Biology and Conservation of Emydine Turtles
2024 Northeastern Naturalist 31(Special Issue 12):G28–G46

Baseline Abundances and Population Demographics at Wood Turtle (*Glyptemys insculpta*) Monitoring Sites in Wisconsin

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Abstract - Wisconsin encompasses a substantial portion of the Upper Midwest distribution for the globally endangered *Glyptemys insculpta* (Wood Turtle). However, the paucity of prior research and population monitoring statewide has limited our understanding of their status and population trends in the state. To address this information gap, we conducted standardized Wood Turtle population surveys at 50 sites across 8 HUC-8 watersheds in Wisconsin from 2018 to 2023 to estimate adult abundance and population demographic parameters. We captured turtles at 29 of 50 sites, and detected 250 unique individuals, consisting of 107 adult females, 77 adult males, and 66 juveniles. Site-level estimated adult abundances varied from 0 to 23 (mean = 5 among all sites surveyed). Our results provide a foundation for assessing long-term population trends and responses to conservation and habitat management efforts for Wood Turtles in Wisconsin.

Introduction

For many cryptic and seasonally constrained non-game wildlife species, state natural resource managers rely on haphazardly collected occurrence records and expert knowledge to perform species status and trend assessments. However, the conclusions and management decisions resulting from these information sources can come under scrutiny due to the varying uncertainty levels of each source (MacKenzie 2005). Standardized population monitoring programs can overcome this challenge by providing higher-resolution data (e.g., abundance, sex ratio, age-class distribution) obtained using a consistent and repeatable method. When effectively implemented, standardized monitoring provides managers with a defensible, quantitative approach to assessing the status and trends of populations (Sauer and Knutson 2008). Long-term monitoring further enables proactive and adaptive conservation measures to manage species more effectively. As a result, standardized monitoring programs are increasingly being used by conservation biologists across a broad array of taxonomic groups (e.g., amphibians [Weir et al. 2009], birds [Sauer et al. 2013], fish [Spurgeon et al. 2016]).

Glyptemys insculpta (Le Conte) (Wood Turtle) is classified by the International Union for the Conservation of Nature as endangered with a decreasing population trajectory (van Dijk and Harding 2011) and is currently under review for

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Manuscript Editor: Lori Erb

federal listing under the US Endangered Species Act. In Wisconsin, Wood Turtles have been ranked as a threatened species since 1982 and are considered a species of greatest conservation need (SGCN) by the Wisconsin Department of Natural Resources (WDNR; WDNR 2016). Population declines have been documented throughout the species' distribution and have been associated with the following factors: habitat loss, alteration, and fragmentation; high levels of nest predation; adult mortality from mesopredators, roads, and agriculture; and the negative consequences of climate change (e.g., increased flooding and loss of specialized niche habitat; Bougie et al. 2020, Jones and Sievert 2009, Jones et al. 2021a, Lapin et al. 2019, Mothes et al. 2020, Roberts et al. 2021, Saumure et al. 2007).

Previous research has resulted in extensive knowledge of the biology and ecology of Wood Turtles (reviewed in Jones and Willey 2021). However, standardized population-survey approaches had not been developed for the species until recently. Federal and state-supported Wood Turtle conservation initiatives led to the creation of 2 widely used standardized survey protocols for the species, typically referred to as the Northeast protocol (Roberts et al. 2021) and Midwest protocol (Brown et al. 2017) because they were independently developed and tested in the 2 regions. The sampling strategy for both protocols include repeated active searches of a defined stream area (hereafter site), but the 2 protocols differ in how the searches are performed. Briefly, the Northeast protocol includes a lead observer who is unconstrained in their search area and an unlimited number of secondary observers (typically 1–3), whereas the Midwest protocol does not include a lead observer and spatially constrains the search area of each observer using transect bands, with transect bands pre-defined based on whether the surveys are aquatic or terrestrial-focused. The Midwest protocol has been adopted for population monitoring in Minnesota (Cochrane et al. 2018) and Wisconsin (this study), and has been recommended for future population monitoring in Michigan (Schneider et al. 2018).

The recent initiation of a US Fish and Wildlife Service species status assessment and creation of standardized survey protocols have enabled state biologists to devote resources for targeted surveying and monitoring of Wood Turtles throughout their US distribution. In 2016, the WDNR created the Wisconsin Wood Turtle Status Assessment and Conservation Strategy, which identified 4 primary objectives: (1) obtain additional distribution and viability data; (2) quantify local, regional, and statewide trends; (3) conduct a population-viability analysis; and (4) prioritize conservation actions (WDNR 2016). Following the creation of the conservation strategy, a population-viability analysis was conducted to address objective 3 (Bougie et al. 2022), and we initiated a Wood Turtle population monitoring program to estimate and track changes in abundance and population demographics within core population areas of Wisconsin, addressing objectives 1 and 2. The purpose of this study is to present baseline abundance and population demographic estimates for Wood Turtle monitoring sites and regions of Wisconsin that were surveyed between 2018 and 2023. This study provides foundational data for monitoring long-term population trends and responses to conservation and habitat management efforts in the state.

Field-Site Description

Between 2018 and 2023, we delineated and surveyed 50 Wood Turtle-monitoring sites in Wisconsin. All sites were located on federal- or state-managed land to ensure long-term accessibility. We selected 16 sites deterministically based on locations of past or potential future conservation actions or prior known Wood Turtle occurrence within monitoring regions of interest. We selected the remaining 34 sites using a stratified random sampling approach to ensure monitoring sites covered a variety of forested and open terrestrial riparian habitat. Additional site-selection information can be found in Staggs (2023).

The 50 Wood Turtle monitoring sites were located across 8 watersheds (Hydrologic Unit Code [HUC 8]) within the Laurentian Mixed Forest and Midwest Broadleaf Forest ecological provinces (Bailey 1980). The riverine systems varied from lentic (e.g., flowages) to lotic systems (e.g., class 1–2 riffles/rapids). Stream width varied from 3 to 150 m, such that 12 of the sites were 3–20 m wide, 31 were 20–60 m wide, and 7 were 60–150 m wide. River substrates consisted of a sand, gravel, or cobble base, with some featuring clay. The rivers were typically tannic, resulting from the decay of upland vegetation interlaced with substrates that occurred naturally on the landscape. Sites with minimal contemporary human impact featured riverine-forested systems with some natural-disturbance regimes. Sites with human infrastructure included a wide array of erosion- and flood-protection infrastructure (e.g., riprap, flowage, dam systems); roads, railroads, and transmission powerlines running parallel or perpendicular to river shorelines; agricultural (e.g., croplands, pine plantations), residential, and recreational features; and Wood Turtle habitat-restoration areas (e.g., created nesting sites).

