Official journal website:
amphibian-reptile-conservation.org

Amphibian & Reptile Conservation
15(2) [General Section]: 50–58 (e283).

Effect of anthropogenic habitat disturbance on the nesting ecology of the Wood Turtle (*Glyptemys insculpta*)

[1,2,*]Alexandra Vlk, [1]Elizabeth Bastiaans, [1]Daniel Stich, and [1]Donna Vogler

[1]*Department of Biology, State University of New York-College at Oneonta, 108 Ravine Parkway, Oneonta, New York, 13820 USA* [2]*Department of Biology, Randolph-Macon College, 114 College Avenue, Ashland, Virginia, 23005 USA*

***Abstract.*—In species that lack parental care beyond nesting, the fitness of the mother depends on the selection of a high-quality nest site. Unfortunately, given the importance of nest site selection, anthropogenic habitat degradation continues to decrease the availability of high-quality nest sites. This study focuses on nest-site selection by a population of Endangered Wood Turtles (*Glyptemys insculpta*) in a disturbed site with a high amount of human activity and invasive plant species. Logistic regression was used to examine nest-site microhabitat characteristics such as soil composition, moisture, temperature, slope, vegetation type and cover, canopy cover, and distances to water and vegetation. Wood Turtle nest site microhabitat characteristics were also characterized in a protected site and compared to those of the disturbed site using a series of *t*-tests and χ^2 tests. Soil composition and a slight slope were the most important factors for Wood Turtle nest-site selection at the disturbed site. Turtles at the disturbed site preferred a high amount of sand and small gravel, with little or no larger gravel or clay. The disturbed site had a higher maximum temperature overall, with an average of 35 °C versus 28 °C at the protected site. The turtles at both sites nested in sandy habitat, while the nests at the protected site had higher moisture content than those at the protected site and lacked gravel. Since is it common for Wood Turtles to use anthropogenic habitat, identifying, protecting, and managing nesting sites are essential to Wood Turtle conservation efforts. To enhance the overall nesting success of these turtles in disturbed areas, artificial nest sites could be judiciously placed and used by the turtles. Artificial nest sites could be managed to improve the nesting success of this Endangered turtle species and, also, potentially reduce adult loss by modifying the upland movements of adult females during the nesting season.**

Keywords. Connecticut, Emydidae, fragmentation, habitat management, human disturbance, New York, USA

Citation: Vlk A, Bastiaans E, Stich D, Vogler D. 2021. Effect of anthropogenic habitat disturbance on the nesting ecology of the Wood Turtle (*Glyptemys insculpta*). *Amphibian & Reptile Conservation* 15(2) [General Section]: 50–58 (e283).

Accepted: 22 September 2020; **Published:** 24 August 2021

Introduction

Investment in parental care varies across taxa, with some animals watching over and defending their young for many years, while other animals have minimal interactions with their offspring after birth (Gross 2005). Clutton-Brock (1991) defines parental care as any type of parental investment in the offspring after eggs have been deposited or young have been born. For species that do not provide direct parental care to their offspring, strategies to increase the survival of the hatchlings may include allocating energy to eggs in the form of lipid reserves (Nagle et al. 2003; Kamel and Mrosovsky 2005) or selecting a high-quality nest environment (Kolbe and Janzen 2002). Habitat characteristics associated with nest sites, such as temperature (Weisrock and Janzen 1999), can have direct effects on offspring survival and phenotypes (Kolbe and Janzen 2002). Because turtles are long-lived animals which require many years to reach sexual maturity and have high egg and hatchling mortality with no parental care beyond nesting, nest site selection may be important for population persistence since the nest site may directly influence nest success (Lovich et al. 1990; Congdon et al. 1993; Horne et al. 2003). Unfortunately, given the importance of nest site selection by turtles, anthropogenic habitat degradation continues to decrease the availability of high-quality nest sites, which could cause turtles to delay nesting and/or nest in an unfavorable habitat (Walde et al. 2007). Due to habit losses caused by anthropogenic disturbances, reptiles are declining globally (Gibbons et al. 2000). Turtles are particularly threatened by the increasing

Correspondence. **vlkalexandra@gmail.com* (AV), *Elizabeth.Bastiaans@oneonta.edu* (EB), *Daniel.Stich@oneonta.edu* (DS), *Donna.Vogler@oneonta.edu* (DV)

pressures of anthropogenic disturbances (Williams 1999). The International Union for Conservation of Nature (IUCN) lists 148 of the 356 turtle species as either Vulnerable, Endangered, or Critically Endangered (Turtle Conservation Coalition 2018).

This study compares Wood Turtle (*Glyptemys insculpta*) nest site selection between an anthropogenically altered nesting site and a protected nesting site. The Wood Turtle is currently under review for protection under the Endangered Species Act (U.S. Fish and Wildlife Service, 2019) and listed as Endangered by the IUCN (IUCN 2016). The Wood Turtle is particularly vulnerable to habitat loss and fragmentation because it is a long-lived animal that displays low vagility and high site fidelity (Garber and Burger 1995). Since the Wood Turtle prefers open canopy forested areas, Kaufmann (1992) speculated that this species might benefit from the increased habitat openings created by humans. However, anthropogenically generated habitat openings are often the sites of other human impacts, which may reduce the survival of Wood Turtle eggs laid there (Saumure 2004).

