Nesting Habitat Selection and Management of Three Freshwater Turtle Species Along the Shorelines of Lake Champlain

NESTING HABITAT SELECTION AND MANAGEMENT OF THE FRESHWATER TURTLE SPECIES ALONG THE SHORELINES OF LAKE CHAMPLAIN

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Destini Acosta

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Thesis Examination Committee:

Brittany A. Mosher, Ph.D., Co-Advisor
James Murdoch, Ph.D., Co-Advisor
Laura May-Collado, Ph.D., Chairperson
Noelia Barrios-Garcia, Ph.D.
Holger Hoock, DPhil, Dean of the Graduate College

Abstract

Habitat loss, caused by factors like urbanization and land conversion, disrupts ecosystems and can lead to population declines and even extinctions of species that rely on those habitats for survival. Loss of shoreline habitat has been widespread and reduces nesting grounds for species like freshwater turtles, often threatening their reproductive success and population viability. In the Lake Champlain Basin, several turtle species have experienced declines and recovery efforts are limited by a lack of information on habitats selected during the crucial period of nesting. This study aimed to identify and characterize nesting habitat selection of freshwater turtles and included two components. The first focused on the painted turtle (*Chrysemys picta*) and snapping turtle (*Chelydra serpentina*) and evaluated the effects of three common habitat management techniques on nest site selection using experimental plots with treatments (control, vegetation removal, debris removal, and both vegetation and debris removal). The second estimated the habitat associations of nesting and non-nesting sites of the threatened spiny softshell turtle (*Apalone spinifera*) based on field surveys and expert opinion data scored through an analytic hierarchy process. The first study showed that the painted turtle selected both vegetation and debris removal treatment plots for nesting more frequently than control plots, whereas the snapping turtle showed no nest site selection based on treatment types. The second study showed that predator presence and human use had the strongest influence on nest site selection over other variables including substrate type, ground cover, beach orientation, and substrate compaction. Experts ranked human use as the most important nest site variable followed by substrate type and substrate temperature. Results indicate that vegetation and debris removal as a shoreline management action along with predation management and minimizing human disturbance of potential nesting sites may offer benefits to Lake Champlain's diverse assemblage of freshwater turtles.

Acknowledgments

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Overview

Turtles are declining on a global level at an alarming rate. In Vermont, 5 of the 7 native turtle species are considered state Threatened or Endangered, including the spiny softshell turtle (*Apalone spinifera*), with fewer than 300 individuals occurring statewide. The Vermont Fish and Wildlife Department has several programs in place to mitigate turtle declines, but management is difficult due to a lack of fundamental information on species ecology. Despite the lack of data, scientists have concluded that the leading cause of the decline in turtles in the region is habitat loss. Patterns of habitat selection, especially for nesting, are poorly known for most species in Vermont and the northeastern US, which creates challenges for identifying and proactively protecting key habitat resources from alteration, conversion, or loss.

This study aimed to quantify the habitat characteristics of nesting sites for a set of ecologically important turtle species in Vermont. The study consisted of two components including 1) a field experiment (Chapter 1) and 2) an observational study supplemented with expert elicitation data (Chapter 2). The goal of the field experiment was to assess the habitat associations of two species, including the painted turtle (*Chrysemys picta*) and common snapping turtle (*Chelydra serpentina*). The field experiment occurred at a beach site (Delta Park) in Colchester, Vermont and included four treatments that evaluated the effects of vegetation and debris. Weekly nest searches were conducted across treatments to locate nests and collect fine-scale habitat conditions like soil and vegetation characteristics. Data were analyzed using logistic regression model and chi-squared test to determine whether the number of turtle nests varied by treatment type and predator presence.

The goal of the second chapter was to estimate the habitat associations of spiny softshell turtle. This study involved comparing and synthesizing data from two sources: 1) field data and 2) expert opinion data. Field data were collected at 4 known spiny softshell nesting sites and 10 sites that are not known to support spiny softshell nesting in the shorelines of Lake Champlain. At these sites, surveys were conducted to characterize vegetation, substrate, temperature, predators, and human use. A logistic regression and model selection approach was used to evaluate the habitat characteristics that most influence nest site selection. Expert opinion data on nesting habitat was elicited from spiny softshell biologists and managers using an online survey. Data were analyzed using an analytic hierarchy process (AHP) to rank the importance of habitat variables that influence spiny softshell nesting habitat quality. The results of both studies will be used to develop a scorecard for wildlife agencies and landowners to quickly and easily rank the quality of any given shoreline site for spiny softshell nesting.

This study provided information on habitat selection of freshwater turtles along the shorelines of Lake Champlain in Vermont. The results provide a foundation for improving assessments of the status of turtles (e.g., by informing the Vermont Wildlife Action Plan) and management activities for each species by state agencies. The results also provide accessible tools, like the scorecard, that may be used as a guide to shoreline conservation decision-making.

Chapter 1: Nesting Habitat Selection of the Painted Turtle and Snapping Turtle Along the Shoreline of Lake Champlain

Introduction

Turtles are among the most imperiled major group of vertebrates with 61% of species classified as threatened or recently extinct (Lovich et al., 2018). Though previously showing evolutionary success by outliving even the dinosaurs, turtle populations have declined at unprecedented levels mainly due to the activities of humans (Lovich et al., 2018; Stanford et al., 2020). Six major threats created by humans affect turtles including introduced invasive species, environmental pollution, disease, climate change, unsustainable use, and habitat loss (Gibbons et al., 2000; Lovich et al., 2018; Stanford et al., 2020). Although the leading cause of declines globally is unsustainable use, in the Americas turtle population decline is mainly due to habitat loss and degradation (Stanford et al., 2020). There is a growing need for information on the fundamental ecology of species to better manage these threats and to reverse population declines.

Turtles are renowned for their longevity and slow reproductive rate, with some species living for several decades or even over a century (Congdon, 1993; Marchand et al., 2019). These ancient reptiles under natural conditions may live over 20 to 30 years while anecdotal records of giant tortoises are reported living more than 100 years (Gibbons, 1987; Gibbons & Semlitsch, 1982). Turtles also experience a slower rate of reaching sexual maturity which is more accurately correlated to size than age (Edmonds et al., 2021; Frazer et al., 1993; Litzgus & Brooks, 1998; Mosimann & Bider, 1960). Freshwater turtles typically reach sexual maturity between the ages of 6 – 12 years of age (Edmonds et al., 2021; Gibbons, 1968; Hulse, 1982; Plummer, 1977) and their slow development to sexual maturity and reproduction, make them particularly vulnerable to population declines (Brooks et al., 1991; Ernst & Lovich, 2009; Marchand et al., 2019).

Nesting habitat is essential for turtle survival, as females require suitable areas with sandy or gravelly soil to lay their eggs (Mortimer, 1990; Paterson et al., 2013). Unfortunately, habitat loss due to urbanization (Rubin et al., 2001), agriculture (Saumure et al., 2007), and shoreline development (Defeo et al., 2009) poses a significant challenge for nesting turtles. Habitat loss, fragmentation, and degradation directly impact key resources for turtles. For example, vegetation serves as a critical source of food and shelter from predation but also as a cooling system providing a 5-7 ºC difference in shaded areas (Armson et al., 2012; Pietrek et al., 2009). The loss of vegetation along shorelines presumably affects turtles, especially during the nesting period. While loss of vegetation may have thermal implications for microclimate, increased vegetation through encroachment can have direct effects on nesting turtles and nest success. Thick vegetation can obstruct nesting turtles access to suitable nesting sites, forcing them to lay eggs in suboptimal locations (Chen et al., 2007; Conrad et al., 2011) or making it more challenging for hatchlings to emerge from the nest (Bustard & Greenham, 1968; Conrad et al., 2011). Nesting habitats may also be altered by woody debris accumulation that can discourage or obstruct turtles from coming ashore to nest (Fujisaki & Lamont, 2016). Large logs and branches may create physical barriers, making it difficult for turtles to access suitable nesting sites.

The development of shorelines has introduced novel threats to nesting turtles, including increased predation and human disturbance (Antworth et al., 2006; Marchand & Litvaitis, 2004). As urbanization and infrastructure expansion encroach upon natural habitats, generalist predators such as raccoons (*Procyon lotor*) and foxes (*Vulpes vulpes*) thrive in human-altered environments, exploiting new opportunities for food and shelter (Bateman & Fleming, 2012; Prugh et al., 2009). These predators, adept at exploiting human-altered landscapes, have seen their populations surge, leading to heightened predation pressure on nesting turtle sites (Urbanek & Sutton, 2019). Furthermore, the increased use of shoreline habitats by humans and pets further disrupts nesting turtles, causing stress and potential nest destruction (Fowler, 1979; Moore & Seigel, 2006; Selman et al., 2013). As a result, nesting turtle populations face a double-edged threat: habitat loss due to development and heightened predation from opportunistic predators flourishing in human-altered landscapes.

In addition to habitat loss and predation pressures, climate change poses another significant challenge to nesting turtle populations. Climate change is altering the seasonal dynamics of lakes, leading to less frequent freezing and significant changes in shoreline ice formation (Shimoda et al., 2011; Woolway et al., 2020). As temperatures rise, lakes experience shorter periods of ice cover during winter months, impacting ecosystems and wildlife that depend on these frozen habitats (Havens & Jeppesen, 2018; Stager & Thill, 2010). Additionally, climate change contributes to increased erosion along shorelines as wave action and storms batter unprotected coastlines (Rajasree et al., 2016; Toimil et al., 2020). The scraping of ice along the shorelines, once a common winter occurrence, becomes less frequent, altering the natural processes that shape these landscapes.

Lake Champlain, located between the US states of Vermont and New York and extending into Quebec, Canada has a shoreline of 945 km and harbors many nesting turtle species. Shoreline habitats along the lake have also faced considerable alteration due to development and climate change. There are 7 native freshwater turtle species that occur in the lake on the Vermont side, of which 4 are classified by the state as threatened, endangered, or of conservation concern primarily due to habitat loss (Stanford et al., 2020; Vermont Fish and Wildlife Department, 2009). The wood turtle (*Glyptemys insculpta*), for example, travels long distances in the summer and, because of habitat fragmentation, experiences high injury and mortality caused by vehicle strikes, agricultural machinery, and mammal attacks (Parren, 2013; Saumure et al., 2007; Walde, 2007). Other Vermont species that nest along Lake Champlain may be subject to degraded nesting habitat due to vegetation encroachment, beach debris, and increased predation. These shoreline nesting species include two common species: the painted turtle (*Chrysemys picta*) and snapping turtle (*Chelydra serpentina*), and several less common species including the spiny softshell turtle (*Apalone spinifera*), northern map turtle (*Graptemys geographica*), and eastern musk turtle (*Sternotherus odoratus*). Though conservation efforts are being considered to support nesting of some of these less common species, there is a need to better understand habitat requirements to adequately conserve, restore, or protect sites.

Experimental studies play a vital role in understanding habitat selection by turtles, providing valuable insights that inform restoration, management, and conservation efforts (Brooks et al., 1991; Castilla, 2000; Cooke et al., 2017; McGarigal & Cushman, 2002; Ockendon et al., 2021; Resasco et al., 2017). By manipulating variables such as habitat structure, temperature, and predator presence, researchers can shed light on the specific factors influencing turtle behavior and habitat preferences. These studies help identify critical nesting sites, determine optimal habitat conditions, and assess the effectiveness of conservation strategies. Furthermore, experimental research allows for the evaluation of potential habitat enhancements or restoration techniques to create suitable nesting environments for turtles (Crain et al., 1995; Steen et al., 2012). By applying the knowledge gained from experimental studies, conservationists can develop targeted management plans to mitigate threats, preserve vital habitats, and ensure the long-term survival of turtle populations.