Adjacent upland habitat consisted of both deciduous and mixed deciduous–coniferous components. Forested canopies featured old growth, mixed-age, and early successional stands with varying levels of commercial tree harvests (e.g., clear cut, shelterwood, seed trees, wildlife openings), and canopy gaps from natural blowdown events. The upper-canopy tree species of most relevance within our sites were *Pinus strobus* L. (Eastern White Pine), *Abies balsamea* (L.) Mill (Balsam Fir), *Tsuga canadensis* (L.) Carr (Eastern Hemlock), *Betula papyrifera* Marshall (White Birch), *Betula alleghaniensis* Britton (Yellow Birch), *Acer rubrum* L. (Red Maple), *Acer saccharinum* L. (Silver Maple), *Populus* spp. (poplar; e.g., *Populus tremuloides* Michx. [Quaking Aspen] and *Populus balsamifera* L. [Balsam Poplar]), and *Fraxinus nigra* Marshall (Black Ash). Sub-canopy species included *Alnus incana* (L.) Moench (Speckled Alder), *Corylus americana* Walter (American Hazelnut), *Corylus cornuta* Marshall (Beaked Hazelnut), *Cornus sericea* L. (Red Osier Dogwood), *Salix interior* Rowlee (Sandbar Willow), *Zanthoxylum americanum* Mill. (Northern Prickly Ash), *Lonicera* spp. (honeysuckle; e.g., *Lonicera tatarica* L. [Tatarian Honeysuckle]), and *Rhamnus cathartica* L. (Common Buckthorn). Notable ground vegetation included *Carex* spp. (native and non-native sedge species), *Pteridium* sp. (bracken fern), *Symplocarpus foetidus* (L.) Salisb. ex W.P.C. Barton (Skunk Cabbage), and *Phalaris arundinacea* L. (Reed Canary Grass).

To adhere to Wisconsin's endangered- and threatened-species data-practices law, we are withholding the county, river, and watershed names of our study area to protect this species from concerns associated with illegal collection. By the recommendation of Partners in Amphibian and Reptile Conservation – Turtle Networking Team's Collaborative to Combat the Illegal Turtle Trade, we are also limiting the provision of specific habitat features and place names that would otherwise compromise specific watershed locations within our study areas to further protect the populations presented herein. Future research attempting to utilize the data within this study may seek its access by filing the appropriate Natural Heritage Inventory research permits, data requests, and data-sharing agreements available through the Wisconsin Department of Natural Resources' Endangered Resources Review Program.

Methods

Survey design and implementation

Following the Midwest protocol (Brown et al. 2017), we performed active searches on foot within 2 transect bands on each side of the river (mean length = 0.95 km, min–max = 0.42–1.14 km), with transect bands centered at 0 m and 15 m from the river–land interface. We also surveyed islands ≥10 m² in total area and recorded habitat characteristics when present at sites. Our surveys began between 22 April and 8 May, corresponding with daytime air temperatures exceeding 10 °C (Brown et al. 2017). Surveys concluded during the first week of June prior to the beginning of the nesting season in Wisconsin. Each survey was completed by 1–2 surveyors, including the authors and trained field technicians.

We typically conducted 6 survey replications at sites where at least 1 Wood Turtle was detected during the first 3 surveys. If no Wood Turtles were detected, we ceased survey efforts at the site, unless resources allowed for additional surveys near the end of the survey season. Exceptions to this sampling approach include 2 occupied sites surveyed in 2022, where only 3 survey replications were performed using this survey protocol, and 3 occupied sites surveyed in 2018, where 7–8 survey replications were performed. Brown et al. (2017) demonstrated that if no individuals are detected in 3 surveys, then the site is likely to be unoccupied or a low-density site. At each site, we performed surveys across multiple weeks to ensure variation in survey temperatures and phenological conditions. To further maximize detection success, the majority of surveys (>80%) were conducted when air temperatures were 12–28 °C (Brown et al. 2017, Ernst 1986). We surveyed 4 to 10 sites within each watershed.

Data collection

For each survey replication, we recorded total survey time (omitting turtle processing time). At the start and end of each survey, we recorded time, weather conditions (i.e., clear, partly cloudy, cloudy/overcast, fog, drizzle, showers, or snow), and air temperature (°C). Beginning in 2021, we also recorded water temperature (°C). At the beginning and end of each site, we recorded stream and terrestrial characteristics following the Northeast Wood Turtle population assessment protocol (NWTWG 2021). For captured Wood Turtles, we recorded standard measurements described in Iverson and Lewis (2018), including midline carapace length and width (CL, CW; mm), plastron length and width (PL, PW; mm), body depth (shell height; mm), and mass (g). We counted scute annuli on the plastron, an often-utilized technique considered reliable to estimate age up to ~20 years (Harding 1991, Parren 2013). In addition, we estimated plastron wear to approximate general ages of older individuals (Jones 2009). We sexed each turtle using the presence of secondary sex characteristics, such as plastron concavity, tail size and length, and location of cloaca relative to the edge of the carapace. We noted whether females were gravid as determined by manual palpation. We recorded individuals as juveniles when CL $\leq$ 170 mm (Harding and Bloomer 1979, Walde et al. 2003), regardless of the presence of secondary sexual characteristics.

We gave each turtle a unique mark, following Buhlmann et al.'s (2008) scheme for notching of the marginal scutes. We also marked individuals using a 10-mm 134.2 kHz passive integrated transponder (PIT) tag (Biomark, Boise, ID) between 2018 and 2022 and a 12-mm 125 kHz PIT tag (Biomark) in 2023 to align with previous PIT-tag efforts in that watershed. We used this dual-marking approach to deter illegal Wood Turtle collection at our sites and to promote reporting of opportunistic recapture data of notched individuals from land managers after the project period. We recorded general health and behavior of all captured individuals, as well as major and minor injuries. We took carapace and plastron photographs as a third form of identification to cross-reference for future recapture events if PIT tags and notching identification fail. We identified recaptures using a combination of PIT-tag number, scute-notch number, and photographs. To limit stress on the individual, we did not handle them further, although we collected location and environmental data at the time of capture.