Wood Turtles require a variety of habitats (Arvisais et al. 2004). Studies in Pennsylvania (Kaufmann 1992) and Ontario (Foscarini 1994) showed that Wood Turtles selected their habitat nonrandomly relative to availability (Arvisais et al. 2004). They are known as an "edge species" according to Kaufmann (1992), with a strong selection of riparian habitat within 300 m of streams (Arvisais et al. 2004). Wood Turtles often use forested areas with openings in the canopy to allow for foraging on herbaceous undergrowth and/or slugs (Lee 1999). During the reproductive season, turtles require additional areas of habitat. For example, gravid females travel hundreds of meters seeking nest sites, hatchlings migrate from nests to water, and males may travel in search of a mate (Bol 2007).

Depending on latitude, the Wood Turtle nesting season occurs between late May and mid-July (Arvisais 2002). Females construct nests on sandy beaches, railway embankments, agricultural fields, and gravel quarries; selecting for well-drained, sloped, and exposed areas close to a water source (Harding and Bloomer 1979; Foscarini 1994; Walde et al. 2007). The turtles spend a few hours to several days exploring suitable nest sites (A. Vlk, pers. obs.). The time investment in finding a nest site indicates that females are selective about where they lay their eggs, likely to increase hatchling success (Hughes et al. 2009). Unlike some other turtles, Wood Turtles have genetic sex determination rather than temperature-dependent sex determination (Ewert and Nelson 1991). This suggests that females select nesting locations based on maximizing hatchling survival rather than balancing the sex ratio of the clutch (Hughes et al. 2009). Therefore, identifying, protecting, and managing nesting sites are essential to Wood Turtle populations because female Wood Turtles are highly sensitive to disturbance prior to the initiation of egg laying (Walde et al. 2007). Furthermore, our lack of knowledge about the nesting ecology and reproductive behavior of this species hinders conservation efforts (Bury 2006; McCallum and McCallum 2006). The goal of this study was to locate and characterize Wood Turtle nesting habitat at two Wood Turtle occupied sites, one disturbed and one protected, to increase our knowledge of the usefulness of anthropogenic sites and better inform the management of these areas.

Materials and Methods

Study sites. The disturbed study site, located in the Susquehanna watershed, was a park used for recreation activities such as hiking, soccer, softball, picnics, and angling. The forest consisted of mixed deciduous Oak-Maple-Birch-Sycamore (*Quercus, Acer, Betula,* and *Platanus*). The floodplains were mainly composed of Spotted Knapweed (*Centaurea*), Common Lady's Thumbprint (*Persicaria*), Mugwort (*Artemesia*), and Goldenrod (*Solidago*). A highly invasive plant species native to Asia, Japanese Knotweed (*Fallopia japonica*), dominated the floodplains and forests forming dense stands that excluded most other vascular plants and shrubs. Litter invaded the Wood Turtle habitat and vegetation in the park was periodically mowed (A. Vlk, pers. obs.). On the other side of the creek, across from the park, was a field that was mowed periodically for hay and included a building supply store which provides masonry products to the public. Daily uses of the supply store include the operation of boom trucks, tractor trailers, box trucks, and concrete mixers.

The protected site was located in the Great Swamp Wildlife Management Area (WMA), Putnam County, Connecticut, bordering New York. This area is managed by the New York State Department of Environmental Conservation, with an emphasis on habitat preservation and restoration for the benefit of native species (NYS DEC 2021). This WMA covers 444 acres of the Great Swamp, which encompasses natural Wood Turtle nesting habitat that is monitored by the staff, and free from anthropogenic disturbances.

The exact study location of each site has been omitted from this article to prevent illegal collection of the Wood Turtles, but is available upon request at the authors' discretion.

Data collection. At both the disturbed and protected sites, Wood Turtles were captured along the shoreline in the spring and summer of 2017 and 2018. The individual adult and juvenile turtles captured were weighed, sexed based on plastron concavity, and aged by counting growth annuli on dorsal scutes (Harding and Bloomer 1979). Measurements (± 0.01 mm) of the carapace and plastron lengths were taken using calipers. Turtles smaller than 180 mm were considered juveniles (Walde 1998). To establish a unique identification for each turtle,

Table 1. List and descriptions of covariates that were used in the first subset of Wood Turtle nesting habitat selection models.

Covariate	Covariate descriptions
Soil composition	large gravel (> 5 cm), small gravel (< 2 mm), sand, clay
Temperature (°C)	Average, maximum

Table 2. List and descriptions of landscape nest covariates that were used in second subset of Wood Turtle nesting habitat selection models.

Covariate	Covariate descriptions
Vegetation	bare, herbaceous, woody
Canopy	open, partial, full
Vegetation nest cover	none, partial, full

notches were filed using a Dremel tool along the edge of the scutes with notch codes provided by New York Department of Environmental Conservation (DEC) and Connecticut Department of Energy and Environmental Protection (DEEP). Each turtle weighing at least 400 g was fitted with a radio transmitter (Advanced Telemetry Systems, Isanti, Minnesota, USA), which was glued with epoxy gel to the rear marginal scutes of the carapace. The transmitter weighed approximately 16 g and never exceeded 5% of body mass. All procedures were reviewed and approved by the SUNY Oneonta Institutional Animal Care and Use Committee (IACUC #2018-25), DEC (DEC Scientific permit #2136), and DEEP (DEEP Scientific permit # 1718008).