This study aims to identify nesting habitat selection for two freshwater turtle species, including the painted turtle and common snapping turtle. The first objective of this study was to assess whether turtle nest site selection is influenced by two nesting beach management treatments: debris and vegetation removal. The second objective of the study was to describe nest site selection at the microhabitat level. The results will provide information along with assessment tools that will allow decision makers to better evaluate management activities for both species.

Methods

Study site

The field site was located in Delta Park (1,500 m^2), where the Winooski River enters Lake Champlain in Colchester, Vermont, USA. Lake Champlain is a large freshwater lake situated between New York and Vermont that extends into Quebec, Canada. It is a long (192 km), narrow (20 km at its widest point) lake with an average depth of 19.5 meters and is the sixth largest freshwater lake in the United States behind the Great Lakes.

The study area is the northern shoreline at the mouth of the Winooski River and is bisected by a pedestrian and bike path. The shoreline on the west side of the path is part of the Winooski Valley Park District, a non-profit that owns and manages natural areas in the region. Most of the east shoreline is owned by the Town of Colchester, Vermont and managed by the Vermont Fish and Wildlife Department.

Located north of the field site is a non-tidal marsh supporting wildlife such as the northern leopard frog (*Lithobates pipiens*) and the painted turtle. The west side is mainly an open beach that has been encroached upon by young silver maple (*Acer saccharinum*) trees. This side collects large woody debris that floats by the mouth of the river. The east side is dominated more by shrubby willows (*Salix* spp.). There is more shade cover on the east side of the beach during the late spring/early summer which may affect the nests. During the nest laying season, vegetation is minimal, which may lead the turtles into selecting nest sites that appear to allow for more sunlight and increase the speed of incubation (Staines et al., 2019). However, vegetation growth is substantial over the course of the season, creating dense thickets of willow and silver maple by the middle and end of summer.

There is substantial human activity around Delta Park, in part due to its proximity to the pedestrian and bike path. Humans that are biking, walking, kayaking, fishing, or picnicking in or near the park may deter turtles from entering the beach and nesting. Delta Park also borders a suburban neighborhood on the north side.

Study species

The painted and snapping turtle use the site for nesting. Both species begin to nest from mid-May to mid-June followed by an incubation period of 72-80 days for painted turtles and 80-90 days for snapping turtles. For both species, hatchlings emerge from mid-August to mid-October. Delta Park was historically known as a nesting site for the spiny softshell turtle but is no longer used by the species. However, it has been identified by the Vermont

Fish and Wildlife Department as a candidate site for management to restore spiny-softshell nesting. Nesting beach management for the painted turtle and snapping turtle may also serve to benefit the nesting beach management of the spiny softshell turtle.

Treatments

To assess the influence of vegetation and debris on the probability of turtle nesting, the experimental approach involved creating four treatments: 1) vegetation removal, 2) debris removal, 3) vegetation and debris removal, and 4) a control that included natural vegetation and debris. The plots were 10 m in width and their length varied according to the contour of the beach (~ 8-12 m). Five plots were located on the west side of a pedestrian bridge and 10 plots occurred on the east side of the bridge (Figures 1 & 2). The 'vegetation removal' (v) plots had any vegetation that would cause shade/ground cover, such as willow or silver maple, removed. The 'debris removal' (d) plots had any woody debris such as sticks and logs that washed-up on shore removed. We removed all debris that was > 5 cm in diameter, with the exception of a few extremely large (> 40 cm DBH, > 7 m long, and/or partially buried) pieces of debris. The 'vegetation and debris removal' plots (b) had both vegetation and debris removed. Lastly, the control (c) plots were not altered.

We randomly selected plot types without replacement within 5-plot blocks, for a total of 6 control sites, 3 vegetation removal sites, 3 debris removal sites, and 3 vegetation and debris removal sites. We hypothesized that the turtles would select open beach with little vegetation or debris for nesting based on historical conditions when turtle nesting occurred more regularly and natural history accounts by the state (Vermont Fish and Wildlife Department, 2009). The study occurred during the turtle nesting, incubation, and emergence season in 2022 and 2023, with initial implementation of treatments in May 2022 and biweekly maintenance as vegetation grew and new debris was deposited.

Monitoring

Surveys were conducted weekly during the nesting period (mid-May to mid-July) and incubation period (mid-July to mid-August). From mid-August to mid-October, during the emergence period, surveys were conducted three times per week. The surveys were conducted during the years of 2022 and 2023. In 2023, surveys were halted due to flooding that caused the nesting site to be submerged from June to August.

Plots were monitored using visual encounter surveys conducted for the presence of nests. During each survey, the surveyor performed a detailed visual encounter at each plot to search for predated or emerged nests. Predated nests were identified by the presence of scattered eggshells around a dug-up hole (Figure 3). An emergence hole is harder to detect and would appear as either a 2.5 cm drill hole, an 8-10 cm collapsed bowl to a hole, bowl only, slight hole only, or a swirl of the substrate (Figure 4).

Located nests were excavated for data collection, which included recording the plot type, species, number of eggs, and presence of live and dead hatchlings. To excavate the nest, a dry mote was dug from a 15 cm radius from the center of the perceived nest (Figure 5). This left a plateau of substrate that was carefully sifted through for eggs and hatchlings. The depth of the nest and number of eggs identified the species: 9 cm deep and 4-8 eggs for a painted turtle and 13-15 cm deep and 20-50 eggs for a snapping turtle. Since predated nests were already dug up and unlikely to contain intact eggs and hatchlings, these nests were directly excavated from the center. Eggshells were collected and spread out into individual piles to be pieced together to estimate the total number of eggs. After the data were collected, eggs were removed from the site and the empty nest was filled in. This aids in covering the scent of the eggs/hatchlings which may attract predators to remaining nests.

Additional variables

<u>Temperature</u>

Turtles are poikilothermic and nesting behavior (and incubation time) is inherently influenced by temperature. To account for the influence of temperature on nesting, we collected temperature data in each plot type. Temperature data were recorded with data loggers (HOBO pendant temperature and light data loggers, Onset Computer Corporation, Bourne, Massachusetts, USA). Data loggers (n = 8) were placed on each side of the pedestrian path in each treatment type. The data loggers were placed in June 2022 and remained in place until October 2022 and recorded the temperature of the soil every 15 min. Loggers placed in control plots were placed near the base of vegetation or debris to reflect temperatures in the shaded areas that were characteristic of the unmanaged plots.

<u>Predators</u>

Common nest predators in the region include raccoon and red fox. The presence of these predators in each plot was recorded using track surveys. Surveys were performed once a week and involved starting at one end of the plot and walking a transect through the plot treatments. The start and end time of the surveys were noted for each side of the bridge. The transect began 5 m from the water's edge because nesting turtles typically begin to nest 5 m inland. The transect was established at the start of the season and maintained as the water receded through the season.

Analysis

We used logistic regression to compare the probability of turtle nesting in different treatment types. Logistic regression estimates the probability of an outcome or event and can include the effect of covariates. In our case, we compared three models: where the probability of a nest occurring was 1) constant, or a function of 2) treatment plot type, or 3) predator activity. The painted turtle and snapping turtle nests were analyzed separately and we used a model selection approach to evaluate support for each model. We also used a chi squared test to test the relationship between the total number of nests and treatment plot types.

All nests discovered during this study were discovered through predation. Predation was therefore analyzed as a response variable in relation to nest presence to show that although nests were discovered through predation, nest presence and predator tracks were not dependent on the other. A logistic regression model for predator activity through time (day of year) was also analyzed to determine whether predator activity varied over the course of the season. These analyses were completed for painted turtle nests only, due to sample size constraints. All analyses were performed using the R programming language (R Core Team, 2021).

Results

We identified 13 painted turtle and five snapping turtle nests in 2022, and two painted turtle and one snapping turtle nests in 2023. All nests recorded during the surveys were discovered through predation, despite frequent nest surveys. For painted turtles, two nests were found in control plots, four in vegetation removal plots, 1 in debris removal plots, and six in plots with both vegetation and debris removal (Figure 6). For snapping turtles, three nests were found in vegetation removal plots and two nests were found in debris removal plots. In 2023, the site became flooded and only three nests were recorded: two painted turtles (both in control plots) and one snapping turtle nest (also in a control plot; Figure 7). Flooding began in early June 2023 and disrupted any further data for that year.

Vegetation and debris removal plots resulted in striking visual differences between plot types (Figure 8). While we had a small sample size of temperature loggers (one logger per treatment type on each side of the bridge, for a total of two datapoints per treatment), we did see some differences in temperature that are likely linked to our vegetation management. The average July temperature by treatment was: 23.4 C (control), 26.6 C (vegetation removal), 23.2 C (debris removal), and 26.5 C (removal of both vegetation and debris) (Figure 9).

Logistic regression results for painted turtles suggested that plot type influenced the probability of nesting. The probability of a painted turtle nest being in the both removal treatment plots was significantly higher than in the control ($p = 0.02$, $\beta_1 = 1.86$, $SE = 0.83$). Debris only treatments were not significantly different than the control ($p = 1.00$, $\beta_2 = 0.00$, $SE = 1.23$) and the vegetation removal treatment was somewhat different than the control ($p = 0.10$, $\beta_3 = 1.43$, $SE = 0.88$). The probability of finding a painted turtle nest in the "both" removal plot during each visit was 0.08. The probability of finding a painted turtle nest in the vegetation removal plot during each visit was 0.05. The probability of finding a painted turtle nest in the control plot or the debris removal plot during each visit was 0.01 (Figure 10).

Our logistic regression results for snapping turtles suggested that plot type did not influence the probability of snapping turtle nests. The p-values for the probability of a snapping turtle nests in the different treatment plot types compared to the control ranged from 0.993 to 1.000. The sample size for both turtle species was small and may reflect results.

We performed a chi-squared test of independence to examine the relationship between number of painted nests in treatment types and the probability of painted turtles nesting in each plot type. There appeared to be a relationship between painted nests and treatment plot type ($X^2 = 8.15$, df = 3, p = 0.04). Chi-squared results for snapping turtles showed less of a relationship between nests and treatment plot type ($X^2 = 8$, df = 3, p = 0.05) but we caution against strong inference due to the very small sample size.

Our logistic regression results with predator activity as a response variable indicated that predator tracks were discovered regardless of whether a painted turtle nest was discovered ($\beta_1 = -0.21$, SE = 0.96, p = 0.82) or a snapping turtle nest was discovered ($\beta_1 = -15.04$, SE = 1.68e-3, p = 0.99). Therefore, despite nests being discovered through predation, predation was not an indicator for nests. Predator tracks also showed no relationship between treatment plot types and appeared to be distributed throughout treatment plots (p-values ranged from 0.27 to 0.34 for both species). There was a significant effect of predator activity over time ($\beta_1 = -0.03$, SE = 0.0067, $p < 0.01$) in our logistic regression model. Predator activity occurred at the start of the nesting season and tapered off during the remainder of the season (Figure 11).

Discussion

Treatment

The painted turtle's association with sites where both vegetation and debris were removed underscores the importance of habitat maintenance for the species. In the study's four treatment types – control, vegetation removal, debris removal, and both vegetation and debris removal – the painted turtle demonstrated a clear affinity for environments devoid of both obstacles. This suggests selection for open, unobstructed spaces. The snapping turtle showed no habitat selection based on the treatment types which may be due to the small sample size. Increasing the sample size could lead to improved insights on habitat selection. The findings highlight the importance of habitat management strategies that prioritize the removal of vegetation and debris to create optimal conditions for the painted turtle's habitat selection.

Temperature

The observed differences in nest temperatures among various treatment plots provide valuable insights into the thermal dynamics of turtle nesting habitats. With an average temperature of 26.5 C, plots subjected to both vegetation and debris removal exhibited the highest temperatures. In contrast, the control treatment plot and the debris removal plot recorded temperatures three degrees cooler on average. This discrepancy suggests that the removal of vegetation and debris contributes to higher nest temperatures, potentially leading to a faster incubation period. This accelerated development could offer significant advantages to turtle populations, reducing the need for overwintering in nests and potentially enhancing reproductive success (Denver & Licht, 1991; Sinervo & Adolph, 1989). The findings emphasize the importance of habitat management strategies aimed at optimizing nest temperatures to support the reproductive needs of turtle species.

