Given the variables used in the BCI equation, this seems logical (i.e., smaller turtle = lower BCI); however, dePersio et al. (2019) explored this relationship when selecting the model that best related fat content to morphological measurements. Although juvenile turtles are smaller in size than adults, the best model still accounted for 73% of the variation in growth range percentiles, indicating that a large proportion of the variation is explained even when looking at younger individuals. Therefore, there remains uncertainty on the processes driving juvenile eastern box turtles' BCI.

Additionally, our study exhibits male-biased sex ratios in eastern box turtles across Long Island, a finding consistent with other studies throughout the United States (Stickel 1978; Dodd 1997; Nazdrowicz et al. 2008). Several explanations have been proposed for male-biased sex ratios in eastern box turtles. One possible explanation is that many studies do not account for the increased movement of nesting female turtles (Dodd 2002). Movement of nesting females may cause increased female mortality as females are more likely to encounter roads, humans, and predators when searching for suitable nesting sites (Gibbs and Steen 2005; Nazdrowicz et al. 2008). Road mortality is a well-documented cause of death in eastern box turtles and is likely a major cause of box turtle death on Long Island due to the region's high road densities (Gibbs and Steen 2005). Ready et al. (2020) found that over 50% of the eastern box turtles admitted to the Turtle Rescue Team (TRT) at the North Carolina State University College of Veterinary Medicine between 1996 and 2017 were admitted for vehicular trauma. However, Sack et al. (2017) found that of the 947 eastern box turtles admitted to the TRT in North Carolina, only 40% were female, compared with 48% male. If increased movement of nesting female turtles drove the male-biased sex ratios, we would expect to see a greater proportion of females admitted to the TRT compared with males. Specific to Long Island, Nichols (1939) studied the species at the William Floyd Estate, located on the southern shore of Long Island. Although Nichols did not explicitly study sex ratio, he grouped individuals into 2 groups (male, female) based on what are now considered secondary sexual characteristics. Nichols classified 149 individuals with flat plastrons (i.e., females) into one group and 238 individuals with concave plastrons (i.e., males) into another group. These data suggest a male-biased sex ratio in eastern box turtles on Long Island several decades prior to when intense urbanization began on the island during the mid to late 20th century. Another possible justification for male-biased sex ratios is related to temperature-dependent sex determination, which has been found in the species (Ewert and Nelson 1991). Although more research is needed, Ewert and Nelson (1991) found that eggs incubated at cooler temperatures resulted in a significantly higher proportion of male to female hatchlings. Therefore, the eastern box turtle population on Long Island may be male-biased because of factors unrelated to Long Island's human population density and urban landscape, and due to its climate instead.

In an effort to understand the most effective approaches for eastern box turtle conservation, future work should focus on assessing potential drivers of health and shell damage that were not fully explored in this study. Additionally, a more comprehensive health assessment should be conducted on Long Island's eastern box turtles, including the collection of heart and respiratory rates, oral examinations, bloodwork, and screenings for parasites and pathogens. These data will provide a more robust assessment of eastern box turtle health on Long Island than the use of BCI alone. Similarly, there is a general consensus that agricultural equipment and predators (e.g., raccoons) are 2 of the primary causes of shell damage in the species. Determining the incidence of these damaging encounters and other possible sources of damage are critical future research directions.

A limitation posed by our study is the absence of data on mortality rates and a focus on exclusively living individuals. Future work focused on species mortality rates, and from what degree of damage a turtle can make a full recovery, will prove useful in conserving the species. Although our findings offer insight into the Long Island eastern box turtle population—a region with high human population density and intense urbanization and development—more work on this subject is needed to ensure the long-term viability of the species.

ACKNOWLEDGMENTS

We thank all of the researchers who assisted with turtle collection in 2016 and 2017, including J. Mangalathu. We thank M. Allender for providing the BCI data on the Illinois eastern box turtles. We also thank T. Green and Brookhaven National Laboratory; C. Boelke and the Suffolk County Department of Parks, Recreation & Conservation; D. Dayton and the Friends of the Long Pond Greenbelt; C. Crasson, F. Quevedo, and the South Fork Natural History Museum & Nature Center; M. Williams and the US Fish and Wildlife Service (Research and Monitoring Special Use Permit 2014-16-27); K. Muessig and the Nassau County Department of Parks, Recreation and Museums; B. Simmons and City of New York Parks and Recreation Natural Resources Group; P. Stringer and the NYDEC (License to Collect or Possess: Scientific 2040); and Stony Brook University (Institutional Animal Care and Use Committee: IRBNet 763072).

LITERATURE CITED

ADAMOVICZ, L., ALLENDER, M.C., ARCHER, G., RZADKOWSKA, M., BOERS, K., PHILLIPS, C., DRISKELL, E., KINSEL, M.J., AND CHU, C. 2018. Investigation of multiple mortality events in eastern box turtles (*Terrapene carolina carolina*). PLoS ONE 13: p.e0195617.

ADAMOVICZ, L., BRONSON, E., BARRETT, K., AND DEEM, S.L. 2015. Health assessment of free-living eastern box turtles (*Terrapene carolina carolina*) in and around the Maryland Zoo in Baltimore 1996–2011. Journal of Zoo and Wildlife Medicine 46:39–51.