In May–August, the spring and summer active season of the turtles, 14 turtles at the disturbed site were located by radiotelemetry every other day during the pilot season in 2017. In 2018, 17 Wood Turtles were tracked. Turtles were located between 0800 and 2000 h (most of the location events were during 0800–1400 h). Beginning on 26 May 2018, excursions were made between 1700 and 2030 h to observe any nesting female behavior (Ernst et al. 1994; Walde et al. 2007). The first signs of nesting occurred on 28 May 2018 at 2000 h. The turtle was sniffing and throwing dirt on her carapace, which indicates nesting behavior (Harding and Bloomer 1979). Because Wood Turtles are known to start nest activity at approximately 1700 h or later (Walde et al. 2007), radio tracking began every day from 1200–1500 h to locate turtle nesting grounds and avoid disturbing nesting females. In the evening, once nesting females were located, observations were made from concealed locations to prevent the females from abandoning their nests. If a Wood Turtle stayed in the nesting ground past 2030 h, observations continued until the turtle retreated to the stream (Walde et al. 2007).

Eighteen Wood Turtles were tracked at the protected site every other day during the nesting season by one of the Great Swamp biologists. Known nesting sites were checked daily during 1900–2100 h beginning 26 May, while 30 May marked the beginning of the nesting season at this site. Once the nesting season was initiated, the same protocols were followed for observations at the disturbed and protected sites.

At both sites, after a female was done nesting, the turtle eggs were excavated, and microhabitat variables were measured (Tables 1 and 2). The eggs at the disturbed site were placed in vermiculite in an incubator at 28 °C, and were then used in another study (Janzen and Morjan 2002), while the eggs at the protected nest site were left in the ground with an exclosure placed over the nest. Many of the nests at the unprotected site were found by digging in suitable Wood Turtle nesting habitat, which included floodplains with sand and/or small gravel present with little vegetation or canopy cover. Soil samples (445 g) were collected at approximately 10 cm depths from all nests to measure grain size and moisture content (Hughes et al. 2009). A sieve was used to separate 400 g of soil into three different categories of large gravel (> 5 cm), small gravel (< 2 mm), and sand (Table 1). Clay was separated from the sand by adding water to the sample, mixing the contents, and leaving it sit for two days to allow separation. The amount of soil in each category was expressed as a percentage. To determine moisture content, 45 g of the sand separated out from the soil sample was placed in a small tin, which was placed in an Isotemp Programmable Muffle Furnace 650-750 Series (Fisher Scientific, Dubque, Iowa, USA) for two weeks at 110 °C (Hughes et al. 2009). After two weeks, the soil samples were weighed again to determine how much moisture weight was lost.

When all observed nesting activity ceased on 27 June, waterproof iButton (iButtonLink, LLC, Whitewater, Wisconsin, USA) temperature dataloggers were placed 15 cm deep at the site of each nest, which is the approximate nest depth of Wood Turtles (Foscarini 1994; Walde 1998; Compton 1999; this study). To prevent disturbance of the eggs at the protected site, temperature loggers were placed approximately 10 cm from the clutch and 15 cm deep. Temperatures were recorded at 4-hour intervals during the incubation period until 20 August when all hatchlings had hatched. The dataloggers were placed in 15-inch PCV pipes and waterproofed by cementing a coupler to each end of the PCV pipe.

Other microhabitat variables recorded in a radius of 1 m (around the nest) included: slope, canopy cover, nest cover, vegetation type, and distances to nearest vegetation and aquatic habitat (Table 2). At the disturbed site, habitat was measured both at the nest location and at a nearby randomly selected unused nest habitat with availability at the same place and time, based on a random compass bearing and a random distance selected uniformly from ~0.3–17 m (Compton 2002; Dragon 2014).

Data Analysis

Disturbed site. To estimate the probability of Wood Turtles using specific nesting microhabitat in the

Table 3. Candidate model selection statistics for Wood Turtle nesting choice first subset. K is the number of parameters in each of the models. AICc is the AIC score corrected for sample size. ΔAIC is the difference in AICc between the best model and each of the other models. AIC wt is the probability that a given model is the best model in the candidate set.

Model	K	AICc	ΔAIC	AIC wt
Soil PC 1 + soil PC 2	3	25.23	0.00	0.54
Soil PC 2	2	26.68	1.44	0.26
Soil PC 1	2	29.26	4.03	0.07
Average	2	29.99	4.76	0.05
Maximum temperature	2	30.61	5.38	0.04
Moisture	2	31.89	6.66	0.02
Maximum temperature + average	3	32.77	7.53	0.01
Maximum temperature + average + soil PC 1 + soil PC 2 + moisture	6	34.32	9.09	0.01

disturbed site, logistic regression in the lme4 (Bates et al. 2015) package in R (R Core Team 2013) was used based on a binary response (1 = used, 0 = random). A set of models were fit using maximum likelihood estimation. A total of 16 models were constructed using *a priori* combinations of explanatory variables. The explanatory variables were divided into two subsets used to make models: (1) nest characteristics, including soil composition, moisture content, and temperature (Table 3); and (2) landscape features, including slope, canopy cover, amount of nest cover, type of vegetation and distances from the nearest vegetation and aquatic habitat (Table 4).

Due to the small sample size of nesting turtles and the soil variables being intercorrelated, a Principal Component Analysis (PCA) was used on the soil variables to reduce the dimensionality. The four soil variables (large gravel, small gravel, sand, and clay) were grouped into two PC axes that explained 81% of the variation combined in soil composition (Table 5). The logistic regression model for the nest characteristics subset was constructed using 10 paired nest locations due to the loss of two temperature loggers in a flash flood. The landscape model consisted of 12 paired nest locations. Akaike's Information Criterion (AIC) was used to rank each competing model using the AICcmodavg package (Mazerolle 2017). The model with the lowest AIC score was considered the best supported (Burnham and Anderson 2002).