Predation

Nests were difficult to discover by the surveyors, but mammalian predators have a keen sense of smell that allowed them to discover nests prior to the nest surveys conducted. Our study showed that predators were discovered throughout whether nests were found. A concern for vegetation management was whether clearing plots of vegetation and debris would allow predators to discover nests more effectively. Our study showed that predation was evenly distributed through the control, vegetation removal, debris removal, and both removal plots. Predation occurred more frequently during the nesting and decreased as the season went on. This suggests that the predators rely more on olfactory clues than visual clues. To increase nesting success, decision makers may consider predator management.

Implications

The study of painted turtle and snapping turtle nesting habitat conservation may aid other species such as those that fall under species of concern like the Vermont spiny softshell turtle population. Painted turtles, snapping turtles, and spiny softshell turtles exhibit both similarities and differences in nest site selection. Like painted and snapping turtles, spiny softshell turtles prefer sandy or gravelly areas along the shoreline for nesting (Parren et al., 2021; Tornabene et al., 2017). However, there are notable differences in their nesting behaviors. Spiny softshell turtles may exhibit more site fidelity (Lazure et al., 2019), returning to the same nesting areas year after year, whereas painted and snapping turtles exhibit nest site fidelity but may explore multiple nesting sites within their range (Congdon et al., 1987; Lindeman, 1992). Despite these variations, all three species share the fundamental need for suitable nesting habitat to ensure the survival of their offspring.

Turtle selection for open nest sites devoid of vegetation and debris carries significant implications for their reproductive success and population dynamics. First, such sites with fewer obstacles not only offer warmer nest temperatures, as observed in this study, but also facilitate faster incubation periods. This can be crucial for turtle species, as it reduces the risk of nests being subjected to extended overwintering periods, ultimately enhancing hatching success rates. Additionally, there were concerns of increased predation risk in open nest sites compared to sites with dense vegetation or debris cover, removing vegetation and debris did not contribute to decreasing nest survival rates but predators were keenly aware of nests. Therefore, the findings highlight the importance of habitat management practices that prioritize maintaining open nesting areas, which provide favorable thermal conditions along with predation management to mitigate predation pressure, ultimately benefiting turtle populations.

Figure 1-1. Five treatment plots monitored for turtle nesting on the west side of Delta Park, Colchester, Vermont, USA.

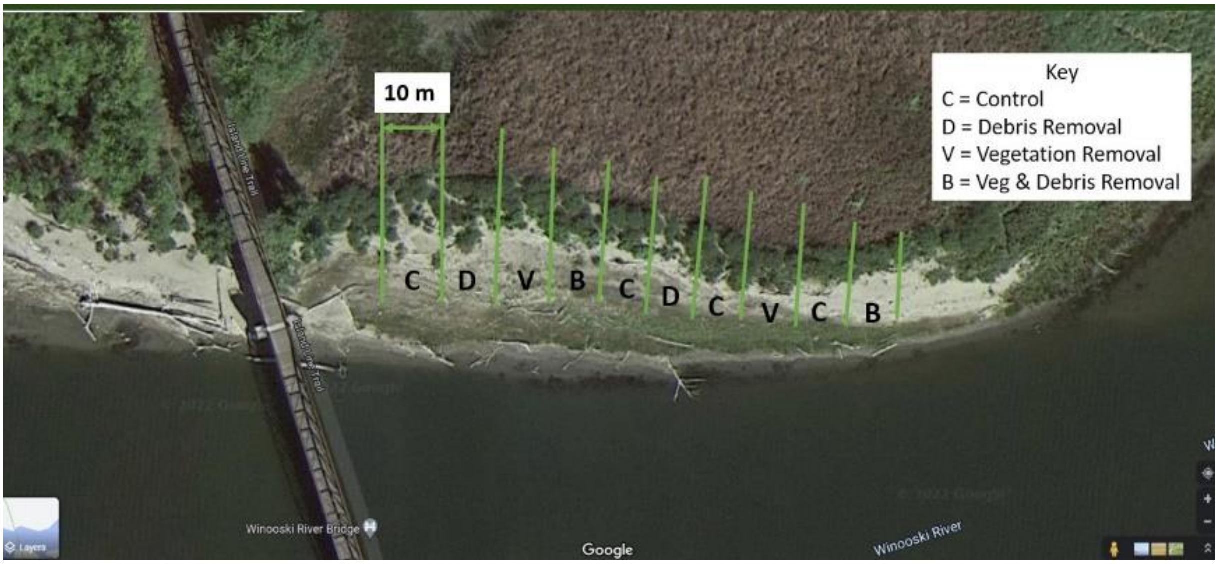

Figure 1-2. Ten treatment plots monitored for turtle nesting on the east side of Delta Park, Colchester, Vermont, USA.

Figure 1-3. A predated snapping turtle (*Chelydra serpentina*) nest recorded at Delta Park, Colchester, Vermont, USA in 2022.

Figure 1-4. An example of an emergence hole used to identify some turtle nests.

Figure 1-5. Partial excavation of a turtle nest with an emergence hole in center.

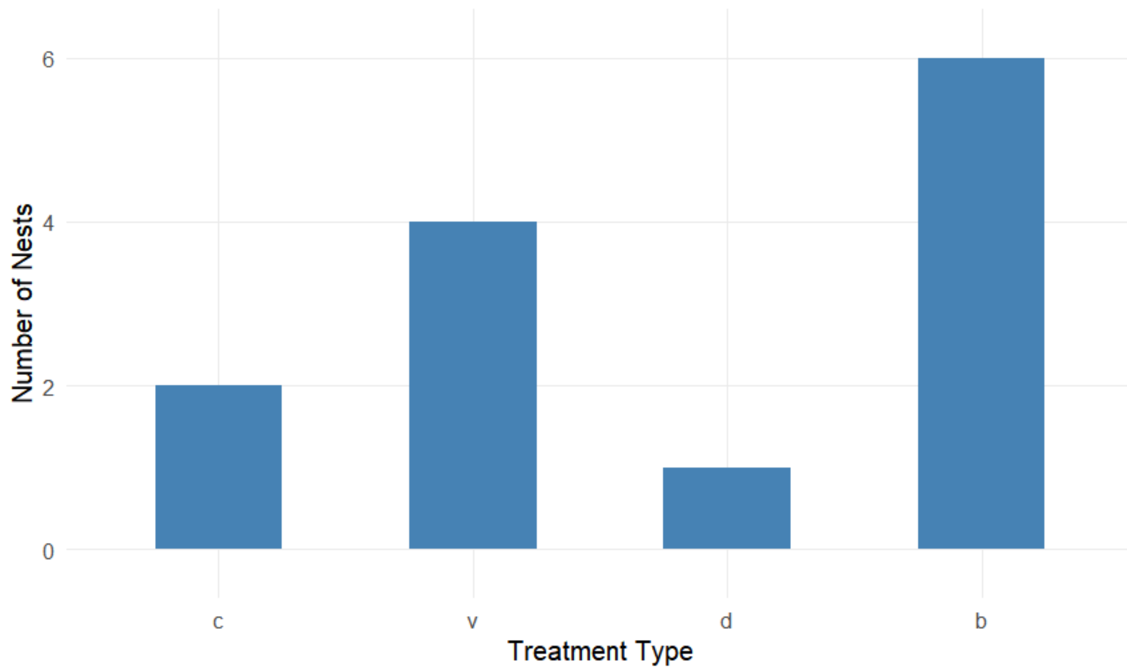

Figure 1-6. The number of painted turtle (*Chrysemys picta*) nests found in each treatment plot type: c for control plot, v for vegetation removal plot, d for debris removal, and b for both vegetation and debris removal plot.

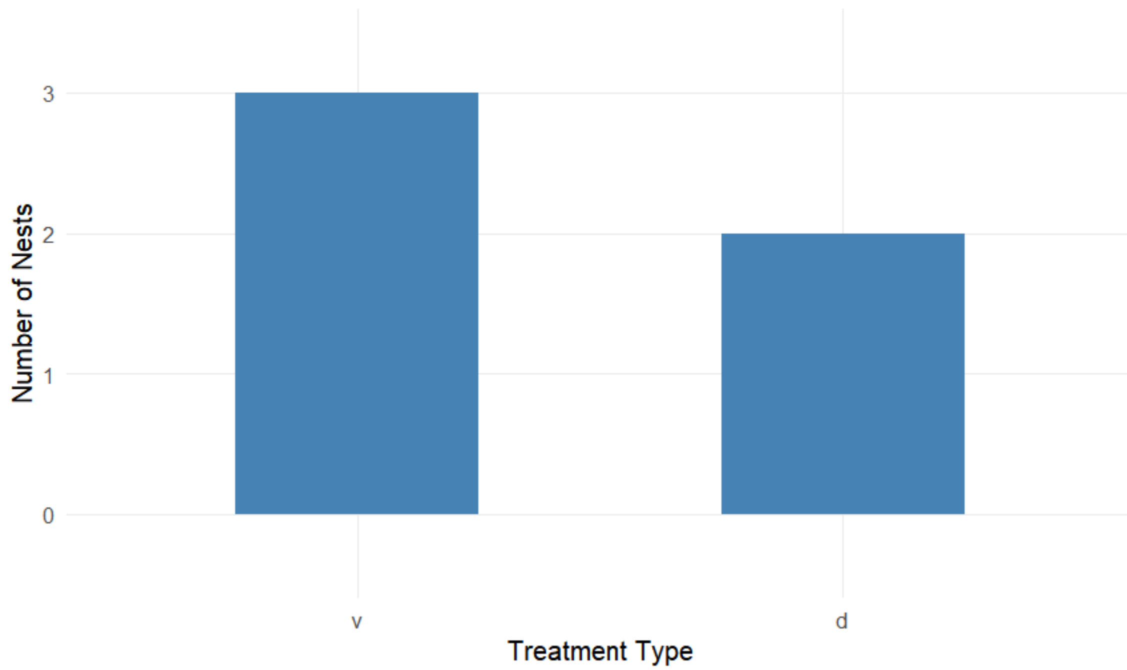

Figure 1-7. The number of snapping turtle (*Chelydra serpentina*) nests found in each treatment plot type: v for vegetation removal plot and d for debris removal plot.

Figure 1-8. Top image shows both (vegetation and debris removal) plot before management. Bottom image displays plot after management.