ANDREADIS, K.A., SCHUMANN, G.J.-P., AND PAVELSKY, T. 2013. A simple global river bankfull width and depth database. Water Resources Research 49:7164–7168.

BOUCHER, T.P. AND ERNST, C.H. 2004. *Terrapene carolina carolina* (eastern box turtle). Injuries. Herpetological Review 35:56–57.

Brown, J.D. and Sleeman, J.M. 2002. Morbidity and mortality of reptiles admitted to the wildlife center of Virginia, 1991 to 2000. Journal of Wildlife Diseases 38:699–705.

Burke, R.L. and Capitano, W. 2011a. Eastern box turtle, *Terrapene carolina*, neonate overwintering ecology on Long Island, New York. Chelonian Conservation and Biology 10:256–259.

Burke, R.L. and Capitano, W. 2011b. Nesting ecology and hatching success of the eastern box turtle, *Terrapene carolina*, on Long Island, New York. American Midland Naturalist 165:137–142.

Center for International Earth Science Information Network (CIESIN), Columbia University, and Information Technology Outreach Services (ITOS), and University of Georgia. 2013. Global roads open access data set, version 1 (gROADSv1). Palisades, New York: NASA Socioeconomic Data and Applications Center (SEDAC). doi: 10.7927/H4VD6WCT (12 September 2020).

Center For International Earth Science Information Network (CIESIN), Columbia University, and Information Technology Outreach Services (ITOS), and University of Georgia. 2018. Gridded Population of the World, version 4 (GPWv4). Palisades, New York: NASA Socioeconomic Data and Applications Center (SEDAC). doi: 10.7927/H49C6VHW.

Cherepanov, G. 2014. Patterns of scute development in turtle shell: symmetry and asymmetry. Paleontological Journal 48:1275–1283.

Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES). 1994. Ninth meeting of the Conference of the Parties: proposals for amendment of appendices I and II. Fort Lauderdale, FL: CITES.

Currylow, A.F., Zollner, P.A., Macgowan, B., and Williams, R.N. 2010. A survival estimate of Midwestern adult eastern box turtles using radiotelemetry. American Midland Naturalist 165:143–149.

dePersio, S.A., Allender, M.C., Dreslik, M.J., Adamovicz, L., Phillips, C.A., Willeford, B., Kane, L.P., Joslyn, S.K., and O'Brien, R. 2019. Body condition of eastern box turtles (*Terrapene carolina carolina*) evaluated by computed tomography. Journal of Zoo and Wildlife Medicine 50:295–302.

Dodd, C.K., Jr. 1997. Population structure and the evolution of sexual size dimorphism and sex ratios in an insular population of Florida box turtles (*Terrapene carolina bauri*). Canadian Journal of Zoology 75:1495–1507.

Dodd, C.K., Jr. 2002. North American Box Turtles: A Natural History. Norman: University of Oklahoma Press, 231 pp.

Dodd, C.K., Jr., Franz, R., and Johnson, S.A. 1997. Shell injuries and anomalies in an insular population of Florida box turtles (*Terrapene carolina bauri*). Herpetological Natural History 51:66–72.

Dodd, C.K., Jr., Hyslop, N.L., and Oli, M.K. 2012. The effects of disturbance events on abundance and sex ratios of a terrestrial turtle, *Terrapene bauri*. Chelonian Conservation and Biology 11:44–49.

Dolbeer, R.A. 1969. A study of population density, seasonal movements and weight changes, and winter behavior of the eastern box turtle, *Terrapene c. carolina* L., in eastern Tennessee. MS Thesis, University of Tennessee, Knoxville.

Erb, L. and Jones, M.T. 2011. Can turtle mortality be reduced in managed fields? Northeastern Naturalist 18:489–496.

Ernst, C.H., Lovich, J.E., and Barbour, R.W. 1994. Turtles of the United States and Canada. Washington, DC: Smithsonian Institution Press, 578 pp.

ESRI. 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Evans, L.T. 1951. Endocrine relationships in turtles: III. Some effects of male hormone in turtles. Herpetologica 8:11–15.

Ewert, M.A. and Nelson, C.E. 1991. Sex determination in turtles: diverse patterns and some possible adaptive values. Copeia 1991:50–69.

Ewing, H.E. 1939. Growth in the eastern box-turtle, with special reference to the dermal shields of the carapace. Copeia 1939:87–92.

Figueras, M.P., Green, T.M., and Burke, R.L. 2021. Consumption patterns of a generalist omnivore: eastern box turtle diets in the Long Island Pine Barrens. Diversity 13:345.

Gibbs, J.P. and Steen, D.A. 2005. Trends in sex ratios of turtles in the United States: implications of road mortality. Conservation Biology 19:552–556.

Hall, R.J., Henry, P.F.P., and Bunck, C.M. 1999. Fifty-year trends in a box turtle population in Maryland. Biological Conservation 88:165–172.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O. and Townshend, J.R.G. 2013. High-resolution global maps of 21st-century forest cover change. Science 342:850–853. http://www.sciencemag.org/content/342/6160/850.abstract.