Comparisons of the disturbed and protected sites. To determine if nest site microhabitat characteristics differed between the disturbed and protected sites, a series of *t*-tests and χ^2 tests were conducted in jamovi (Jamovi Project 2018). The statistical tests were conducted only using actual turtle nests. Multiple *t*-tests were used to identify differences in the variables: "temperature," "slope," "distance vegetation," "distance water," "soil composition," and "moisture" between the disturbed and protected sites. The variables "distance vegetation" and "distance water" were log-transformed due to the violation of normality and equal variances. Since moisture and soil microhabitat variables were correlated, a second PCA analysis comparison was performed between the two sites that grouped the four soil explanatory variables and moisture together on habitat that was used for nesting (Table 6). The variables with an eigenvalue above one were then used in a *t*-test to compare soil compositions of the two nest sites. Chi-square tests were performed on the categorical variables "vegetation," "canopy," and "nest cover" to determine whether the frequency of various categories differed between disturbed and protected sites. Since multiple statistical tests were performed, Bonferroni correction was used to adjust the *p*-value to 0.003 to minimize type I errors.

Results

Twelve nests were observed at the disturbed nest site and seven at the protected nest site. The number of eggs in each nest ranged from one to 16 (8.3 ± 4.84) at the disturbed site and eight to nine at the protected site (7.67 ± 0.70). Most

Table 4. Candidate model selection statistics for Wood Turtle nesting choice second subset. Variable definitions are as indicated in Table 3.

Model	K	AICc	ΔAIC	AIC wt
Slope degree	2	32.21	0.00	0.48
Slope degree + vegetation	4	33.25	1.04	0.29
Vegetation	3	34.81	2.60	0.13
Nest cover	2	37.59	5.38	0.03
Distance vegetation	2	37.64	5.43	0.03
Distance water	2	37.83	5.62	0.03
Canopy	4	40.40	8.19	0.01
Slope degree + vegetation + distance vegetation + canopy + nest cover + distance water	10	53.63	21.43	0.00

Table 5. Loading matrix from a Principal Component Analysis (PCA) of four microhabitat variables measured at N = 10 disturbed Wood Turtle nest sites and N = 10 random paired locations.

Covariate	PC 1	PC 2
Large gravel	-0.98	0.12
Small gravel	0.42	0.79
Sand	0.85	-0.50
Clay	0.57	0.37

Table 6. Loading matrix from a Principal Component Analysis (PCA) of five microhabitat variables measured at N = 10 disturbed Wood Turtle nest sites and N = 7 protected Wood Turtle nest sites.

Covariate	PC 1	PC 2
Large gravel	-0.94	0.0019
Small gravel	-0.78	0.34
Sand	0.97	-0.21
Clay	0.45	-0.76
Moisture	0.70	0.58

female turtles started nest construction at approximately 1930 h, corresponding to sunset, and completed their nests 2–3 hours later. Warm humid rainy days stimulated nesting activity from multiple turtles at the same time (A. Vlk, pers. obs.).

Disturbed site. In 2018, 12 Wood Turtle nest sites were located at the disturbed site. In 2017 and 2018, Wood Turtle nesting began on 28 May and ended approximately 19 June. For the nest characteristics subset, "soil PC 2" was the most important predictor of nesting habitat selection based on its inclusion in both top models. The best model indicated significant effects of both "soil PC 1" (GLM: $\chi^2_1 = 4.23$, $P = 0.03$) and "soil PC 2" (GLM: $\chi^2_1 = 6.82$, $P = 0.009$) (Table 3). This model suggested that the likelihood of Wood Turtles using habitat increased when there was a high amount of small gravel and sand along with lower amounts of large gravel and clay. Turtles were more likely to use habitat with high values of "soil PC 1," which corresponded to minimal amounts of large gravel and a higher amount of sand in addition to small gravel and clay. The second-best model contained the explanatory variable "soil PC 2." This model indicated that there was a higher probability of use when there was a high amount of small gravel and no clay present.

The presence of a slope, which ranged from 7–50°, was the most significant predictor variable of nesting habitat selection for the landscape subset of models (GLM: $\chi^2_1 = 5.63$, $P = 0.01$) (Table 4). The use of nesting habitat was reduced when zero slope was present. The second-best model contained the explanatory variables "slope" and "vegetation." Slope in combination with herbaceous vegetation resulted in a higher likelihood of Wood Turtles selecting for that particular habitat. The turtles were least likely to select nesting habitat with no vegetation or slope present.

Comparisons of Disturbed and Protected Sites

Soil composition and moisture. In the overall comparison between selected nest habitat at the disturbed and protected nest sites, soil composition and moisture principal component variables were significantly different ($t = 3.72$, df = 15, $P = 0.002$). The principal component variable revealed that at the protected site, turtles were more likely to select sandy habitat with a higher amount of moisture and clay and no gravel compared to the disturbed site. At the disturbed site, the nests had more small gravel and less moisture and clay.

Temperature. The maximum temperature was also significantly different between the disturbed and protected field sites ($t = 7.04$, df = 12, $P = 0.001$). Although the disturbed site had lower nest temperatures during the morning hours, there was a higher maximum temperature with an average of 35 °C compared to the protected site with an average maximum temperature of 28 °C. The minimum average temperatures at the disturbed and protected sites were 15 °C and 19 °C, respectively ($t = -3.42$, df = 12, $P = 0.005$), which did not reach the threshold for a statistically significant difference after Bonferroni correction. The average temperatures were 24 °C at the disturbed site and 22 °C at the protected site ($t = 2.70$, df = 12, $P = 0.019$).