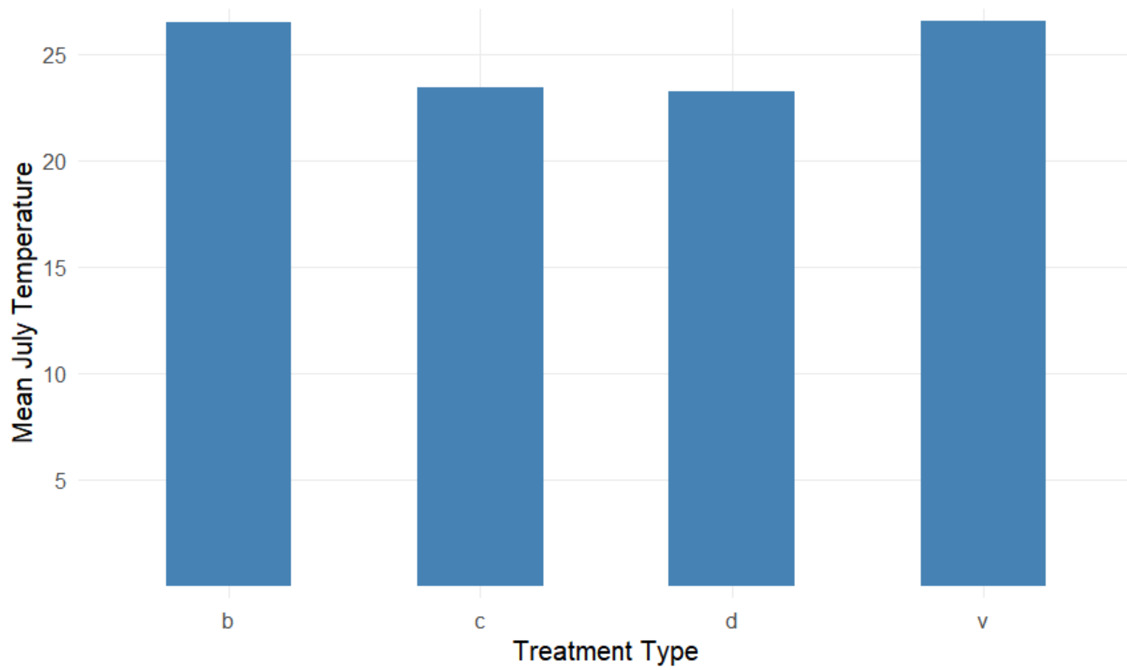

Figure 1-9. Average soil temperature in each treatment type for both removal (26.5 C), control (23.4 C), debris removal (23.2 C), and vegetation removal plots (26.6 C).

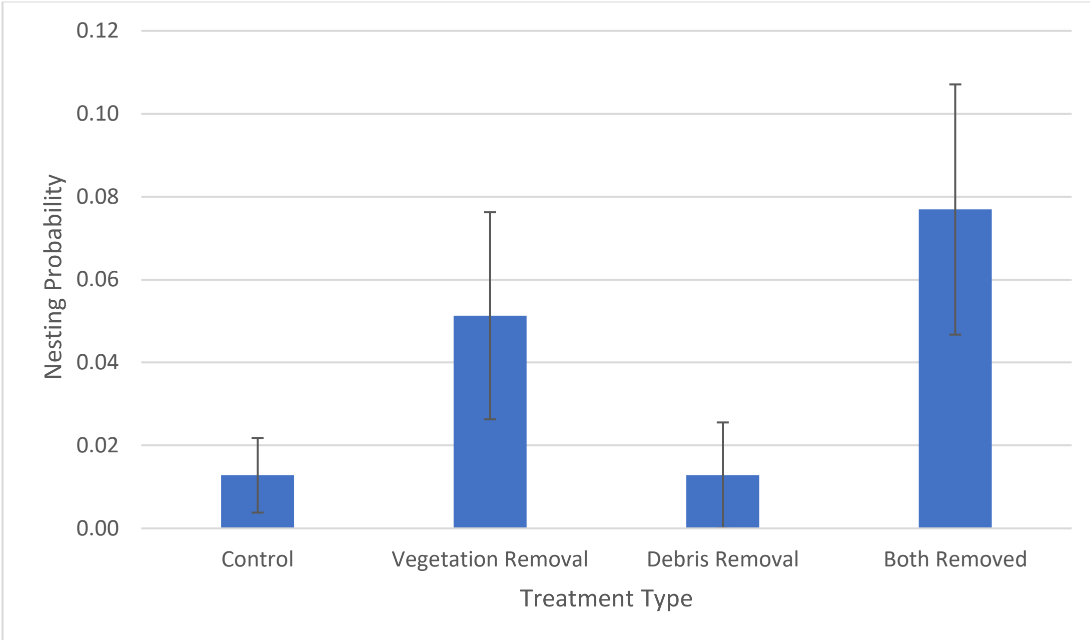

Figure 1-10. The probability of finding a painted turtle (*Chrysemys picta*) nest in each treatment type during each survey visit at Delta Park in Colchester, Vermont, USA.

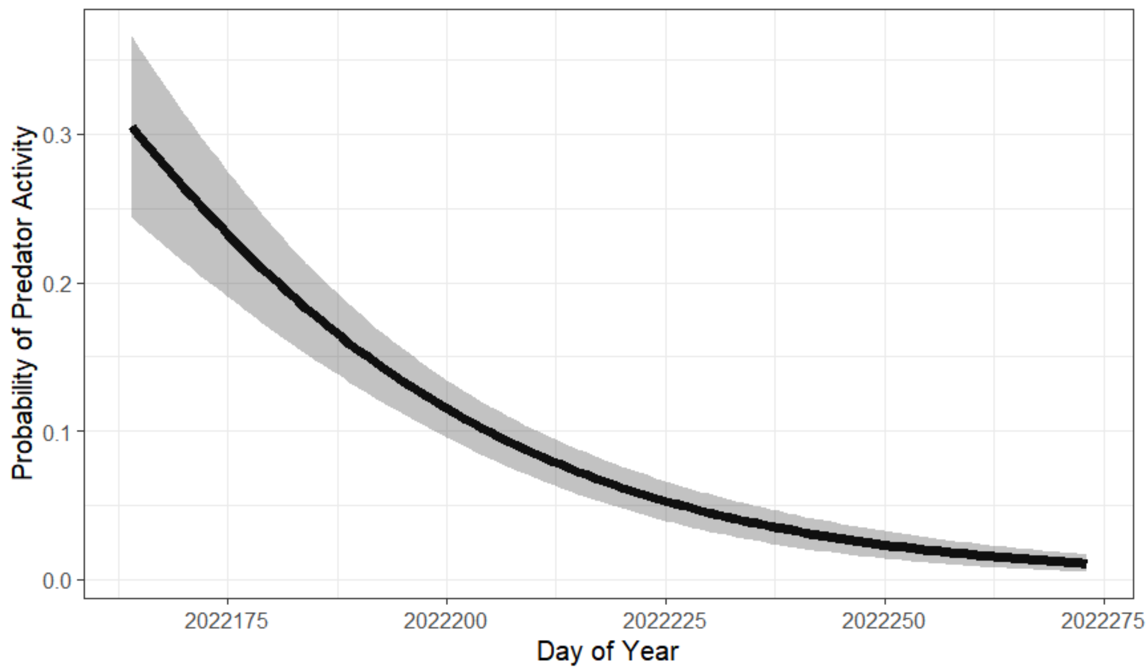

Figure 1-11.The probability of predator activity during the nesting, incubation, and emergence period displayed by Julian date.

Table 1-1. Model selection table for painted turtle (*Chrysemys picta*) nesting. The probability of nesting was modeled as either constant (Null Model) or as a function of covariates. Model names reflect the model structure. Akaike's Information Criterion corrected for sample size (AICc), the difference in AICc values compared to the top model (ΔAICc), model weights (AICcWt), number of parameters (K), and log-likelihood (LL) values are shown for each model.

Model Names	K	Δ AICc	AICcWt	LL
Treatment Model	4	0.00	0.66	-52.98
Null Model	1	1.94	0.25	-57.00
Predator Model	2	3.90	0.09	-56.97

References

Armson, D., Stringer, P., & Ennos, A. R. (2012). The effect of tree shade and grass on surface and globe temperatures in an urban area. *Urban Forestry & Urban Greening*, *11*(3), 245–255.

Bateman, P. W., & Fleming, P. A. (2012). Big city life: Carnivores in urban environments. *Journal of Zoology*, *287*(1), 1–23.

Brooks, R. J., Brown, G. P., & Galbraith, D. A. (1991). Effects of a sudden increase in natural mortality of adults on a population of the common snapping turtle (Chelydra serpentina). *Canadian Journal of Zoology*, *69*(5), 1314–1320.

Bustard, H. R., & Greenham, P. (1968). Physical and Chemical Factors Affecting Hatching in the Green Sea Turtle, Chelonia Mydas (L.). *Ecology*, *49*(2), 269–276.

Chen, H.-C., Cheng, I.-J., & Hong, E. (2007). The Influence of the Beach Environment on the Digging Success and Nest Site Distribution of the Green Turtle, Chelonia mydas, on Wan-an Island, Penghu Archipelago, Taiwan. *Journal of Coastal Research*, *23*(5 (235)), 1277–1286.

Congdon, J. D. (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), 826–832.

Congdon, J. D., Breitenbach, G. L., Sels, R. C. van L., & Tinkle, D. W. (1987). Reproduction and Nesting Ecology of Snapping Turtles (Chelydra serpentina) in Southeastern Michigan. *Herpetologica*, *43*(1), 39–54.

Conrad, J. R., Wyneken, J., Garner, J. A., & Garner, S. (2011). Experimental study of dune vegetation impact and control on leatherback sea turtle Dermochelys coriacea nests. *Endangered Species Research*, *15*(1), 13–27.

Defeo, O., McLachlan, A., Schoeman, D. S., Schlacher, T. A., Dugan, J., Jones, A., Lastra, M., & Scapini, F. (2009). Threats to sandy beach ecosystems: A review. *Estuarine, Coastal and Shelf Science*, *81*(1), 1–12.

Denver, R. J., & Licht, P. (1991). Dependence of body growth on thyroid activity in turtles. *Journal of Experimental Zoology*, *258*(1), 48–59.

Ernst, C. H., & Lovich, J. E. (2009). *Turtles of the United States and Canada*. JHU Press.

Fowler, L. E. (1979). Hatching Success and Nest Predation in the Green Sea Turtle, Chelonia Mydas, at Tortuguero, Costa Rica. *Ecology*, *60*(5), 946–955.

Fujisaki, I., & Lamont, M. M. (2016). The effects of large beach debris on nesting sea turtles. *Journal of Experimental Marine Biology and Ecology*, *482*, 33–37.

Gibbons, J. W., Scott, D. E., Ryan, T. J., Buhlmann, K. A., Tuberville, T. D., Metts, B. S., Greene, J. L., Mills, T., Leiden, Y., Poppy, S., & Winne, C. T. (2000). The Global Decline of Reptiles, Déjà Vu Amphibians. *BioScience*, Havens, K., & Jeppesen, E. (2018). Ecological Responses of Lakes to Climate Change. *Water*, *10*(7), Article 7.

Lazure, L., Pare, P., Bouthillier, L., & Galois, P. (2019). Nesting biology and conservation of a northern population of spiny softshell turtles (Apalone spinifera). *Herpetological Conservation and Biology*, *14*(3), 659–667.

Lovich, J. E., Ennen, J. R., Agha, M., & Gibbons, J. W. (2018). Where Have All the Turtles Gone, and Why Does It Matter? *BioScience*, *68*(10), 771–781.

Marchand, K. A., Somers, C. M., & Poulin, R. G. (2019). Spatial ecology and multi-scale habitat selection by Western Painted Turtles (*Chrysemys picta bellii*) in an urban area. *The Canadian Field-Naturalist*, *132*(2), 108–119.

Moore, M. J. C., & Seigel, R. A. (2006). No place to nest or bask: Effects of human disturbance on the nesting and basking habits of yellow-blotched map turtles (*Graptemys flavimaculata*). *Biological Conservation*, *130*(3), 386–393.

Mortimer, J. A. (1990). The Influence of Beach Sand Characteristics on the Nesting Behavior and Clutch Survival of Green Turtles (Chelonia mydas). *Copeia*, *1990*(3), 802–817.

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*(15), 176–190.

Parren, S. G., Parren, M. K., & Gieder, K. D. (2021). Nest Counts and Hatchling Emergence Timing for the Spiny Softshell (Apalone spinifera) and Associated Turtle Species at Managed Sites in Vermont, USA. *Herpetological Conservation and Biology*, *16*(1), 194–202.

Paterson, J. E., Steinberg, B. D., & Litzgus, J. D. (2013). Not just any old pile of dirt: Evaluating the use of artificial nesting mounds as conservation tools for freshwater turtles. *Oryx*, *47*(4), 607–615.

Pietrek, A. G., Walker, R. S., & Novaro, A. J. (2009). Susceptibility of lizards to predation under two levels of vegetative cover. *Journal of Arid Environments*, *73*(4), 574–577.