Howell, H.J. and Seigel, R.A. 2019. The effects of road mortality on small, isolated turtle populations. Journal of Herpetology 53:39–46.

Kemp, S.J., Kemp, M.J., and Guers, C. 2022. Decline of woodland box turtles (*Terrapene carolina carolina*) over 40 years in southeastern Pennsylvania, USA. Herpetological Conservation and Biology 17:196–203.

Kiester, A. and Willey, L. 2015. *Terrapene carolina* (Linnaeus 1758) — eastern box turtle, common box turtle. Chelonian Research Monographs 5:85.1–85.25.

Latham, R. 1916. Notes on *Cistudo carolina* from Orient, Long Island. Copeia 34:65–67.

Nazdrowicz, N.H., Bowman, J.L., and Roth, R.R. 2008. Population ecology of the eastern box turtle in a fragmented landscape. Journal of Wildlife Management 72:745–753.

New York Department of Environmental Conservation. 2013. New York Department of Environmental Conservation species status assessment: *Terrapene carolina carolina*. https://www.dec.ny.gov/docs/wildlife_pdf/sgcnwoodlandboxturtl.pdf.

Nichols, J.T. 1939. Data on size, growth, and age in the box turtle, *Terrapene carolina*. Copeia 1939:14–20.

Northeast Partners in Amphibian and Reptile Conservation (NEPARC). 2010. Northeast Amphibian and Reptile Species of Regional Responsibility and Conservation Concern. NEPARC. Fort Collins, Colorado. Publication 2010-1.

Parren, S.G. 2013. A twenty-five year study of the wood turtle (*Glyptemys insculpta*) in Vermont: movements, behavior, injuries, and death. Herpetological Conservation and Biology 8:176–190.

R Core Team. 2020. R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Ready, Z., Chen, E., and Lewbart, G.A. 2020. Temporal patterns in admission of eastern box turtles (*Terrapene carolina carolina*) at a North Carolina wildlife clinic as a reflection of climate. Journal of Zoo and Wildlife Medicine 51:363–370.

Sack, A., Butler, E., Cowen, P., and Lewbart, G.A. 2017. Morbidity and mortality of wild turtles at a North Carolina wildlife clinic: a 10-year retrospective. Journal of Zoo and Wildlife Medicine 48:716–724.

SAUMURE, R.A., HERMAN, T.B., AND TITMAN, R.D. 2007. Effects of haying and agricultural practices on a declining species: the North American wood turtle, *Glyptemys insculpta*. Biological Conservation 135:581–591.

STEEN, D. A., ARESCO, M.J., BEILKE, S.G., COMPTON, B.W., CONDON, E.P., DODD, C.K., JR., FORRESTER, H., GIBBONS, J.W., GREENE, J.L., JOHNSON, G., LANGEN, T.A., OLDHAM, M.J., OXIER, D.N., SAUMURE, R.A., SCHUELER, F.W., SLEEMAN, J.M., SMITH, L.L., TUCKER, J.K., AND GIBBS, J.P. 2006. Relative vulnerability of female turtles to road mortality. Animal Conservation 9:269–273.

STICKEL, L.F. 1950. Populations and home range relationships of the box turtle, *Terrapene c. carolina* (Linnaeus). Ecological Monographs 20:278–351.

STICKEL, L.F. 1978. Changes in a box turtle population during three decades. Copeia 1978:221–225.

US CENSUS BUREAU. 2010. Quick facts: New York. https://www.census.gov/quickfacts/NY.

US GEOLOGICAL SURVEY (USGS). 2017. Long Island—location and physical setting. https://www.usgs.gov/centers/new-york-water-science-center/science/long-island-location-and-physical-setting#:~:text=The%20total%20length%20of%20Long,is%20about%201%2C400%20square%20miles.

US GEOLOGICAL SURVEY (USGS). 2018. North America land cover characteristics data base. Version 2.0. https://www.usgs.gov/media/images/north-america-land-cover-characteristics-data-base-version-20.

VAN DIJK, P.P. 2011. *Terrapene carolina*. The IUCN Red List of Threatened Species 2011:e.T21641A97428179. doi: 10.2305/IUCN.UK.2011-1.RLTS.T21641A9303747.en.

WILDLIFE CONSERVATION SOCIETY (WCS), CENTER FOR INTERNATIONAL EARTH SCIENCE INFORMATION NETWORK (CIESIN), AND COLUMBIA UNIVERSITY. 2005. Last of the wild project, version 2, 2005 (LWP-2): global human footprint dataset (geographic). Palisades, New York: NASA Socioeconomic Data and Applications Center (SEDAC). doi: 10.7927/H4M61H5F.

WILLEY, L.L. 2010. Spatial ecology of eastern box turtles (*Terrapene c. carolina*) in central Massachusetts. PhD Dissertation, University of Massachusetts, Amherst.

Received: 3 October 2022
Revised and Accepted: 26 June 2023
Published Online: 17 January 2024
Handling Editor: Peter V. Lindeman