Landscape features. Since the amounts of canopy and vegetation nest cover were low at both the disturbed and protected sites, there was no significant difference in canopy cover ($\chi^2 = 0.62$, df = 1, $P = 0.43$) or vegetation nest cover ($\chi^2 = 0.31$, df = 1, $P = 0.58$). The turtles at both sites selected for bare nesting ground with no vegetation present ($\chi^2 = 7.28$, df = 3, $P = 0.06$). The average slopes for the nests at the disturbed and protected sites were 13.40° and 14.17°, respectively ($t = -0.16$, df = 17, $P = 0.87$). Distance of vegetation from each nest site averaged 15.24 cm for the disturbed site and 22.86 cm for the protected site ($t = -0.74$, df = 14, $P = 0.47$). The turtles at both the disturbed and protected sites nested on the floodplains or close to a water source ($t = -0.11$, df = 17, $P = 0.91$). Although the maximum distance to the nearest water from nests was 69 m at the protected site and 24 m at the disturbed site, the average at the protected site, including two outlier nests, was 20 m (± 11.16) compared to 4 m (± 1.4) at the disturbed site.

Discussion

Wood Turtles are known to select nesting habitat that is open, slightly sloped, and well-drained (Walde et al. 2007; Hughes et al. 2009), which the results presented here supported. Nest site selection at the disturbed site was nonrandom based on microhabitat characteristics.

Both disturbed and protected nest sites consisted of open canopy, sandy patches, and little or no vegetation.

Soil composition. The soil composition appeared to be one of the most important factors when selecting nest habitat at the disturbed site. The turtles preferred to nest in soil that was primarily composed of sand, with some small gravel and clay but limited large gravel. This pattern is most likely related to thermoregulation and drainage because sandy soils warm up more quickly in the sun and do not hold water as well as soils rich in organic substrates (Brady and Weil 2002).

At both field sites, females selected nesting areas based on the same microhabitat characteristics. However, the selected nest habitat differed in soil composition between the disturbed and protected sites. Due to the absence of random points at the protected field site, it is not clear whether this difference represents differences in nesting preferences between the two turtle populations or differences in soil composition between the two sites. While turtles in both sites nested in sandy habitats, the female turtles at the protected nest site selected for higher moisture content with no gravel.

Temperature. Although temperature was not a significant predictor of nest site selection in the disturbed habitat, other literature has shown its importance in nest selection in various turtle species (Compton 1999; Hewavisenthi and Parmenter 2002; Hughes et al. 2009). There was a significant difference in the maximum temperature of nest sites between the two sites. Overall, the disturbed site had warmer nest temperatures. Compton (1999) suggested that in the northern portion of the Wood Turtle's range, finding nest sites that encourage successful hatchling incubation is critical. To increase development rate, the Wood Turtles in the northern range select for warm and variable nest temperatures rather than a narrow temperature range (Compton 1999; Hughes et al. 2009), which was seen in the disturbed nest site in this study. The disturbed site had lower nest temperatures during the morning hours as well, causing high temperature variation, which may promote shorter incubation periods (Hughes 2009). Although northern Wood Turtle populations are known to select for warm nest temperature, a maximum temperature of 35℃ at the disturbed site may potentially be harmful to hatchlings by decreasing their survival rate. In some cases, embryonic mortality of nests may increase with high incubation temperatures (Matsuzawa et al. 2002; Hawkes et al. 2007; Maulany et al. 2012). For example, a study found that by incubating freshwater Mary River Turtle (*Elusor macrurus*) eggs at 32 °C, hatchling success was lower (Micheli-Campbell et al. 2011); and the same was true for Chinese Three-keeled Pond Turtle (*Chinemys reevesii*) eggs exposed to temperatures above 32 °C (Du et al. 2007).

Landscape features. Wood turtles at both sites selected for slightly sloped habitat. Many turtle species use slope as an environmental nesting cue (Schwarzkopf and Brooks 1987; Horrocks and Scott 1991). Slope may reflect a change in elevation making it an important cue (Horrocks and Scott 1991). A change to a greater slope could indicate that the turtle has reached an elevation that increases the probability of hatching success for her nest (Wood and Bjorndal 2000).

At the disturbed site, 42% of the turtles selected nest sites with no vegetation, while 58% chose nests near small herbaceous plants. The most common plants the turtles nested next to were Spotted Knapweed (*Centaurea stoebe*) and Common Lady's Thumbprint (*Persicaria pensylvanica*). Nesting near herbaceous vegetation may be advantageous if it provides a concealing structure for females without shading the nest (Harding and Bloomer 1979; Hughes et al. 2009). The herbaceous root system may also help prevent slope erosion caused by rainfall (Buhlmann and Osborn 2011). Alternatively, vegetation can have a negative impact on the nests due to root invasion and reduced sunlight exposure, leading to egg mortality (Congdon et al. 2000; Behler and Castellano 2005). Root invasion and shading were common problems at the disturbed site, especially as the vegetation grew.