Statistical analyses

We used the population survey data to estimate Wood Turtle abundances at the site-level. In 2018, we compared 2 abundance models (i.e., *N*-mixture and capture–recapture models) using 4 occupied Wood Turtle sites: 2 with high survey returns and 2 with low survey returns. We note that the *N*-mixture site estimates used for this comparison were derived from a larger data-set analysis that included 20 sites. Both models resulted in similar abundance estimates for the 2 high survey-return sites, but only the *N*-mixture models provided reasonable estimates for the low survey-return sites (WDNR 2019). A similar outcome was found in the eastern US (Jones and Willey 2015), where 9 survey replicates were typically needed for convergence of capture–recapture models, indicating *N*-mixture models are more suitable for monitoring-program data analyses, which include a wide variety of site-level abundances and typically lower survey-replication effort. *N*-mixture models use both spatial and temporal replication of count data to jointly estimate abundance and detection probability, accounting for observed numbers being a product of both ecological and observational processes (Kéry and Royle 2016, Royle 2004). Brown et al. (2017) recommended the use of a removal (i.e., depletion) sampling observation process, which we adopted for this study. We constructed models using the package 'unmarked' in program R v. 4.3.1 (Fiske and Chandler 2011, Kellner et al. 2023; R Development Core Team, R Foundation, Vienna, Austria) and report the mean and 95% confidence interval for Wood Turtle adult abundance estimates at the site-level. We included mean survey air temperature, mean survey percent cloud cover, leaf-out stage (i.e., pre, early, mid, full), and survey time as candidate covariates for detection probability (*p*; Brown et al. 2017). We ranked candidate models using Akaike's information criterion corrected for small sample size (AIC*c*; Symonds and Moussalli 2011), including each individual covariate model and additive models of covariates with strong support (AIC*c* < 2). A recent study found that for the Midwest survey design, *p* is substantially higher for adult Wood Turtles than juveniles (Beard et al. 2024). To address this model assumption violation, we restricted analysis of the count data set to adult Wood Turtles, and thus, our estimates represent abundance of adult Wood Turtles. We assessed model goodness-of-fit using a 10,000-replication parametric bootstrap of the Pearson chi-square statistic (Kéry and Royle 2016), which indicated that overdispersion was minor ($\hat{c}$ = 1.75).

In addition to estimating abundances, we calculated a variety of abundance-based and demographic statistics at the site-, watershed-, and state-level using the survey capture data. For example, we calculated unique individuals captured per survey per river-km, to allow for comparisons of capture success across space and time. We computed descriptive statistics for commonly monitored demographic parameters such as adult sex ratio and age class distribution. We also report CL statistics for each site to allow for size comparisons across space and time.

Results

We surveyed 50 sites, spanning 8 HUC-8 watersheds in Wisconsin, between 2018 and 2023. A total of 244 surveys were completed statewide, with 3−8 surveys completed per site (mean = 4.9). We documented Wood Turtle presence at 29 sites. We captured 344 Wood Turtles during surveys, including 250 unique turtles (mean captures/individual = 1.4). An additional 57 turtles (33 adults and 24 juveniles) were captured outside of the standardized population surveys and were not included in abundance or demographic calculations.

For sites containing detected Wood Turtles, total captures varied from 1 to 33 (mean = 11.9) per site, and unique individuals captured per site varied from 1 to 21 (mean = 8.6). Watershed totals varied from 3 to 90 (mean = 31.3) unique individuals. At the watershed-level, mean captures per survey per river-km varied from 0.1 to 2.4 (mean = 1.2) and mean unique turtles captured per river-km varied from 0.5 to 10.3 (mean = 5.4). Capture statistics for each scale of analysis are provided in Appendix 1.

Our most supported detection model included leaf-out stage and mean survey air temperature as a quadratic term (Tables 1, 2). Detection probability decreased with increasing leaf-out stage, with a maximum detection probability of 0.17 at 19–21 ˚C

(Fig. 1). Estimated adult abundances (n) varied from 0 to 23 (mean = 5) across all sites, and from 1 to 23 (mean = 8) across sites with at least 1 captured Wood Turtle (Appendix 1).

Table 1. Model-selection results using Akaike's information criterion corrected for small sample size (AIC*c*) to determine the most supported *N*-mixture model for estimating detection of *Glyptemys insculpta* (Wood Turtle) captured at 50 sites in Wisconsin between 2018 and 2023. Candidate variables included mean survey air temperature (°C; air temp), mean survey percent cloud cover, leaf-out stage (i.e., pre, early, mid, full), and survey time (min). Model weight represented as *w*.

Models	Parameters	AIC*c*	ΔAIC*c*	*w*
Air temp^2 + leaf out	5	685.17	0.00	0.30
Leaf out	3	685.09	0.18	0.27
Air temp^2	4	686.39	1.22	0.16
(.)	2	687.06	1.89	0.12
Survey time	3	688.83	3.66	0.05
Air temp	3	689.01	3.84	0.04
Cloud cover	3	689.25	4.08	0.04
Cloud cover^2	4	691.50	6.33	0.01

Table 2. Parameter estimates (β) and 85% confidence intervals (CI) for the most supported *N*-mixture model explaining detection probability for *Glyptemys insculpta* (Wood Turtle) captured at 50 sites in Wisconsin between 2018 and 2023. Detection covariates included mean survey air temperature (°C; air temp) and leaf-out stage (i.e., pre, early, mid, full).