Prugh, L. R., Stoner, C. J., Epps, C. W., Bean, W. T., Ripple, W. J., Laliberte, A. S., & Brashares, J. S. (2009). The Rise of the Mesopredator. *BioScience*, *59*(9), 779–791.

Rajasree, B. R., Deo, M. C., & Sheela Nair, L. (2016). Effect of climate change on shoreline shifts at a straight and continuous coast. *Estuarine, Coastal and Shelf Science*, *183*, 221–234.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rubin, C. S., Warner, R. E., Bouzat, J. L., & Paige, K. N. (2001). Population genetic structure of Blanding's turtles (*Emydoidea blandingii*) in an urban landscape. *Biological Conservation*, *99*(3), 323–330.

Saumure, R. A., Herman, T. B., & Titman, R. D. (2007). Effects of haying and agricultural practices on a declining species: The North American wood turtle, Glyptemys insculpta. *Biological Conservation*, *135*(4), 565–575.

Selman, W., Qualls, C., & Owen, J. C. (2013). Effects of human disturbance on the behavior and physiology of an imperiled freshwater turtle. *The Journal of Wildlife Management*, *77*(5), 877–885.

Shimoda, Y., Azim, M. E., Perhar, G., Ramin, M., Kenney, M. A., Sadraddini, S., Gudimov, A., & Arhonditsis, G. B. (2011). Our current understanding of lake ecosystem response to climate change: What have we really learned from the north temperate deep lakes? *Journal of Great Lakes Research*, *37*(1), 173–193.

Sinervo, B., & Adolph, S. C. (1989). Thermal sensitivity of growth rate in hatchling Sceloporus lizards: Environmental, behavioral and genetic aspects. *Oecologia*, *78*(3), 411–419.

Stager, J. C., & Thill, M. (2010). Climate Change in the Champlain *Basin* (pp. 1–44). *The Nature Conservancy.*

Staines, M. N., Booth, D. T., & Limpus, C. J. (2019). Microclimatic effects on the incubation success, hatchling morphology and locomotor performance of marine turtles. *Acta Oecologica*, *97*, 49–56.

Stanford, C. B., Iverson, J. B., Rhodin, A. G. J., Paul van Dijk, P., Mittermeier, R. A., Kuchling, G., Berry, K. H., Bertolero, A., Bjorndal, K. A., Blanck, T. E. G., Buhlmann, K. A., Burke, R. L., Congdon, J. D., Diagne, T., Edwards, T., Eisemberg, C. C., Ennen, J. R., Forero-Medina, G., Frankel, M., Walde, A. D. (2020). Turtles and Tortoises Are in Trouble. *Current Biology*, *30*(12), R721–R735.

Toimil, A., Camus, P., Losada, I. J., Le Cozannet, G., Nicholls, R. J., Idier, D., & Maspataud, A. (2020). Climate change-driven coastal erosion modelling in temperate sandy beaches: Methods and uncertainty treatment. *Earth-Science Reviews*, *202*, 103110.

Tornabene, B. J., Bramblett, R. G., Zale, A. V., & Leathe, S. A. (2017). Spatiotemporal Ecology of Apalone spinifera in a Large, Great Plains River Ecosystem. *Herpetological Conservation and Biology*, *12*, 252–271.

Urbanek, R. E., & Sutton, H. (2019). Mesocarnivore presence and behavior on a barrier island during sea turtle nesting season. *Ocean & Coastal Management*, *178*, 104850.

Walde, A. D. (2007). Nesting Ecology and Hatching Success of the Wood Turtle, Glyptemys insculpta, in Québec. *Herpetological Conservation and Biology*, *2*(1), 49–60.

Woolway, R. I., Kraemer, B. M., Lenters, J. D., Merchant, C. J., O'Reilly, C. M., & Sharma, S. (2020). Global lake responses to climate change. *Nature Reviews Earth & Environment*, *1*(8), 388–403.

Chapter 2: Nesting Habitat Selection of the Spiny Softshell Turtle Along Lake Champlain

Introduction

Shoreline ecosystems surrounding freshwater lakes represent a conservation priority due to their unique biodiversity and ecological, economic, and cultural benefits (Paterson et al., 2010; Santana-Cordero et al., 2016). In the United States, shorelines, not including lakes and streams, encompass approximately 153,646 km (National Oceanic and Atmospheric Administration, 2023) and contribute to several important ecosystem services such as flood control, water filtration, and structural integrity to the water's edge (Rao et al., 2015; Sierszen et al., 2012). Shorelines also attract the public for recreation and other uses that generate important economic activity and support cultural interests (Paterson et al., 2010; Scheld et al., 2024).

Despite their ecological value, shoreline ecosystems face significant development pressures in many regions that have imperiled species and habitats (Defeo et al., 2009). For example, shorebirds such as plovers and sandpipers use beach habitat as nesting and overwintering sites. Development and alteration of this habitat affects nesting density (Cohen et al., 2009), the incubation of eggs (Stephens et al., 2004), and introduces novel predators (Burns et al., 2013) and invasive species (Catling, 2005), all of which can impact shorebird population dynamics. Marine and freshwater turtles are another particularly vulnerable group that relies on shoreline habitat for nesting. In the US, nearly 61% of turtle species were classified as threatened or extinct by 2017 (Lovich et al., 2018) with the leading cause of decline for turtle populations being habitat loss (Stanford et al., 2020).

Lake Champlain, which consists of 945 kilometers of shoreline, is nestled between the states of Vermont and New York and extends at its northern end into Quebec, Canada.

A substantial amount of the shoreline has been developed, highlighting the significant impact of human activity on the lake's coastal areas (Vermont Fish and Wildlife Department, 2009). Ongoing development projects, such as waterfront properties and infrastructure expansion pose a threat to the delicate balance of the lake's ecosystem. Lakeshore development may increase human activity, increase predation, alter beaches by manipulating vegetation and substrate, increase pollution, and/or cause a loss of nesting habitat (Folkerts Caldwell et al., 2023; Rosenberger et al., 2008). This development encroachment can disrupt nesting turtle habitats along the shoreline, endangering species like spiny softshell turtle (*Apalone spinifera*), which relies on beach habitat for nesting.

The spiny softshell turtle, while widespread in North America, has experienced acute declines and near extirpation in Lake Champlain. One of the earliest written accounts of the spiny softshell occurred in 1853 by Thompson along with Babcock (1919) who recorded the spiny softshell occurring only on the Vermont side of Lake Champlain, the species appearing particularly at the mouth of the Winooski River. In 2016, the Canadian population of spiny softshell was designated as endangered under the Canadian Endangered Species Act while the Vermont population has been listed as a state threatened species since 1987 and faced continued decline (Committee on the Status of Endangered Wildlife in Canada, 2016; Parren et al., 2021). In Vermont, the species is also listed as a Species of Greatest Conservation Need in the Vermont Wildlife Action Plan and estimated to have fewer than 300 individuals leading to local extinction concerns (Vermont Fish & Wildlife Department, 2009, 2015). This subpopulation of the spiny softshell turtle is at the western most extent of its range and not found elsewhere in the northeastern US.

Several factors threaten the spiny softshell including human disturbance, dams on rivers, aquatic activities such as boating for fishing leading to injury, predation on nests, and nesting habitat (Vermont Fish and Wildlife Department, 2009). Lakeshore houses and development have also led to significant impacts on nesting species including loss of suitable nesting substrate, erosion, reductions in water quality, and the planting of vegetation that have resulted in shading nesting sites (Vermont Fish and Wildlife Department, 2009). Currently, the Vermont spiny softshell nests in only 4 locations along the shoreline of Lake Champlain. Having limited nesting grounds can lead to greater risk of complete reproductive failure and population declines due to stochastic events like natural disasters (i.e. flooding), human disturbances, and/or predation (Lande, 1993).

Limited research has been performed on the Vermont population of the spiny softshell turtle due to their elusive nature and small population, which has led to a limited understanding of quality nesting habitat. Through an extensive literature review, key turtle nesting habitat factors have been identified and include: substrate type, nest temperature, soil compaction, and human disturbance (Crain et al., 1995; Mitchell & Janzen, 2023; Parren et al., 2021; Selman et al., 2013; Tornabene et al., 2018; Turcotte et al., 2023). Other factors considered are ground cover, vegetation type, beach orientation, and proximity to development, which have been shown to be influenced by shoreline development but have not been evaluated extensively for freshwater turtles (Gonzalez-Abraham et al., 2007; Kolbe & Janzen, 2002; Wilson, 1998). Another key factor may lie in whether nest sites are limiting for the spiny softshell turtle or whether this small population is limited by nest site fidelity. Determining whether suitable habitat remains or whether it is limiting will aid decision-makers as they consider turtle nesting habitat actions including site restoration, the creation of new nesting sites, and/or the possible release of hatchlings at new sites, all of which are options in the Vermont Recovery Plan (Vermont Fish and Wildlife Department, 2009). The results of the study will allow for a greater understanding of nest site requirements, availability, and quality of current and potential nest sites.

The goal of this study was to identify the characteristics of spiny softshell nesting habitat to inform management, conservation, and restoration activities. We addressed this goal in two ways. First, we used an observational study to identify characteristics of spiny softshell nesting habitat by comparing habitat features of known nesting sites to sites that do not support nesting. This informs the question of whether nesting habitat is limiting for this species in the Vermont portion of Lake Champlain. Second, we used expert elicitation and the analytic hierarchy process referred to as AHP (Saaty, 1987) to rank the importance of nesting habitat variables. This part of the study identified variables that could be targeted in management or restoration activities and will inform the creation of a scorecard to assess spiny softshell nesting habitat potential on the ground (Appendix B). We hypothesized that the spiny softshell turtle actively selects open beaches, with a shale substrate, and little human use of the site. Insights from our study will help decision makers, non-profit conservation groups, and private landowners understand the value of shoreline habitat parcels for spiny softshell nesting success, help them prioritize parcels for management, conservation, or restoration, and identify restoration activities that could improve nesting habitat quality

Methods

The importance of nesting habitat characteristics was quantified in two ways. The first was through an observational study where data on soil type, soil compaction, soil temperature, beach and vegetation characteristics, and human use were collected at both used and unused softshell nesting sites. The second was through an expert elicitation survey that asked experts to score the importance of nesting habitat variables. We used two separate studies (i.e., observational and survey-based) due to the limited number of extant nesting sites in the Lake Champlain basin but the relatively large number of regional experts who work with this species. This approach allows us to leverage both empirical data and collective expertise to maximize our learning in this system.

Observational study

Study area

Lake Champlain is a freshwater lake that is located in the northeastern United States. It is situated between New York and Vermont and extends into Quebec, Canada. We identified 16 study sites consisting of private and public shorelines along Lake Champlain between Burlington and Swanton, Vermont. The spiny softshell turtle currently nests at 4 of the 16 beaches selected. The remaining 12 sites do not currently support spiny softshell nesting and are a mix of known historic nesting sites (2) and non-historic sites (10 sites). Sites were selected based on the known range of softshell turtles, historical importance as a nesting site, and/or habitat similarities to the current known nesting sites.

Surveys

We surveyed sites 3 times each during the summer of 2022 to collect information on habitat characteristics. A plot of 50 m was selected at each site unless the beach was smaller than 50 m which was noted. If the site had considerable variation in habitat (e.g., significant changes in substrate, vegetation type, orientation, etc.), then additional survey plots were added. Sites were surveyed multiple times to ensure that seasonal changes in beach size, vegetation, and shoreline were assessed. On each visit, we collected information on substrate characteristics (soil type and compaction), vegetation characteristics, temperature conditions, predator presence, and human use. The presence of turtle nests from any species and the microhabitat characteristics around those nests were noted as ancillary information.