Anthropogenic nest sites. It is common for Wood Turtles to use anthropogenic nest sites, such as agricultural fields, yards, clear-cuts, railway embankments, and roadsides (Congdon et al. 2000; Saumure et al. 2007). Although human-impacted nesting sites may provide appropriate canopy openings, this disturbed habitat can negatively affect the turtles (Kolbe and Janzen 2002). Nesting in an anthropogenic site increases the probabilities of nests being walked on, predation, collecting, mortality associated with crossing roads, shading and/or root invasion by invasive plant species (Garber and Burger 1995). In addition, anthropogenic disturbances could cause Wood Turtles to delay nesting and/or to nest in unfavorable habitat since this species is extremely sensitive to disturbance prior to egg laying (Walde et al. 2007). Turtle use of human impacted areas, however, indicates that conservation measures can be taken to mitigate such negative effects. Artificial nesting mounds could be built that enhance nesting success (Beaudry et al. 2010). If actively managed, these mounds could potentially reduce exposure to many of the common threats that nesting females face (Buhlmann and Osborn 2011).

Conclusions

Because Wood Turtles are long-lived organisms with delayed sexual maturity, populations may require a long time to recover; and so conservation biologists seeking to manage them face a pressing challenge in a world that is undergoing rapid changes (Garber and Burger 1995; Kolbe and Janzen 2002). Thus, efforts to understand what effects human impacts have on Wood Turtle nesting habitat and population dynamics is crucial. It is also important to recognize which factors contribute to suitable Wood Turtle nesting habitat for the persistence and conservation of this species (Kolbe and Janzen 2002). To help protect this Endangered turtle, our research provides data that identifies the microhabitat variables Wood Turtles are selecting for in a nest habitat. Future studies should include a "false nest" subset, i.e., nests constructed by the female but then abandoned. This might provide more evidence as to what habitat the female is actively selecting for and/or rejecting, which could improve our ability to protect or construct appropriate nesting habitat for this Endangered species.

Acknowledgments.—Alexander Robillard provided knowledge, comments, and guidance during this project. We thank Hannah Harby and Timothy Gochenour for their field contributions and photography. Previous drafts of this manuscript were reviewed by Donna Vogler, Sean Robinson, Jeffrey Heilveil, and Russell Burke. Funding for this work was supported by Hudson River Foundation (79063, 2017), Western New York Herpetological Society (80415, 2018), Riverbanks Society (79530, 2017), International Herpetological Symposium (79454, 2017), American Wildlife Conservation Fund (77108, 2017), and Rhode Island Zoological Society (80007, 2017). All procedures were reviewed and approved by the SUNY Oneonta Institutional Animal Care and Use Committee (IACUC) and DEC (DEC Scientific permit #2136 and IACUC #2018-25).

Literature Cited

Arvisais M, Bourgeois J-C, Lévesque E, Daigle C, Masse D, Jutras J. 2002. Home range and movements of a Wood Turtle (*Clemmys insculpta*) population at the northern limit of its range. *Canadian Journal of Zoology* 80(3): 402–408.

Arvisais M, Levesque E, Bourgeois J, Daigle C, Masse D, Jutras J. 2004. Habitat selection by the Wood Turtle (*Clemmys insculpta*) at the northern limit of its range. *Canadian Journal of Zoology* 82(3): 391–398.

Bates D, Maechler M, Bolker B, Walker S. 2015. Fitting linear mixed effects models using lme4. *Journal of Statistical Software* 67(1): 1–48.

Beaudry F, Demaynadier PG, Hunter Jr ML. 2010. Nesting movements and the use of anthropogenic nesting sites by Spotted Turtles (*Clemmys guttata*) and Blanding's Turtles (*Emydoidea blandingii*). *Herpetological Conservation and Biology* 5(1): 1–8.

Bol L. 2007. *Massachusetts Forestry Conservation Management Practices for Wood Turtles*. Natural Heritage and Endangered Species Program, No. 2007.1. Massachusetts Division of Fisheries and Wildlife, Westborough, Massachusetts, USA. 21 p.

Brady NC, Weil RR. 2002. *The Nature and Properties of Soils. 13th Edition*. Pearson Education Canada, Upper Saddle River, New Jersey, USA. 960 p.

Buhlmann KA, Osborn CP. 2011. Use of an artificial nesting mound by Wood Turtles (*Glyptemys insculpta*): a tool for turtle conservation. *Northeastern Naturalist* 18(3): 315–334.

Burnham KP, Anderson DR. 2002. *Model Selection and Multimodel Inference*. Springer-Verlag, New York, New York, USA. 488 p.

Bury RB. 2006. Natural history, field ecology, conservation biology, and wildlife management: time to connect the dots. *Herpetological Conservation and Biology* 1(1): 56–61.

Clutton-Brock TH. 1991. *The Evolution of Parental Care*. Princeton University Press, Princeton, New Jersey, USA. 352 p.

Compton BW. 1999. Ecology and conservation of the Wood Turtle (*Glyptemys insculpta*) in Maine. M.S. Thesis, Department of Wildlife Ecology, University of Maine, Orono, Maine, USA.

Compton BW, Rhymer JM, McCollough M. 2002. Habitat selection by Wood Turtles (*Clemmys insculpta*): an application of paired logistic regression. *Ecology* 83(3): 833–843.

Congdon JD, Dunham AE, Van Loben Sels RC. 1993. Delayed sexual maturity and demographics of Blanding's Turtles (*Emydoidea blandingii*): implications for conservation and management of long-lived organisms. *Conservation Biology* 7(4): 826–833.

Congdon JD, Nagle RD, Kinney OM, Osenioski M, Avery HW, Van Loben Sels RC, Tinkle DW. 2000. Nesting ecology and embryo mortality: implications for hatchling success and demography of Blanding's Turtles (*Emydoidea blandingii*). *Chelonian Conservation and Biology* 3(4): 569–579.

Dragon J. 2014. Habitat selection, movement, and survival of hatchling Wood Turtles (*Glyptemys insculpta*) in an atypical habitat. M.S. Thesis, Department of Environmental Science and Policy, George Mason University, Fairfax, Virginia. USA.