Model	Predictor	β	85% CI
Abundance	Intercept	2.100	1.543 to 2.648
Detection	Intercept	-1.248	-1.893 to -0.604
	Air temp	-0.048	-0.185 to 0.089
	Air temp^2	-0.162	-0.273 to -0.050
	Leaf out	-0.254	-0.428 to -0.080

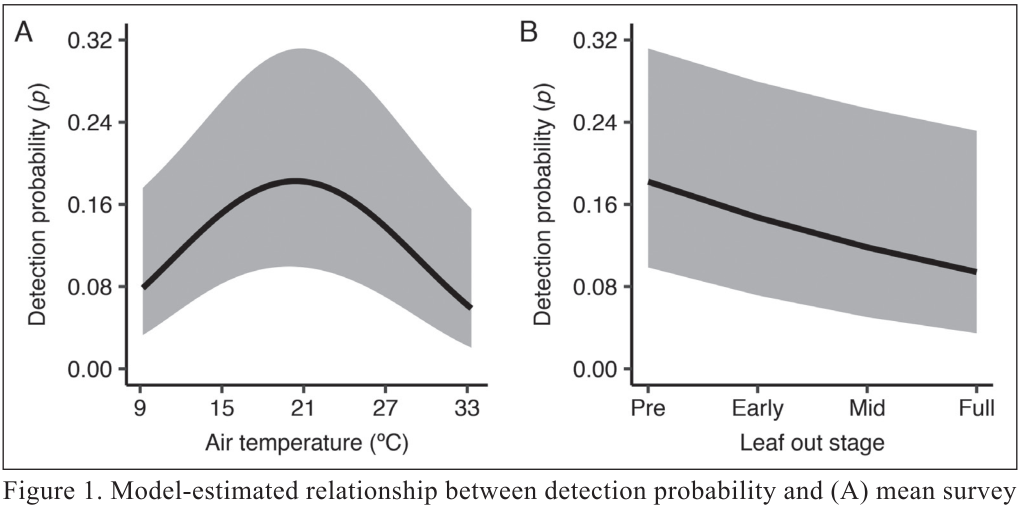

Figure 1. Model-estimated relationship between detection probability and (A) mean survey air temperature (°C) and (B) leaf-out stage (i.e., pre, early, mid, full) for *Glyptemys insculpta* (Wood Turtle) captured at 50 sites in Wisconsin between 2018 and 2023.

Of the total individuals captured, 73.6% were adults (*n* = 184), with an observed adult:juvenile ratio of 1.0:0.4, and 55% were at least 20 years old (*n* = 137; Fig. 2). For the adults, 41.8% were males (*n* = 77), with an observed male:female ratio of 1.0:1.4. At the watershed-level, we captured 0−26 (mean = 9.6) adult males, 3−35 (mean = 13.4) adult females, and 0−29 (mean = 8.3) juveniles. The proportion of adult captures within watersheds varied from 0.58 to 1 (mean = 0.76), and for adults, the proportion of male captures varied from 0 to 0.49 (mean = 0.34). CL varied from 50 to 231 mm (mean = 177 mm, *SD* = 44.2 mm, *n* = 250) for all Wood Turtles captured during surveys, 171 to 221 (mean = 195, *SD* = 11.4, *n* = 107) for adult females, 179 to 231 (mean = 208, *SD* = 12, *n* = 77) for adult males, and 50 to 169 (mean = 112, *SD* = 32.9, *n* = 66) for juveniles (Fig. 2, Appendix 2). Demographic statistics for each scale of analysis are provided in Appendix 2.

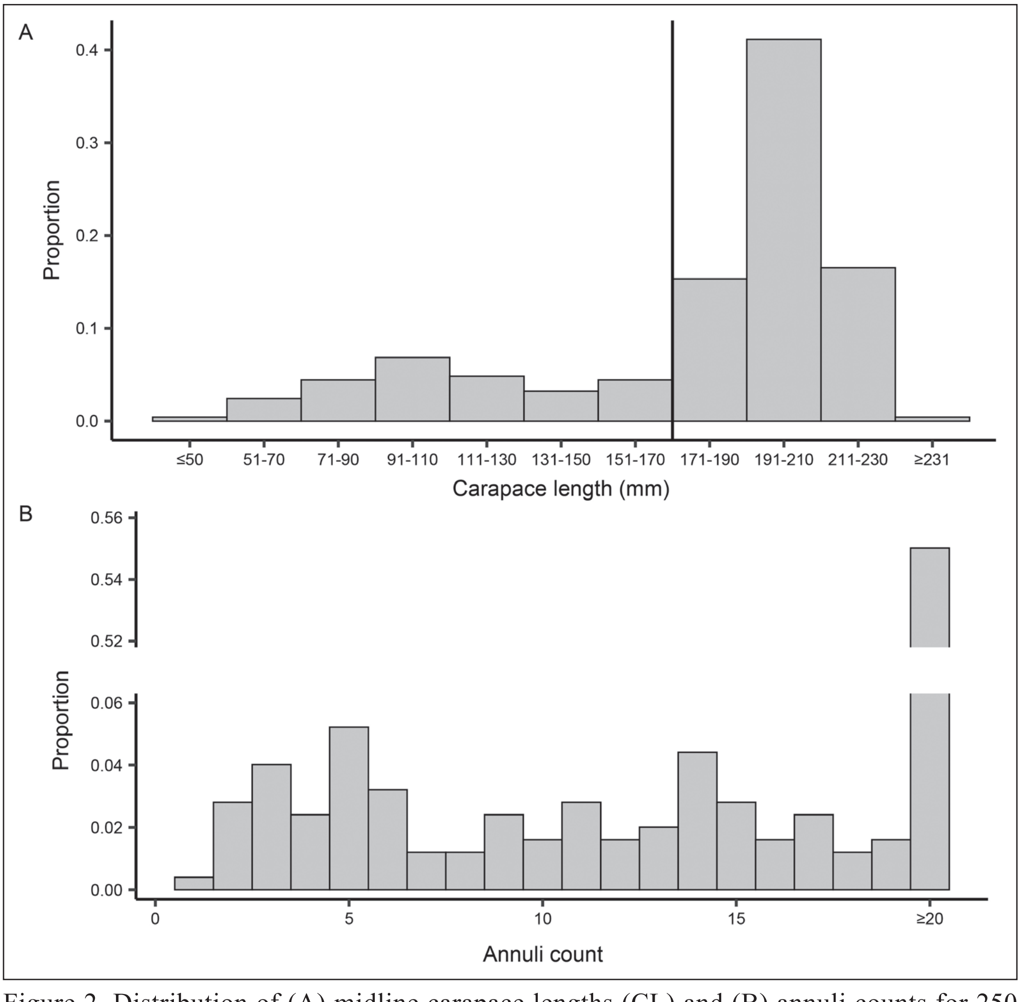

Figure 2. Distribution of (A) midline carapace lengths (CL) and (B) annuli counts for 250 *Glyptemys insculpta* (Wood Turtle) captured through standardized population surveys conducted between 2018 and 2023 at 50 sites located across eight HUC-8 watersheds in Wisconsin. Juveniles are defined as ≤170 mm CL, as indicated by the vertical line in (A).