1) Soil characteristics

We characterized the soil of each site by 5 types based on sediment composition, which included soft sand (SS), gritty sand (GS), sand with woody debris (SW), pebble and sand mixture (PS), and pebble (P). Soil type is an important variable to consider because turtle eggs are porous. Substrates vary in their capacity to store, retain, and drain water. A substrate with more biomass (e.g., SW) may retain more water and since eggs are porous this may affect the growth of the embryo (Mitchell & Janzen, 2023; Wilson, 1998). Soil type was assigned using visual inspection while digging mock nests of a depth of 9 - 15 centimeters at the site. Sites that contained multiple substrate types were noted.

Different substrates may also retain heat differently. Though the spiny softshell turtles' sex is not determined by temperature (Greenbaum & Carr, 2001), temperature does affect the incubation duration (Ji et al., 2003; Mitchell & Janzen, 2023; Staines et al., 2019; Stanford et al., 2020). In general, warmer temperatures speed up the incubation period for turtle eggs while cooler temperatures delay incubation and may also cause overwintering in the nest if the hatchling is not ready to enter the water (Staines et al., 2019; Wilson, 1998). This may also increase the risk of predation. We hypothesized that the spiny softshell turtle would prefer to nest in a shale substrate similar to other softshell populations at their northern most ranges such as those in Montana, USA and Canada (Tornabene et al., 2018).

We also estimated the degree of soil compaction using an ordinal scale determined by the depth at which an individual may dig without resistance: 1) can dig 15-20 cm without resistance, 2) can dig 10-15 cm without resistance, 3) can dig 5-10 cm without resistance, 4) can dig 2.5 cm without resistance, and 5) fully compact soil that resists digging. Soil compaction affects the ability of a turtle to dig a suitable nest of the ideal depth, which for spiny softshells is typically 9-15 cm (Vermont Fish and Wildlife Department, 2009). We hypothesized that the spiny softshell would prefer to nest in soil that is between a soil compaction score of 1 and 2.

2) Vegetation characteristics

We recorded vegetation characteristics at each site which included vegetation type and ground cover. Vegetation type influences temperature, provides cover for hiding, and may even cause egg mortality if the root system engulfs a nest (Staines et al., 2019). The dominant vegetation type was recorded for each site. Vegetation types included willow (*Salix*), maple (*Acer*), oak (*Quercus*), and sumac (*Rhus*). Percent ground cover was noted only within the 50-m plot at each site and reflected the amount of ground cover based on 0 – 25 % increment categories. We hypothesized that known spiny softshell sites would have less vegetative cover and prefer sites with 25% ground cover or less than unused sites.

3) Temperature

Temperature was recorded using data loggers (HOBO pendant temperature and light data loggers, Onset Computer Corporation, Bourne, Massachusetts, USA). We placed data loggers at each in the sampling plot, and sometimes placed multiple loggers depending on each site's individual characteristics. For example, if the plot was predominantly shaded then the data logger was placed in a shaded area. If there was considerable variability to the plot in terms of vegetation or substrate, then 2 loggers were placed to capture the potential variability in temperature. The data loggers recorded the temperature of the soil every 15 min at a depth of approximately 3.5 to 6 inches, which is the approximate depth of a spiny softshell nest. We hypothesized that the spiny softshell sites would have higher temperatures when compared to non-nesting sites.

4) Predator presence

We used tracks to measure predator presence at each site. The identification of predators was recorded through track surveys that were performed during every site visit, unless it had recently rained, and involved walking a 50 m transect through the site and recording the presence or absence of tracks from the primary nest predators in our study system: raccoon, fox, and skunk. The transect began 5 m from the water's edge which was determined at the start of the season and is where nesting turtles will begin to nest. As the water receded through the season, the transect line remained fixed and did not change. We hypothesize that predator presence is a significant factor to nesting success of the spiny softshell turtle.

5) Human use

Human use was categorized as presence or absence during each visit to sites. Sites were visited during the mornings and afternoons while nesting and human disturbance would coincide (Lazure et al., 2019). Data collection would typically take 30 minutes at each site and the presence or absence of humans would be noted during the 30-minute duration. This included human activities on land or in the water within a 50-m radius of the designated “nesting” site. We hypothesize that the current spiny softshell nesting sites have no human use compared to non-nesting sites.

6) Beach orientation

Sites were categorized as either northward facing or southward facing beaches. Southward facing beaches provide warmer nesting environments for turtles like the spiny softshell turtle, which thrive in higher temperatures during nesting (Seabra et al., 2011). The increased warmth on the south facing beaches may contribute to optimal conditions for egg development and hatchling success in spiny softshell turtle nesting habitats as seen in smooth softshell turtles (Janzen & Morjan, 2001).

7) Proximity to development

Proximity to development was used in the expert elicitation and defined as the distance (in kilometers) to human development. Some sites, although they had no human use data collected during surveys conducted, were located in proximity to human development. Proximity to development was described as a site being within 1 km radius of development to encompass the home range of female spiny softshells during the spring/summer months (Galois et al., 2002).

Analysis

We used logistic regression to compare characteristics of nesting and non-nesting sites, including historical nesting beaches. Logistic regression is used to estimate the probability of a discrete outcome and can include the effect of variables (i.e., covariates) on that probability. In our case, we classified nesting sites as ‘1’ and non-nesting sites as ‘0’ and used logistic regression to model the probability of a ‘nest site’ as a function of different covariates. A model selection approach was used to evaluate the effects of covariates, which included soil type, substrate compaction, substrate temperature, vegetation type, ground cover, beach orientation, proximity to development, and human use (Anderson & Burnham, 2002). Models included only single covariates due to the sparseness of our dataset, and we used Akaike's Information Criterion with a correction for small sample size (AICc) to evaluate the relative support of each model (Anderson & Burnham, 2002). All analyses were performed using the R programming language (R Core Team, 2021).

Expert elicitation

Due to the lack of empirical information on spiny softshell in the Lake Champlain Basin and limited opportunities to monitor populations, expert elicitation was used to rank the importance of nesting habitat variables. This approach allowed us to harness the collective knowledge and experience of wildlife managers, researchers, and academics beyond what is published in the scientific literature. Although there are limitations to expert opinion data (Martin et al., 2012, Williams et al., 2019), expert elicitation has aided in conservation and ecology research for many species, including for turtles (Joseph et al., 2009; Martin et al., 2012; Teck et al., 2010; Williams et al., 2019). For example, Rees et al. 2016 used expert opinion to create a review of global research priority for conservation and management of sea turtles, demonstrating expert opinion is becoming an increasingly used tool to further conservation science (Rees et al., 2016). Expert elicitation is especially useful in systems where the rarity of a species limits the amount of empirical data available (Martin et al., 2012).

Given the difference in habitat, threats, and population status across the spiny softshell range, we enlisted regional experts to participate in a survey of nesting habitat. Experts were those identified as those who have worked with softshells or other turtle species in the Lake Champlain region. Individuals were identified as "experts" if they met any of the following criteria: 1) they authored peer-reviewed papers on subjects related to nesting habitat or wildlife management, conservation, and ecology of spiny softshells, 2) they are (or were) employed by a state or provincial wildlife management agency where they worked on Lake Champlain turtle species or specifically on spiny softshells, or 3) they are (or were) employed by a non-profit conservation group where their work focused on Lake Champlain turtle species or specifically on spiny softshells. A total of 15 experts were identified from the states of New York and Vermont, USA and province of Quebec, Canada.

We developed an online survey that asked each expert to rate the importance of different nesting habitat characteristics. These characteristics were identified through a literature review on the biology of nesting turtles and through the consultation of biologists from the Vermont Fish and Wildlife Department. There were 8 habitat variables identified, including soil type, soil compaction, soil temperature, ground cover, vegetation type, beach orientation, proximity to development, and human use. The experts were given a description of each variable. Soil type was defined as the texture of the soil which included sand, shale, and clay. Soil compaction was defined by the difficulty as it relates to digging a nest. Soil temperature was defined as the temperature of the soil at nest depth. Ground cover was defined by low lying plants and vines with extensive root systems. Vegetation type was defined by the type of trees and shrubs present. Beach orientation was defined by whether the site was a North, East, West, or South facing beach which may affect the amount of sunlight the site receives. Proximity to development was defined by the proximity to human development. Human use was defined by the intensity of use by people. These definitions allowed the experts to rank the variables based on the same understanding.

The survey was created using Qualtrics Survey Tool (Qualtrics, Provo, Utah, USA) and consisted of 28 pairwise comparison questions, one question ranking all 8 variables, and an open-ended question for comments. The pairwise comparisons were set up in two-part questions. In the first part of the question, the expert identified the variable that was more important out of the pair. In the second part of the question, the expert rated the relative importance of the variable chosen on a slider scale from 1 to 9, where 1 indicated equal importance and 9 indicated extreme importance of the variable chosen. If the expert chose the first variable, then the scale would be based off positive integers. If the expert chose the second variable as being more important, then the scale would be based off negative integers. The experts were then asked to rank all 8 variables from most to least important and finalize the survey with any last remarks. More details on the survey are provided in Appendix A.

Analysis

Survey results were analyzed using the analytic hierarchy process (AHP), which uses pairwise comparisons between a set of criteria (variables in our case) using the 1-9 Saaty scale above to generate priority scores for each (Saaty, 1990). A priority score is the weight of how important one criterion is in comparison to another criterion (Saaty, 1987). A matrix of the variables was created containing all pairwise comparisons, and where negative values were converted to reciprocals based on the Saaty scale. The geometric mean was chosen to calculate each priority score (Saaty, 1987; Saaty & Tran, 2007). To determine final priority scores, the geometric mean or 8^{th} root of the product of each matrix row was calculated. To allow for an easier interpretation of values, the priorities were normalized on a scale from 0 to 1. Each priority was divided by the sum value of priorities for the final weighted value of each variable.

The standard deviation for each variable score was calculated by taking the square root of the distance between each priority score and the mean of the criterion. The summed values were divided by the number of data points (in this case 8; Table 1). We then wanted to capture the results of any inconsistency throughout the matrix. A consistency ratio was calculated to measure the consistency between pairwise comparisons and can be interpreted as a measurement of deviation in expert judgement (Saaty & Tran, 2007). We calculated the consistency ratio (CR) using the formula: $CR = (\lambda - n)/((n-1)(RI))$, where λ is the maximum eigenvalue of the pairwise comparison matrix, n is the number of covariates, and RI is the random index. Saaty indicated that a consistency ratio of ≤ 0.1 is acceptable but a more conservative benchmark of ≤ 0.2 may be used for cases involving qualitative attributes like our covariates (Saaty, 1988). Given that, we used ≤ 0.2 as our benchmark. All survey results were analyzed in Program R (R Core Team, 2021) using the "ahpsurvey" package (Cho, 2019).

Results

Observational study

Logistic regression results indicated that there were some differences between nesting and non-nesting sites, even with our limited sample size. The best supported model included the effect of predation and received 72% of the weight (Table 2-1). This model indicated that predation negatively impacted the probability of nesting use by spiny softshells (β_1 = -19.57, SE = 3.80e+3). The second-best supported model included the human use covariate and received 14% of the weight (Table 2-1). This model indicated that the presence of humans negatively impacted probability of nesting use by spiny softshells (β_1 = -19.01, SE = 4.06e+3). Models containing soil type, soil compaction, ground cover, and beach orientation were not supported and received less than 5% of the weight each.

Results from the top two models were consistent with our predictions that the presence of both predators and humans would decrease the probability of a site being used by spiny softshell turtles. The top model estimated a probability of use of 0.50 (SE = 0.18) for sites without predation, and 0.00 (SE = 0.00001) for sites with predation. The second model estimated a probability of use of 0.36 (SE = 0.15) for sites without human use, and 0.00 (SE = 0.00001) for sites with human use.