Du WG, Hu LJ, Lu JL, Zhu LJ. 2007. Effects of incubation temperature on embryonic development rate, sex ratio, and post-hatching growth in the Chinese Three-keeled Pond Turtle, *Chinemys reevesii*. *Aquaculture* 272(1): 747.

Ernst CH, Lovich JE, Barbour RW. 1994. *Turtles of the United States and Canada*. Smithsonian Institution Press, Washington, DC, USA. 578 p.

Ewert MA, Nelson CE. 1991. Sex determination in turtles: diverse patterns and some possible adaptive values. *Copeia* 1991(1): 50–69.

Foscarini DA. 1994. Demography of the Wood Turtle (*Clemmys insculpta*) and habitat selection in the Maitland River valley. M.S. Thesis, Department of

Integrative Biology, University of Guelph, Guelph, Ontario, Canada. 123 p.

Garber SD, Burger J. 1995. A 20-year study documenting the relationship between turtle decline and human recreation. *Ecological Applications* 5(4): 1,151–1,162.

Gibbons JW, Scott ED, Ryan TJ, Buhlmann KA, Tuberville TD, Metts BS, Greene JL, Mills T, Leiden Y, Poppy S, et al. 2000. The global decline of reptiles, déjà vu amphibians. *BioScience* 50(8): 653–666.

Gross MR. 2005. The evolution of parental care. *The Quarterly Review of Biology* 80(1): 37–46.

Harding JH, Bloomer TJ. 1979. The Wood Turtle, *Clemmys insculpta*: a natural history. *Bulletin of the New York Herpetological Society* 15(1): 9–26.

Hawkes L, Broderick A, Godfrey M, Godley B. 2007. Investigating the potential impacts of climate change on a marine turtle population. *Global Change Biology* 13: 1–10.

Hewavisenthi S, Parmenter CJ. 2002. Incubation environment and nest success of the Flatback Turtle (*Natator depressus*) from a natural nesting beach. *Copeia* 2002(2): 302–312.

Horne BD, Brauman RJ, Moore MJC, Siegel RA. 2003. Reproductive and nesting ecology of the Yellow-blotched Map Turtle, *Graptemys flavimaculata,* for conservation and management. *Copeia* 2003(4): 729–738.

Horrocks JA, Scott NM. 1991. Nest site location and nest success in the Hawksbill Turtle (*Eretmochelys imbricata*) in Barbados, West Indies. *Marine Ecology Progress Series* 69(1–2): 1–8.

Hughes GN, Greaves WF, Litzgus JD. 2009. Nest-site selection by Wood Turtles (*Glyptemys insculpta*) in a thermally limited environment. *Northeastern Naturalist* 16(3): 321–338.

IUCN. 2016. Wood Turtle, *Glyptemys insculpta*. The IUCN Red List of Threatened Species 2011: e.T4965A97416259.

Jamovi Project. 2018. Jamovi (Version 0.9.5.12). Available: https://www.jamovi.org [Accessed: 31 January 2020].

Janzen FJ, Morjan CL. 2002. Egg size, incubation temperature, and posthatching growth in Painted Turtles (*Chrysemys picta*). *Journal of Herpetology* 36(2): 308–311.

Kamel SJ, Mrosovsky N. 2005. Repeatability of nesting preferences in the Hawksbill Sea Turtle, *Erotmochelys imbricata*, and their fitness consequences. *Animal Behaviour* 70(4): 819–828.

Kaufmann JH. 1992. Habitat use by Wood Turtles in central Pennsylvania. *Journal of Herpetology* 26(3): 315–321.

Kolbe JJ, Janzen FJ. 2002. Impact of nest-site selection on nest success and nest temperature in natural and disturbed habitats. *Ecology* 83(1): 269–281.

Lee Y. 1999. *Special Animal Abstract for Glyptemys insculpta (Wood Turtle)*. Michigan Natural Features Inventory, Lansing, Michigan, USA. 4 p.

Lovich JE, Ernst CH, McBreen JF. 1990. Growth, maturity, and sexual dimorphism in the Wood Turtle, *Clemmys insculpta*. *Canadian Journal Zoology* 68(4): 672–677.

Matsuzawa Y, Sato K, Sakamoto W, Bjorndal K. 2002. Seasonal fluctuations in sand temperature: effects on the incubation period and mortality of Loggerhead Sea Turtle (*Caretta caretta*) pre-emergent hatchlings in Minabe, Japan. *Marine Biology* 140(3): 639−646.

Maulany R, Booth D, Baxter G. 2012. Emergence success and sex ratio of natural and relocated nests of Olive Ridley Turtles from Alas Purwo National Park, East Java, Indonesia. *Copeia* 2012(4): 738−747.

Mazerolle MJ. 2017. AICcmodavg: model selection and multimodel inference based on (Q)AIC. R package version 2.1-1. Available: https://cran.rproject.org/package=AICcmodavg [Accessed: 31 January 2020].

McCallum ML, McCallum JL. 2006. Publication trends of natural history and field studies in herpetology. *Herpetological Conservation and Biology* 1(1): 62–67.

Micheli-Campbell MA, Campbell H, Cramp RL, Booth D, Franklin C. 2011. Staying cool, keeping strong: incubation temperature affects performance in a freshwater turtle. *Journal of Zoology* 285(4): 266–273.

Nagle RD, Plummer MV, Congdon JD, Fischer RU. 2003. Parental investment, embryo growth, and hatchling lipid reserves in Softshell Turtles (*Apalone mutica*) from Arkansas. *Herpetologica* 59(2): 145–154.