Discussion

The results of this study characterize the variety of site-level adult abundances that are expected to occur throughout Wood Turtle streams in Wisconsin. While higher-density stream sections may exist in the state, several of the non-randomly selected sites included in this study targeted what are thought to be the largest populations in the state based on previous research and monitoring activities. Wood Turtle occurrence and mean abundance were highly variable across streams, consistent with other portions of their distribution (Jones et al. 2021b, Willey et al. 2022). An important implication of our study is that local abundances can vary dramatically within high-density Wood Turtle streams and watersheds. For example, watershed B contained some of the highest estimates of abundance of adult turtles for the study (n = 19, 19, and 20), but it also contained 2 sites with no captures, 1 of which was located only a few km from high abundance sites. The observed large variation in site-level abundances within the watersheds is likely influenced by local variation in aquatic and terrestrial habitat quality (Arvisais et al. 2004, Jones 2009, Staggs 2023).

Our study suggests that Wisconsin is an important contributor to the regional distribution and abundance of Wood Turtles, with occurrence documented in all 8 HUC-8 watersheds and over 300 unique individuals encountered at 58% of the 50 surveyed sites. However, several studies have shown that local densities in the Midwest region can exceed those found in our study. For example, Brown et al. (2017) documented up to 54 unique individuals during population surveys at a single monitoring site in Minnesota, whereas we captured 21 individuals at our highest-return site. Similarly, a long-term capture–recapture study conducted across 37.5 km of a river in the Lower Peninsula of Michigan estimated a mean density of 31.9 Wood Turtles per river-km, higher than any of our estimates of site-level adult abundance (note that the Michigan estimate includes juveniles). At the broader scale, Roberts et al. (2021) reported that ~22% of surveyed sites (i.e., 63 of 293) in the eastern US had ≥10 adult turtles documented, whereas our study recorded these levels at only 14% of our sites. The lower percentage of sites with a high abundance of adults in our study may indicate that carrying capacities in Wisconsin are below average or may be an artifact of bias during site selection. Many of the eastern US sites were targeted as known sites containing a high abundance of Wood Turtles, and most of our sites were selected using a stratified random sampling design.

The overall proportion of juveniles (26.4%) documented during our surveys potentially suggests that our populations are primarily composed of adults, consistent with many other studies across the species' distribution (e.g., 19% in Ontario, Canada [Foscarini 1994], 25% and 10% in Michigan [Harding and Bloomer 1979, Schneider et al. 2018], 34% in Maine [Jones and Willey 2013a], 48% in New Hampshire [Jones and Willey 2013b], 21% in West Virginia [McCoard et al. 2018]). However, we emphasize that probability of detecting juveniles during surveys is substantially lower than adults (Beard et al. 2024), and thus the age-class data presented in this study could be biased towards adults. Interestingly, we began documenting juveniles during our terrestrial-focused surveys 1–2 weeks after we began documenting adults, indicating juveniles may delay initiation of terrestrial activity during the spring. For example, we did not detect juveniles at sites B1 and B2 during the first 2 survey replications, but we documented 9 and 6 juveniles at the sites, respectively, after 6 replications.

The possibility of influencing Wood Turtle population health through management actions that improve recruitment is of interest to the WDNR (WDNR 2016). While not a focus of this study, we did note characteristics of nest sites at monitoring sites (see Appendix 1). Three monitoring sites containing known natural nesting sites and no nest-protection efforts had lower percentages of juvenile captures (0–27%) relative to 2 sites with ongoing nest-protection efforts (35% and 63%), potentially suggesting that these management efforts are contributing higher numbers of juveniles to local Wood Turtle populations. In addition, several sites downstream from known nesting areas produced comparatively high numbers of juveniles (e.g., B1 = 9 juveniles [90%], B2 = 6 juveniles [67%], and H_W2 = 7 juveniles [54%]). We suspect that the juveniles were carried downstream by stream currents and recommend that future research be conducted to determine if this is a common occurrence as well as to gain a better understanding of habitat quality for young Wood Turtles. This research could also be used to better plan the location(s) of efforts to create and protect nest sites.

Conservation implications

The primary objective of our study was to obtain baseline abundance and demographic estimates at candidate long-term monitoring sites in Wisconsin. Though time and resource intensive, this study serves as an important foundation to track Wood Turtle population trajectories and the outcome of ongoing conservation efforts in the state. We expect that a subset of the 50 sites will be selected for inclusion in a long-term monitoring program and that the sites selected will capture the variability in site-management actions, population threats, geographic locations, and population demography. The monitoring sites will likely be re-surveyed at 5–10-year intervals, depending on resource availability. Future goals for the monitoring program include: (1) estimating site-, watershed-, and state-level population trends; (2) determining the efficacy of the various conservation actions being implemented; and (3) quantifying the influence of population threats, such as anthropogenic land uses, predators, illegal collection, and climate change.

Acknowledgments

Funding for this study was provided by the US Fish and Wildlife Service via the Great Lakes Fish and Wildlife Restoration Act Grant (#F21AP00170-00), Competitive State Wildlife (C-SWG) Grant (#F21AP01159), and State Wildlife Grant (Formula-SWG) programs. Our Wood Turtle handling and research protocols were approved through the West Virginia University Animal Care and Use Committee (Protocol #2002033297.1). We thank and highlight the substantial survey efforts of Nicholas Schiltz and Tiffany Bougie, in addition to numerous other West Virginia University and Wisconsin Department of Natural Resources staff. We also thank the state and federal property managers who provided assistance with site selection, access, and permission to survey public properties. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the US Government. The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or US Government determination or policy.