Qualitatively, the four nesting sites were observed to have other similarities that were not identified by our models. The nesting sites contained a shale or shale mixture with little compaction. Since the nesting sites were managed, the beaches had very little ground cover, human disturbance, and evidence of predation. The 12 non-nesting sites showed substantial variability in soil type, ground cover, soil compaction, beach orientation, and human use.

Expert elicitation

We invited a total of 15 regional experts to participate in our study and 10 responded (response rate = 67%) to the survey ranking the relative importance of nesting habitat characteristics. The AHP analysis identified that human use had the highest priority score of 0.214, followed by soil type (0.174) and soil temperature (0.108). Ground cover (0.102), beach orientation (0.094), and soil compaction (0.068) followed in weighted scoring. Proximity to development (0.039) and vegetation type had the lowest weighted scores. A consistency ratio of ≤ 0.2 was seen from 7 out of 10 of the experts (Table 2-2).

Discussion

In the observational study, only two variables were identified as significant for spiny softshell nesting habitat. Predator presence and human use influenced the probability of spiny softshell turtles nesting at a site. Current nesting sites were either on private property that had little human disturbance, fenced off to deter disturbance of nesting areas, and/or were difficult to access by foot. These sites were also managed for predators by the Vermont Fish and Wildlife Department to increase nest success. The expert elicitation results indicated similar results with experts ranking human use as having the highest priority score followed by soil type.

Human use was a determining factor for nesting sites based on observation and expert elicitation. Though habitat loss overall is seen as a major threat to biodiversity, human disturbance has shown a considerable significance to the way it can affect a species (Selman et al., 2013; Turcotte et al., 2023). Studies have shown that human disturbance can significantly alter feeding habits, habitat use, and caring for young (Frid & Dill, 2002; Moore & Seigel, 2006). In the case of the spiny softshell turtle, the species will abandon nesting activity in response to human disturbance (Parren et al., 2021). Observation and experts identified high human use of a nesting beach can alter the nesting use of the spiny softshell. Reducing the human use of a site during nesting season may increase nesting activity for the spiny softshell turtle.

In the observational study, soil temperature was the highest-ranking nesting variable. Though softshell turtles do not have temperature-dependent sex determination, optimal soil temperatures aid in the incubation of hatchlings (Janzen & Morjan, 2001; Packard et al., 1981). Temperatures that are sustained above or below the optimal range may cause delays in development and fatality (Janzen & Morjan, 2001; Packard et al., 1981).

Predator presence appeared significant to whether the spiny softshell nested at a site. Similar to human use, predator presence can alter the behavior of a nesting species (Burns et al., 2013). Predators such as raccoons and skunks use their olfactory senses to discover nests and may find several nests in an evening. This can negatively impact a dwindling population. Efforts should continue managing for predation at current nesting sites.

Though soil type was not ranked highly according to the observational study, the experts ranked soil type second to human use. Two of the four known nesting sites consisted of sand substrate while the other two consisted of shale substrate. The spiny softshell throughout its range typically nests in a sand or mixed substrate while the northern most softshell turtle populations such as those in Quebec, Canada and populations in Montana, USA nest in shale substrate despite having nesting beaches with sand available (Tornabene et al., 2018). This may be due to the shale substrate maintaining a higher nest temperature and fluctuating less in temperature.

Ground cover and beach orientation were determined as mid-tier priority compared to the overall variables presented to experts. Ground cover has the ability to alter soil temperature and with an extensive root system "choke out" nests by ensnaring eggs into the root system not allowing hatchling to burrow out and ultimately suffocating them (Bustard & Greenham, 1968; Conrad et al., 2011). Beach orientation also has a similar effect on the nests by altering temperature. South facing beaches receive more sunlight throughout the day resulting in higher temperatures compared to north facing beaches (Seabra et al., 2011). The increased sunlight and higher temperatures on south facing beaches can create warmer nesting environments, which may influence the incubation temperature of the eggs and affect hatchling development.

Soil compaction, vegetation type, and proximity to development showed the least amount of priority for spiny softshell nesting habitat. Though soil compaction may be a concern for nest success (Crain et al., 1995), the sites observed in this study did not qualify as compacted soil. Experts also labeled soil compaction as a lesser concern for the spiny softshell in the region. Vegetation type was observed in the study although vegetation type was not seen as pertinent to quantifying suitable nesting habitat which was similar to expert opinion. Proximity to development had the lowest priority score in the expert elicitation.

There are several limitations to this study. The study's proposal included data collected during the nesting season of 2022 and 2023. Unfortunately, many of the study sites were underwater due to statewide, historic flooding that occurred during the summer of 2023. This limited data collection to one year. Nesting sites were also limited to the 4 known spiny softshell nesting sites and 12 non-nesting sites. Though there are only 4 nesting sites, future research may include a study with several years to enhance the data.

Along with limitations, there are several implications to consider when focusing on nest site conservation for the spiny softshell turtle. The observational study and expert elicitation showed that human disturbance alters the use of a nesting beach along with predation. The experts ranked soil type and soil temperature as important variables to consider as well. Sites may be managed by reserving areas of the beach for turtle nesting by creating barriers to exclude humans and predators. Further actions such as predator trapping and laying a wire mesh over the soil may also be required to deter predation. Suitable substrate may be brought into a site to create a more appealing nesting area for the spiny softshell. Though ground cover was not ranked highly in either study, reducing ground cover and vegetation will aid in achieving optimal nesting temperature (soil temperature being ranked highly) as well as easier nest site access. This study highlights the importance of nesting habitat management through the reduction of disturbance, use of suitable substrate, and maintaining optimal soil temperatures which will provide favorable conditions thus aid in stabilizing and increasing nesting activity and increasing the spiny softshell population.

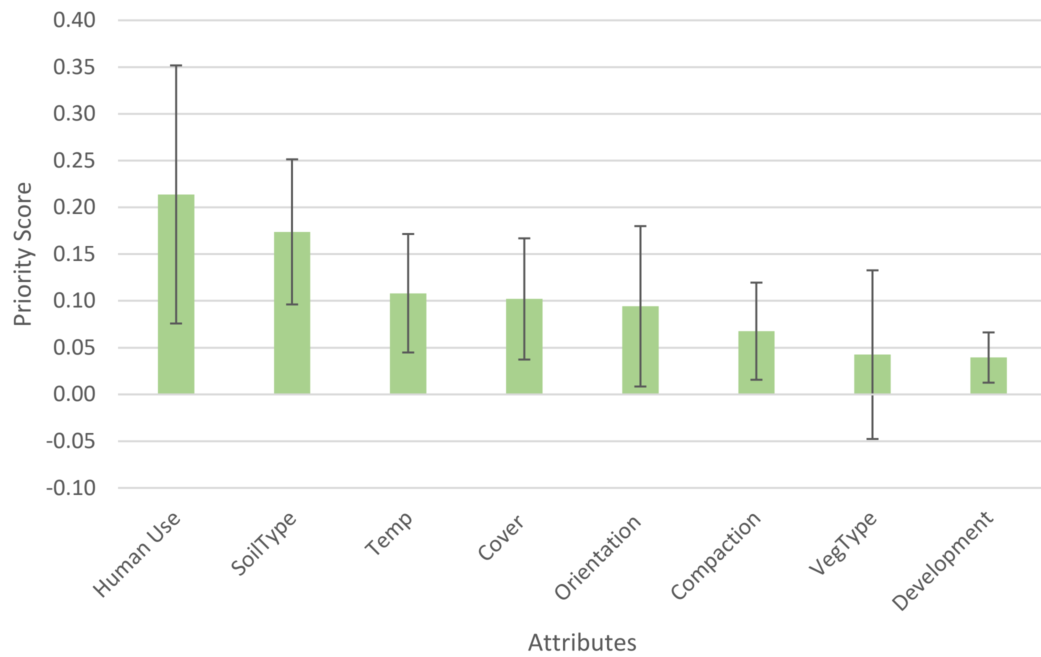

Figure 2-1. Spiny softshell (*Apalone spinifera*) nesting habitat variables ranked by priority score (± SE), which reflects importance. Priority scores were generated through an Analytical Hierarchy Process of expert opinion data.

Table 2-1. Model selection table for spiny softshell (*Apalone spinifera*) nest site selection. The probability of use of a given area for nesting was modeled as either constant (Null Model) or as a function of covariates. Model names reflect the model structure. Akaike's Information Criterion corrected for sample size (AICc), the difference in AICc values compared to the top model (ΔAICc), model weights (AICcWt), number of parameters (K), and log-likelihood (LL) values are shown for each model.

Model Name	K	▲ AICc	AICcWt	LL
Predator	2	0.00	0.72	-5.55
Human Use	2	3.21	0.14	-7.21
Null Model	1	5.31	0.05	-9.53
Ground Cover	2	6.14	0.03	-8.68
Beach Orientation	2	6.68	0.03	-8.95
Soil Type	2	7.79	0.01	-9.50
Soil Compact	2	7.86	0.01	-9.53
Vegetation Type	4	12.26	0.00	-8.60

Table 2-2. The consistency ratio of each expert who participated in the expert elicitation survey of nesting habitat characteristics for spiny softshell turtles (*Apalone spinifera*). An acceptable consistency ratio of ≤ 0.2 was observed in 7 out of 10 experts.

Expert	Consistency Ratio
1	0.165
2	0.348
3	0.057
4	0.142
5	0.366
6	0.175
7	0.076
8	0.206
9	0.041
10	0.140

References

Burns, F., Mcculloch, N., Székely, T., & Bolton, M. (2013). The impact of introduced predators on an island endemic, the St Helena Plover, Charadrius sanctaehelenae. *Bird Conservation International*, *23*(2), 125–135.

Bustard, H. R., & Greenham, P. (1968). Physical and Chemical Factors Affecting Hatching in the Green Sea Turtle, Chelonia Mydas (L.). *Ecology*, *49*(2), 269–276.

Catling, P. M. (2005). Effects of invasive alien plants on birds: Some examples from North America. *Biodiversity*, *6*(3), 30–39.

Cho, F. (2019). *ahpsurvey: Analytic Hierarchy Process for Survey Data* (0.4.1) [Computer software].

Cohen, J. B., Houghton, L. M., & Fraser, J. D. (2009). Nesting Density and Reproductive Success of Piping Plovers in Response to Storm- and Human-Created Habitat Changes. *Wildlife Monographs*, *173*(1), 1–24.

Committee on the Status of Endangered Wildlife in Canada. (2016, September 30). *COSEWIC annual report 2015 to 2016*

Conrad, J. R., Wyneken, J., Garner, J. A., & Garner, S. (2011). Experimental study of dune vegetation impact and control on leatherback sea turtle Dermochelys coriacea nests. *Endangered Species Research*, *15*(1), 13–27.

Crain, D. A., Bolten, A. B., & Bjorndal, K. A. (1995). Effects of Beach Nourishment on Sea Turtles: Review and Research Initiatives. *Restoration Ecology*, *3*(2), 95–104.

Defeo, O., McLachlan, A., Schoeman, D. S., Schlacher, T. A., Dugan, J., Jones, A., Lastra, M., & Scapini, F. (2009). Threats to sandy beach ecosystems: A review. *Estuarine, Coastal and Shelf Science*, *81*(1), 1–12.

Frid, A., & Dill, L. (2002). Human-caused Disturbance Stimuli as a Form of Predation Risk. *Conservation Ecology*, *6*(1), 1–16.

Galois, P., Léveillé, M., Bouthillier, L., Daigle, C., & Parren, S. (2002). Movement Patterns, Activity, and Home Range of the Eastern Spiny Softshell Turtle (Apalone spinifera) in Northern Lake Champlain, Québec, Vermont. *Journal of Herpetology*, *36*(3), 402–411.

Gonzalez-Abraham, C. E., Radeloff, V. C., Hawbaker, T. J., Hammer, R. B., Stewart, S. I., & Clayton, M. K. (2007). Patterns of Houses and Habitat Loss from 1937 to 1999 in Northern Wisconsin, Usa. *Ecological Applications*, *17*(7), 2011–2023.