NYS DEC. 2021. Great Swamp Wildlife Management Area - New York State Department of Environmental Conservation. Available: https://www.dec.ny.gov/outdoor/68929.html [Accessed: 23 August 2021].

R Core Team. 2013. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Boston, Massachusetts, USA. Available: http://www.R-project.org/ [Accessed: 31 January 2020].

Saumure RA. 2004. The spatial ecology and conservation of the North American Wood Turtle (*Glyptemys insculpta*) in a fragmented agri-forest landscape. Ph.D. Dissertation, Department of Natural Sciences, McGill University, Montreal, Quebec, Canada.

Saumure RA, Herman TB, Titman RD. 2007. Effects of haying and agricultural practices on a declining species: the North American Wood Turtle, *Glyptemys insculpta*. *Biological Conservation* 135(4): 565–575.

Schwarzkopf L, Brooks RJ. 1987. Nest site selection and offspring sex ratio in Painted Turtles (*Chrysemys picta*). *Copeia* 1987(1): 53–61.

Turtle Conservation Coalition. 2018. Turtles in trouble: the world's 25+ most endangered tortoises and freshwater turtles. Available: www.iucn-tfsg.org/trouble/ and www.turtleconservancy.org/trouble/

[Accessed: 31 May 2019].

U.S. Fish and Wildlife Service. 2019. Environmental conservation online system species profile for Wood Turtle (*Glyptemys insculpta*). Available: https://ecos.fws.gov/ecp/species/6997 [Accessed: 7 June 2019].

Walde DA. 1998. Ecology of the Wood Turtle*, Clemmys insculpta*. M.S. Thesis, Department of Natural Resources and Science, McGill University, Montreal, Quebec, Canada.

Walde AD, Bider JR, Masse D, Saumure RA, Titman RD. 2007. Nesting ecology and hatching success of the Wood Turtles (*Glyptemys insculpta*), in Quebec. *Herpetological Conservation and Biology* 2(1): 49–60.

Weisrock DW, Janzen FJ. 1999. Thermal and fitness related consequences of nest location in Painted Turtles (*Chrysemys picta*). *Functional Ecology* 13(1): 94–101.

Williams T. 1999. The terrible turtle trade: the pet trade is decimating turtle populations and spreading disease. *Audubon* 101: 44–51.

Wood DW, Bjorndal KA. 2000. Relation of temperature, moisture, salinity, and slope to nest selection in Loggerhead Sea Turtles. *Copeia* 2000(1): 119–128.

Alexandra Vlk obtained her M.S. in Biology from State University of New York-College at Oneonta. She has a B.S. in Biology from James Madison University (Harrisonburg, Virginia, USA), with a concentration in Ecology and Environmental Studies. Her research interests lie in reproductive behavior and how anthropogenic disturbances are affecting wildlife. She now teaches molecular biology and the scientific method at Randolph-Macon College (Ashland, Virginia, USA).

Elizabeth Bastiaans is a professor at State University of New York-College at Oneonta. She completed her B.A. at the University of Chicago (Chicago, Illinois, USA), her Ph.D. at the University of California, Santa Cruz, and a postdoctoral fellowship at the University of Minnesota, Twin Cities (Minneapolis-St. Paul, Minnesota, USA). Elizabeth's previous research focused on sexual signal evolution in Mexican montane lizards and life history evolution in tropical crickets. In this work, she used methods such as capture-mark-recapture studies, mate choice trials, aggression trials, maintenance of lizards in captivity, spatial analyses, DNA sequencing, and molecular phylogenetics. As a postdoctoral fellow at the University of Minnesota, Elizabeth studied the reproductive behavior, life history, and immune physiology of Pacific Field Crickets (*Teleogryllus oceanicus*).

Daniel Stich is a professor at State University of New York-College at Oneonta. He earned his B.T. in Fisheries and Aquaculture at the State University of New York, Cobleskill College of Agriculture and Technology, an M.S. in Fish and Wildlife Conservation at the Virginia Polytechnic Institute and State University (Blacksburg, Virginia, USA), and a Ph.D. in Wildlife Ecology at the University of Maine (Orono, Maine, USA). He previously worked with NOAA Fisheries as a contracted fishery biologist studying the effects of dam passage performance standards and lake connectivity on alosines (shad and herring) in the Northeast, and continues to collaborate with federal agencies on related issues. Daniel uses data-driven approaches to answer questions about a wide range of species and topics that range in breadth from physiology of individual organisms to population-level responses to management actions. These approaches make use of modern quantitative and computer-based modeling techniques to address complex problems faced by both local and regional resource managers, and are extensively supplemented by field and laboratory research.

Donna Vogler was born and educated in the Midwestern United States, with a B.S. from The Ohio State University (Columbus, Ohio, USA), and an M.S. from Iowa State University (Ames, Iowa, USA), before working for the U.S. Fish and Wildlife Service in Washington, DC, USA. Donna earned a Ph.D. from Pennsylvania State University (University Park, Pennsylvania, USA) in Botany, and was a postdoctoral researcher at the University of Pittsburgh (Pittsburgh, Pennsylvania, USA) before joining the SUNY-Oneonta faculty in 2000. Donna's recent research topics include demographic studies of invasive plant species (e.g., Marsh Thistle, *Cirsium palustre*), floral mechanisms related to self vs. outcross pollination, and using Wood Turtle habitat communities and vegetation management at regional airports to reduce wildlife hazards.