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Appendix 1. *Glyptemys insculpta* (Wood Turtle) site-, watershed-, and state-level capture, density, and abundance data collected at 50 sites in Wisconsin between 2018 and 2023. Nesting category codes are as follows: A (adjacent to known nesting area), C (constructed), N (natural), O (observed), P (protected), R (roadside), and S (suspected). Captures/survey/river-km indicates the mean Wood Turtle captures in 1 survey within 1 river-km, whereas individuals/river-km indicates the unique individual Wood Turtles documented per river-km. Adult abundance estimates (*n*-hat) are presented with 95% confidence intervals (CI). Site codes have been modified, to minimize the potential for illegal collection of turtles.

Site code	Transect river length (km)	Nesting category	Survey year	# surveys	Unique adults: juveniles	Total survey captures	Captures/ survey/ river-km	Individuals/ river-km	Unique incidental adults:juveniles	Adult *n*-hat (CI)
A_N1	0.73	SN	2018	6	4:1	6	1.4	6.9	0:0	5 (4–7)
A_S1	0.43	SN	2018	7	7:0	13	4.3	16.1	3:0	8 (7–11)
A_S2	0.74	SN	2018	7	19:1	31	6.0	27.1	1:4	23 (20–27)
A_S3	0.43	SN	2018	8	5:0	10	2.9	11.5	0:0	6 (5–8)
A_S4	0.42	-	2018	4	0:0	0	0.0	0.0	0:0	0
A_S5	0.46	-	2018	4	0:0	0	0.0	0.0	0:0	0
A (total)	3.22	-	2018	36	35:2	60	-	-	4:4	42 (36–53)
A (mean)	0.54	-	2018	6	5.8:0.3	10	2.4	10.3	-	7 (6–9)
B1	1.03	-	2021	6	1:9	11	1.8	9.8	0:0	1 (1–3)
B2	0.98	-	2021	6	3:6	10	1.7	9.2	0:1	4 (3–6)
B4	1.00	-	2021	6	15:6	29	4.8	21.0	1:3	19 (15–23)
B7	1.07	-	2021	6	16:2	33	5.1	16.8	2:3	20 (17–24)
B8	1.07	-	2021	3	0:0	0	0.0	0.0	0:0	0
B9	1.12	ORN	2021	6	1:1	2	0.3	1.8	0:0	1 (1–3)
B11	1.11	ON	2021	6	14:3	24	3.6	15.3	3:0	19 (15–23)
B13	1.11	-	2021	6	4:0	5	0.8	3.6	1:0	5 (4–7)
B14	1.14	-	2021	6	7:2	11	1.6	7.9	0:0	9 (7–13)
B18	1.01	-	2021	3	0:0	0	0.0	0.0	0:0	0
B (total)	10.64	-	2021	54	61:29	125	-	-	7:7	78 (63–102)
B (mean)	1.06	-	2021	5.4	6.1:2.9	12.5	2.0	8.5	-	8 (6–10)
C1	1.04	ON	2021	6	8:3	15	2.4	10.6	2:4	10 (8–14)
C2	1.03	-	2021	6	5:2	15	2.4	6.8	0:0	6 (5–9)
C3	0.99	-	2021	4	0:0	0	0.0	0.0	0:0	0
C9	0.96	-	2021	3	0:0	0	0.0	0.0	0:0	0
C (total)	4.00	-	2021	19	13:5	30	-	-	2-4	16 (13–23)
C (mean)	1.00	-	2021	4.75	3.3:1.3	7.5	1.2	4.4	-	4 (3–6)

Site code	Transect river length (km)	Nesting category	Survey year	# surveys	Unique adults: juveniles	Total survey captures	Captures/ survey/ river-km	Individuals/ river-km	Unique incidental adults:juveniles	Adult *n*-hat (CI)
D3	1.02	-	2022	3	1:1	4	1.3	2.0	2:0	2 (1–4)
D21	1.01	-	2022	3	2:1	4	1.3	3.0	1:2	4 (2–6)
D29	0.99	-	2022	6	3:0	6	1.0	3.0	1:1	4 (3–6)
D32	1.04	-	2022	3	0:0	0	0.0	0.0	0:0	0
D64	1.01	SN	2022	3	0:0	0	0.0	0.0	0:0	0
D74	1.01	-	2022	3	0:0	0	0.0	0.0	0:0	0
D (total)	6.07	-	2022	21	6:2	14	-	-	4:3	10 (6–16)
D (mean)	1.01	-	2022	3.5	1.0:0.3	2.3	0.6	1.3	-	2 (1–3)
E2	1.00	PN	2022	6	11:6	23	3.8	17.0	2:3	13 (11–17)
E9	0.98	-	2022	3	0:0	0	0.0	0.0	0:0	0
E47	1.00	-	2022	6	2:1	3	0.5	3.0	1:0	3 (2–4)
E54	1.00	-	2022	6	2:0	2	0.3	2.0	0:0	3 (2–4)
E59	0.98	-	2022	3	0:0	0	0.0	0.0	0:0	0
E97	1.01	-	2022	3	0:0	0	0.0	0.0	0:0	0
E (total)	5.97	-	2022	27	15:7	28	-	-	3:3	19 (15–25)
E (mean)	1.00	-	2022	4.5	2.5:1.2	4.7	0.8	3.7	-	3 (3–4)
F1	1.00	A	2022	3	0:0	0	0.0	0.0	0:0	0
F15	1.01	A	2022	6	3:3	6	1.0	6.0	1:0	4 (3–6)
F22	1.00	OPC	2022	6	3:5	11	1.8	8.0	2:2	4 (3–6)
F36	1.00	A	2022	6	4:0	4	0.7	4.0	1:0	5 (4–8)
F64	1.01	-	2022	6	1:0	1	0.2	1.0	2:0	1 (1–2)
F78	0.96	-	2022	3	0:0	0	0.0	0.0	0:0	0
F (total)	5.97	-	2022	30	11:8	22	-	-	6:2	14 (11–22)
F (mean)	0.99	-	2022	5	1.8:1.3	3.7	0.6	3.2	-	2 (2–4)
G7	1.03	-	2022	3	0:0	0	0.0	0.0	0:0	0
G11	1.00	-	2022	3	0:0	0	0.0	0.0	0:0	0
G15	1.01	SN	2022	6	3:0	3	0.5	3.0	0:0	4 (3–6)
G20	1.02	-	2022	3	0:0	0	0.0	0.0	0:0	0
G33	0.96	-	2022	3	0:0	0	0.0	0.0	0:0	0
G61	1.00	-	2022	3	0:0	0	0.0	0.0	0:0	0
G (total)	6.03	-	2022	21	3:0	3	-	-	0:0	4 (3–6)
G (mean)	1.00	-	2022	3.5	0.5:0	0.5	0.1	0.5	-	1 (1–1)