Greenbaum, E., & Carr, J. L. (2001). Sexual differentiation in the spiny softshell turtle (Apalone spinifera), a species with genetic sex determination. *Journal of Experimental Zoology*, *290*(2), 190–200.

Janzen, F. J., & Morjan, C. L. (2001). Repeatability of microenvironment-specific nesting behaviour in a turtle with environmental sex determination. *Animal Behaviour*, *62*(1), 73–82.

Ji, X., Chen, F., Du, W.-G., & Chen, H.-L. (2003). Incubation temperature affects hatchling growth but not sexual phenotype in the Chinese soft-shelled turtle, Pelodiscus sinensis (Trionychidae). *Journal of Zoology*, *261*(4), 409–416.

Joseph, L. N., Maloney, R. F., & Possingham, H. P. (2009). Optimal Allocation of Resources among Threatened Species: A Project Prioritization Protocol. *Conservation Biology*, *23*(2), 328–338.

Kolbe, J. J., & Janzen, F. J. (2002). Impact of Nest-Site Selection on Nest Success and Nest Temperature in Natural and Disturbed Habitats. *Ecology*, *83*(1), 269–281.

Lande, R. (1993). Risks of Population Extinction from Demographic and Environmental Stochasticity and Random Catastrophes. *The American Naturalist*, *142*(6), 911–927.

Lazure, L., Pare, P., Bouthillier, L., & Galois, P. (2019). Nesting biology and conservation of a northern population of spiny softshell turtles (Apalone spinifera). *Herpetological Conservation and Biology*, *14*(3), 659–667.

Lovich, J. E., Ennen, J. R., Agha, M., & Gibbons, J. W. (2018). Where Have All the Turtles Gone, and Why Does It Matter? *BioScience*, *68*(10), 771–781.

Marsden, J. E., & Langdon, R. W. (2012). The history and future of Lake Champlain's fishes and fisheries. *Journal of Great Lakes Research*, *38*, 19–34.

Martin, T. G., Burgman, M. A., Fidler, F., Kuhnert, P. M., Low-Choy, S., Mcbride, M., & Mengersen, K. (2012). Eliciting Expert Knowledge in Conservation Science. *Conservation Biology*, *26*(1), 29–38.

Mitchell, T. S., & Janzen, F. J. (2023). Substrate Influences Turtle Nest Temperature, Incubation Period, and Offspring Sex Ratio in the Field.

Moore, M. J. C., & Seigel, R. A. (2006). No place to nest or bask: Effects of human disturbance on the nesting and basking habits of yellow-blotched map turtles (*Graptemys flavimaculata*). *Biological Conservation*, *130*(3), 386–393.

National Oceanic and Atmospheric Administration. (2023, August 8). *How long is the U.S. shoreline?* Oceanservice.Noaa.Gov.

Packard, G. C., Taigen, T. L., Packard, M. J., & Boardman, T. J. (1981). Changes in mass of eggs of softshell turtless (Trionyx spiniferus) incubated under hydric conditions simulating those of natural nests. *Journal of Zoology*, *193*(1), 81–90.

Parren, S. G., Parren, M. K., & Gieder, K. D. (2021). Nest Counts and Hatchling Emergence Timing for the Spiny Softshell (Apalone spinifera) and Associated Turtle Species at Managed Sites in Vermont, USA. *Herpetological Conservation and Biology*, *16*(1), 194–202.

Paterson, S., O'Donnell, A., Loomis, D., & Hom, P. (2010). The Social and Economic Effects of Shoreline Change: North Atlantic, South Atlantic, Gulf of Mexico, and Great Lakes Regional Overview. 1–29. Department of Natural Resources

Rao, N. S., Ghermandi, A., Portela, R., & Wang, X. (2015). Global values of coastal ecosystem services: A spatial economic analysis of shoreline protection values. *Ecosystem Services*, *11*, 95–105.

Rees, A., Alfaro-Shigueto, J., Barata, P., Bjorndal, K., Bolten, A., Bourjea, J., Broderick, A., Campbell, L., Cardona, L., Carreras, C., Casale, P., Ceriani, S., Dutton, P., Eguchi, T., Formia, A., Fuentes, M., Fuller, W., Girondot, M., Godfrey, M., Godley, B. (2016). Are we working towards global research priorities for management and conservation of sea turtles? *Endangered Species Research*, *31*, 337–382.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Saaty, R. W. (1987). The analytic hierarchy process—What it is and how it is used. *Mathematical Modelling*, *9*(3), 161–176.

Saaty, T. L. (1988). What is the Analytic Hierarchy Process? In G. Mitra, H. J. Greenberg, F. A. Lootsma, M. J. Rijkaert, & H. J. Zimmermann (Eds.), *Mathematical Models for Decision Support* (pp. 109–121).

Saaty, T. L., & Tran, L. T. (2007). On the invalidity of fuzzifying numerical judgments in the Analytic Hierarchy Process. *Mathematical and Computer Modelling*, *46*(7), 962–975.

Santana-Cordero, A. M., Ariza, E., & Romagosa, F. (2016). Studying the historical evolution of ecosystem services to inform management policies for developed shorelines. *Environmental Science & Policy*, *64*, 18–29.

Scheld, A. M., Bilkovic, D. M., Stafford, S., Powers, K., Musick, S., & Guthrie, A. G. (2024). Valuing shoreline habitats for recreational fishing. *Ocean & Coastal Management*, *253*, 107150.

Seabra, R., Wethey, D. S., Santos, A. M., & Lima, F. P. (2011). Side matters: Microhabitat influence on intertidal heat stress over a large geographical scale. *Journal of Experimental Marine Biology and Ecology*, *400*(1), 200–208.

Selman, W., Qualls, C., & Owen, J. C. (2013). Effects of human disturbance on the behavior and physiology of an imperiled freshwater turtle. *The Journal of Wildlife Management*, *77*(5), 877–885.

Sierszen, MichaelE., Morrice, JohnA., Trebitz, AnettS., & Hoffman, JoelC. (2012). A review of selected ecosystem services provided by coastal wetlands of the Laurentian Great Lakes. *Aquatic Ecosystem Health & Management*, *15*(1), 92–106.

Staines, M. N., Booth, D. T., & Limpus, C. J. (2019). Microclimatic effects on the incubation success, hatchling morphology and locomotor performance of marine turtles. *Acta Oecologica*, *97*, 49–56.

Stanford, C. B., Iverson, J. B., Rhodin, A. G. J., Paul van Dijk, P., Mittermeier, R. A., Kuchling, G., Berry, K. H., Bertolero, A., Bjorndal, K. A., Blanck, T. E. G., Buhlmann, K. A., Burke, R. L., Congdon, J. D., Diagne, T., Edwards, T., Eisemberg,

C. C., Ennen, J. R., Forero-Medina, G., Frankel, M., … Walde, A. D. (2020). Turtles and Tortoises Are in Trouble. *Current Biology*, *30*(12), R721–R735.

Stephens, S. E., Koons, D. N., Rotella, J. J., & Willey, D. W. (2004). Effects of habitat fragmentation on avian nesting success: A review of the evidence at multiple spatial scales. *Biological Conservation*, *115*(1), 101–110.

Teck, S. J., Halpern, B. S., Kappel, C. V., Micheli, F., Selkoe, K. A., Crain, C. M., Martone, R., Shearer, C., Arvai, J., Fischhoff, B., Murray, G., Neslo, R., & Cooke, R. (2010). Using expert judgment to estimate marine ecosystem vulnerability in the California Current. *Ecological Applications*, *20*(5), 1402–1416.

Tornabene, B. J., Bramblett, R. G., Zale, A. V., & Leathe, S. A. (2018). Factors Affecting Nesting Ecology of *Apalone spinifera* in a Northwestern Great Plains River of the United States. *Chelonian Conservation and Biology*, *17*(1), 63–77.

Turcotte, A., Garant, D., & Blouin-Demers, G. (2023). Effects of human disturbance on risk-taking behavior in painted turtles. *Ethology*, *129*(8), 406–420.

Vermont Fish and Wildlife Department. (2009). *Vermont Spiny Softshell Turtle Recovery Plan.pdf* (pp. 1–56). Agency of Natural Resources.

Williams, J. L., Pierce, S. J., Hamann, M., & Fuentes, M. M. P. B. (2019). Using expert opinion to identify and determine the relative impact of threats to sea turtles in Mozambique. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*(11), 1936–1948.

Wilson, D. S. (1998). Nest-Site Selection: Microhabitat Variation and Its Effects on the Survival of Turtle Embryos. *Ecology*, *79*(6), 1884–1892.

Appendices

Appendix A: Expert Elicitation Survey Information

The survey below was sent to experts who were identified by their work and participation in spiny softshell turtle research, management, or conservation in Lake Champlain. The survey started with an introduction to the study, indicated the number of questions, and included a prompt to help experts understand what to expect. The survey text follows below.

The purpose of this study is to understand nest quality of the threatened spiny softshell turtle in Vermont. The goal of collecting this data is to aid in informing decision makers on conservation and wildlife/habitat management for the species.

You can expect 28 pairwise comparison questions along with 1 question asking to rank the variables and 1 open ended question. See below for the covariates you can expect to see:

- Soil Type
- Soil Compaction
- Soil Temperature
- Vegetation Type
- Ground Cover
- Beach Orientation
- Proximity to Development
- Human Use

The survey should take approximately 30 minutes and we ask that you complete all questions. Your answers will remain anonymous. If there are any questions that arise, you may contact University of Vermont Master's student Destini Acosta at destini.acosta@uvm.edu or through phone at (XXX) XXX-XXXX.

Please Read Prompt:

Imagine that a new potential nesting site for the spiny softshell turtle is discovered. You are asked to visit the site and determine if it is a suitable nesting beach. When you arrive at the site, you have a list of variables such as soil type and human use which you use to determine if a site is suitable, however some of these variables are more important than others. The following questions will ask you to rank the importance of the nesting habitat variables that Influence nest site quality for the spiny softshell turtle.

Which of the following habitat variables do you think is more important for spiny softshell turtle nesting habitat quality?

Soil Type - texture of soil (sand, shale, clay)

Soil Compaction - difficulty relating to nest digging

Equal Importance (Score 1)

On a scale of 1 - 9, how important is the variable you chose above for spiny softshell nesting habitat quality compared to the variable not chosen? If equal importance leave slider at 1.
Use scale below for reference.

Intensity of Importance	Definition
1	The variables are equally important
3	One variable has moderate importance over the other
5	One variable has strong importance over the other
7	One variable has very stong importance over the other
9	One varaible has extreme importance over the other
2,4,6,8	Intermediate values of the scale above

1 3 5 7 9

Score For Variable Chosen

Appendix B: Habitat Suitability Scorecard Template

Example of the scorecard used for nesting site evaluation. Note that this is an example and does not encompass all variables and results. This scorecard can be used to rank candidate sites for future management actions, including hatchling releases, substrate manipulations, human use closures, and predator management. The scorecard can also be used by conservation organizations who acquire shoreline habitat to rank parcels by their turtle nesting habitat potential.

Key Habitat Variables and Conditions						
Date of assessment	Value	Site 1	Site 2	Site 3	Weight	
Soil Type						
Sand	65	65	15	75	0.17	
Shale	75					
Clay	15					
Soil Temperature						
>80	60	60	55	80	0.11	
70 - 80	80					
<70	55					
Ground Cover						
75-100%	25	50	35	65	0.1	
50 -75%	35					
25 -50%	50					
0 -25%	65					
Beach Orentation						
N	25	45	25	65	0.1	
E	45					
S	65					
W	40					
Human Use						
High = More than 15 people at a time	20	20	75	90	0.21	
Medium = between 5 to 15	75					
Low = 5 or less people at a time within 50 m	90					
Total		31.35	30.35	53.45		Weighted Scores