Site code	Transect river length (km)	Nesting category	Survey year	# surveys	Unique adults: juveniles	Total survey captures	Captures/ survey/ river-km	Individuals/ river-km	Unique incidental adults:juveniles	Adult *n*-hat (CI)
H_W1	1.00	A	2023	6	15–2	21	3.5	17.0	2:1	20 (17–24)
H_W2	1.00	A	2023	6	6–7	15	2.5	13.0	0:0	7 (6–10)
H_W3	0.50	OR	2023	6	0–0	0	0.0	0.0	0:0	0
H_E1	1.00	A	2023	6	8–1	10	1.7	9.0	5:0	10 (8–13)
H_E2	1.00	OPC	2023	6	0–0	0	0.0	0.0	0:0	0
H_E3	1.00	OPC	2023	6	11–3	16	2.7	14.0	0:0	13 (11–17)
H (total)	5.50	-	2023	36	40–13	62	-	-	7:1	50 (42–64)
H (mean)	0.92	-	2023	6	6.7–2.2	10.3	1.7	8.8	-	8 (7–11)
Statewide (total)	47.39	-	2018–2023	244	184–66	344	-	-	33:24	233 (189–311)
Statewide (mean)	0.95	-	2018–2023	4.9	3.7–1.3	6.9	1.2	5.4	-	5 (4–6)

Appendix 2. *Glyptemys insculpta* (Wood Turtle) site-, watershed-, and state-level capture, demographic, and morphometric data collected at 50 sites in Wisconsin between 2018 and 2023. Unique adults:juveniles refers to number of unique individual adults and juveniles encountered during standardized population surveys at each site. For each site, observed age class and sex ratio information is provided as percentages (%) and ratios derived from the survey capture data set. Carapace length (CL; mm) measurements are comprised of mean, standard deviation (SD), maximum (adult male and female), and min–max (juvenile; CL ≤ 170 mm) values.

Site code	Unique adults: juveniles	% adult	% juvenile	Adult: juvenile ratio	Unique male: female	% male	% female	M:F ratio	Male CL mean (SD; max)	Female CL mean (SD; max)	Juvenile CL mean (SD; min–max)
A_N1	4:1	80.0	20.0	1:0.3	1:3	25.0	75.0	1:3	193.0 (NA; 193)	191.8 (±7.2; 197)	144.0 (NA; 144)
A_S1	7:0	100.0	0.0	7:0	4:3	57.1	42.9	1:0.8	204.0 (±4.9; 211)	194.0 (±7.8; 203)	-
A_S2	19:1	95.0	5.0	1:0.1	9:10	47.4	52.6	1:1.1	202.0 (±13.5; 222)	185.0 (±9.3; 198)	167.0 (NA; 167)
A_S3	5:0	100.0	0.0	5:0	3:2	60.0	40.0	1:0.7	206.0 (±8.1; 212)	195.0 (±8.5; 201)	-
A_S4	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
A_S5	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
A (total)	35:2	-	-	-	17:18	-	-	-	203.0 (±10.6; 222)	189.0 (±9.0; 203)	156.0 (±15.8; 144–167)
A (mean)	5.8:0.3	94.6	5.4	1:0.1	2.8:3.0	48.6	51.4	1:1.1	-	-	-
B1	1:9	10.0	90.0	1:9	1:0	100.0	0.0	1:0	212.0 (NA; 212)	-	107.1 (±23.9; 69–156)
B2	3:6	33.3	66.7	1:2	1:2	33.3	66.7	1:2	206.0 (NA; 206)	203.0 (±4.2; 206)	99.3 (±41.4; 58–169)
B4	15:6	71.4	28.6	1:0.4	6:9	40.0	60.0	1:1.5	221.7 (±4.5; 228)	205.8 (±7.3; 217)	127.3 (±23.2; 65–106)
B7	16:2	88.9	11.1	1:0.1	6:10	37.5	62.5	1:1.7	208.8 (±12.5; 224)	195.7 (±4.7; 204)	162.5 (±7.8; 157–168)
B8	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
B9	1:1	50.0	50.0	1:1	1:0	100.0	0.0	1:0	224.0 (NA; 224)	-	111.0 (NA; 111)
B11	14:3	82.4	17.6	1:0.2	3:11	21.4	78.6	1:3.7	217.3 (±2.5; 220)	202.0 (±4.8; 210)	117.3 (±19.3; 102–139)
B13	4:0	100.0	0.0	4:0	3:1	75.0	25.0	1:0.3	198.3 (±12.5; 207)	178.0 (NA; 178)	-
B14	7:2	77.8	22.2	1:0.3	5:2	71.4	28.6	1:0.4	211.0 (±21.5; 230)	189.0 (±17.0; 201)	115.0 (±33.9; 91–139)
B18	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
B (total)	61:29	-	-	-	26:35	-	-	0:0	212.6 (±13.4; 230)	199.8 (±8.5; 217)	115.2 (±30.0; 58-169)
B (mean)	6.1:2.9	67.8	32.2	1:0.5	2.6:3.5	42.6	57.4	1:1.4	-	-	-
C1	8:3	72.7	27.3	1:0.4	2:6	25.0	75.0	1:3	222.5 (±12.0; 231)	203.5 (±9; 213)	134.7 (±27.6; 106–161)
C2	5:2	71.4	28.6	1:0.4	1:4	20.0	80.0	1:4	222.0 (NA; 222)	208.5 (±12.3; 221)	61.5 (±16.3; 50–73)
C3	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
C9	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
C (total)	13:5	-	-	-	3:10	-	-	-	222.3 (±8.5; 231)	205.5 (±10.1; 221)	105.4 (±45.3; 50–161)
C (mean)	3.3:1.3	72.2	27.8	1:0.4	0.75:2.5	23.1	76.9	1:3.3	-	-	-

Site code	Unique adults: juveniles	% adult	% juvenile	Adult: juvenile ratio	Unique male: female	% male	% female	M:F ratio	Male CL mean (SD; max)	Female CL mean (SD; max)	Juvenile CL mean (SD; min–max)
D3	1:1	50.0	50.0	1:1	0:1	0.0	100.0	0:1	-	176.0 (NA; 176)	125.0 (NA; 125)
D21	2:1	66.7	33.3	1:0.5	0:2	0.0	100.0	0:2	-	190.0 (±22.6; 206)	84.0 (NA; 84)
D29	3:0	100.0	0.0	3:0	1:2	33.3	66.7	1:2	215.0 (NA; 215)	205.5 (±6.4; 210)	-
D32	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
D64	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
D74	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
D (total)	6:2	-	-	-	1:5	-	-	-	215.0 (NA; 215)	193.4 (±17.1; 210)	104.5 (±29.0; 84–125)
D (mean)	1:0.3	75.0	25.0	1:0.3	0.2:0.8	16.7	83.3	1:5	-	-	-
E2	11:6	64.7	35.3	1:0.6	4:7	36.4	63.6	1:1.8	206.0 (±11.9; 220)	187.7 (±9.0; 199)	81.3 (±21.2; 60–117)
E9	0:0	0.0	0.0	0	0:0	0.0	0.0	-	-	-	-
E47	2:1	66.7	33.3	1:0.5	1:1	50.0	50.0	1:1	209.0 (NA; 209)	180.0 (NA; 180)	83.0 (NA; 83)
E54	2:0	100.0	0.0	2:0	2:0	100.0	0.0	2:0	191.5 (±2.1; 193)	-	-
E59	0:0	0.0	0.0	0	0:0	0.0	0.0	0:0	-	-	-
E97	0:0	0.0	0.0	0	0:0	0.0	0.0	0:0	-	-	-
E (total)	15:7	-	-	-	7:8	-	-	-	202.3 (±11.3; 220)	186.8 (±8.8; 199)	81.6 (±19.3; 60–117)
E (mean)	2.5:1.2	68.2	31.8	1:0.5	1.2:1.3	46.7	53.3	1:1.1	-	-	-
F1	0:0	0.0	0.0	0	0:0	0.0	0.0	0:0	-	-	-
F15	3:3	50.0	50.0	1:1	2:1	66.7	33.3	2:1	212.0 (±4.2; 215)	171.0 (NA; 171)	154.3 (±16.1; 136–166)
F22	3:5	37.5	62.5	1:1.7	1:2	33.3	66.7	1:2	205.0 (NA; 205)	185.5 (±7.8; 191)	94.4 (±28.6; 76–145)
F36	4:0	100.0	0.0	4:0	2:2	50.0	50.0	1:1	203.0 (±7.1; 208)	204.5 (±16.3; 216)	-
F64	1:0	100.0	0.0	1:0	0:1	0.0	100.0	0:1	-	186 (NA; 186)	-
F78	0:0	0.0	0.0	0	0:0	0.0	0.0	0:0	-	-	-
F (total)	11:8	-	-	-	5:6	-	-	-	207.0 (±6.2; 215)	189.5 (±15.2; 216)	116.9 (±38.8; 76–166)
F (mean)	1.8:1.3	57.9	42.1	1:0.7	0.8:1	45.5	54.5	1:1.1	-	-	-
G7	0:0	0.0	0.0	0	0:0	0.0	0.0	0:0	-	-	-
G11	0:0	0.0	0.0	0	0:0	0.0	0.0	0:0	-	-	-
G15	3:0	100.0	0.0	3:0	0:3	0.0	100.0	0:3	-	202.0 (±3; 205)	-
G20	0:0	0.0	0.0	0	0:0	0.0	0.0	0:0	-	-	-
G33	0:0	0.0	0.0	0	0:0	0.0	0.0	0:0	-	-	-
G61	0:0	0.0	0.0	0	0:0	0.0	0.0	0:0	-	-	-
G (total)	3:0	-	-	-	0:3	-	-	-	-	202.0 (±3; 205)	-
G (mean)	0.5:0	100.0	0.0	3:0	0.0:0.5	0.0	100.0	0:3	-	-	-

Site code	Unique adults: juveniles	% adult	% juvenile	Adult: juvenile ratio	Unique male: female	% male	% female	M:F ratio	Male CL mean (SD; max)	Female CL mean (SD; max)	Juvenile CL mean (SD; min–max)
H_W1	15:2	88.2	11.8	1:0.1	7:8	46.7	53.3	1:1.1	205.1 (±10.0; 224)	190.1 (±11.8; 204)	137.3 (±42.0; 108–167)
H_W2	6:7	46.2	53.8	1:1.2	3:3	50.0	50.0	1:1	205.0 (±6.2; 212)	183.3 (±8.5; 192)	98.3 (±23.2; 59–126)
H_W3	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
H_E1	8:1	88.9	11.1	1:0.1	4:4	50.0	50.0	1:1	211.3 (±8.4; 221)	193.3 (±2.1; 196)	118.0 (NA; 118)
H_E2	0:0	0.0	0.0	0:0	0:0	0.0	0.0	0:0	-	-	-
H_E3	11:3	78.6	21.4	1:0.3	4:7	36.4	63.6	1:1.8	213.5 (±13.6; 229)	193.4 (±13.0; 220)	135.7 (±35.6; 97–167)
H (total)	40:13	-	-	-	18:22	-	-	-	208.3 (±10.0; 229)	190.8 (±10.7; 220)	114.4 (±30.4; 59–167)
H (mean)	6.7:2.2	75.5	24.5	1:0.3	3.0:3.7	45.0	55.0	1:1.2	-	-	-
Statewide (total)	184:66	-	-	-	77:107	-	-	-	208.0 (±12.0; 231)	195.0 (±11.4; 221)	112.0 (±32.9; 50–169)
Statewide (mean)	3.7:1.3	73.6	26.4	1:0.4	1.5:2.1	41.8	58.2	1:1.4	-	-	-