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Analyzing the Relationship Between Bog Turtle (*Glyptemys muhlenbergii*) Distribution, Soil and Hydrologic Conditions in Western North Carolina

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Abstract

The goal of this study was to investigate a correlation between soil temperature, water table depth, soil properties and water chemistry in comparison to the distribution of six telemetry tagged bog turtles (*Glyptemys muhlenbergii*) between May to December 2015. The larger purpose of this project was to develop a more thorough understanding of bog turtle habitat requirements and ecology, and to aid mountain wetland conservationists in preservation of the rare bog turtle and its equally unique habitat. The data suggested there may be a correlation between high soil organic carbon percentage at points of high bog turtle activity, and low organic carbon percentage for points classified as little bog turtle activity, with exception to points 2 and 5 which exhibited the opposite. There was a trend of high soil temperatures (7.0 -8.99°C) with turtle's 4.0, 4.1 and 3.4 potential points of hibernation, and the presence of groundwater seeps within each turtle's distribution over the study period. Turtle's 3.4 and 0.4 exhibited wide-spread movement; however, there appeared to be little evidence for correlation to this activity and the fluctuation of water table. When examining all other abiotic factors such as soil pH, water chemistry, water temperature/conductivity/pH, the data suggested that there was no apparent correlation between the distributions of the six telemetry tracked bog turtles. However, with an increased availability to data and time for analysis, a trend may become evident in future studies.

Keywords: Bog Turtles, Distribution, Mountain Bog, North Carolina, Conservation, Soil, Hydrology

1. Introduction

Bog turtle (*Glyptemys muhlenbergii*) southern populations range between the Blue Ridge Mountains of southwestern Virginia and northern Georgia and inhabit mountain fens.[1] Mountain fens are characterized by predominantly groundwater-fed hydrology, hydric soil and vegetation,[2] with a mosaic of wet and dry spaces interspersed throughout the habitat that fulfill a variety of bog turtle needs. Dry areas are used in basking, nesting, and incubating eggs, while soft mucky soils are used in protection, escaping high temperatures in summer, and hibernation in winter.[3] Small fluctuations in water table depth and soil saturation, can have a severe effect on bog turtle ecology as *G. muhlenbergii* rely on moist, mucky soils of up to 15 cm in summer and 45 cm in winter.[4]

Wetlands inhabited by bog turtles have a higher mean water table depth and overall soil and surface saturation than locations not found to be inhabited by bog turtles.[4] Mountain fens experience little water-table fluctuations resulting from the groundwater-fed hydrology[5] and provide flowing groundwater year-round that prevents bog turtles from freezing during hibernation.[3] Bog turtles located in western North Carolina likely cease terrestrial activity earlier than those at lower elevations due to colder temperatures. This naturally enhances *G. muhlenbergii* dependency on these fragile microhabitats.[6] Similarly, as a bog turtle's bodily functions and behavioral cues are controlled by body temperature, it remains highly important for bog turtles to organize themselves in areas with thermally stable soil for hibernation in winter and thermoregulation in summer.[7]

The bog turtle's small size and distinct coloration make it a highly coveted species by poachers across the Eastern U.S; however, habitat loss remains the largest threat facing bog turtle populations today.[1] Mountain wetlands provide sanctuary to a plethora of rare and unique flora and fauna, many of which currently face threats of extinction from irreversible habitat loss.[8] The mountain wetland ecosystem represents one of great importance and concern to conservationists because of the biogeographical isolation that these ecosystems face today. However, with great success the U.S. Fish and Wildlife Service established the Mountain Bogs National Wildlife Refuge in April of 2015, where nearly 23,478 acres across 30 different sites could soon be federally protected from anthropogenic alteration.[8]

The purpose of this study was to investigate a correlation between soil properties, hydrologic conditions, water table depth fluctuations and soil temperature variance, with the distribution of six telemetry-tracked bog turtles over a seven-month period ranging between May to December of 2015. Because of *G. muhlenbergii*'s rare and protected status, this project proves valuable for not only understanding the methodology in identifying suitable bog turtle habitat across Southern Appalachian fens, but also in developing conservation techniques for these fragile ecosystems.

2. Study Area and Methods

Study area. Franklin Bog is located within a rural neighborhood in Henderson County, North Carolina. Since 1975, 143 bog turtles have been marked at Franklin Bog, and it is estimated that 50-100 bog turtles reside there today. Bog turtles have been found at all life stages; however, young bog turtles (<6 years old) have not been found since 1992. The study site has an average low temperature of -4.6°C in winter and an average high temperature of 28.3°C in summer.[9] Muck depth ranges from 3.5 cm and 60.0 cm across the site, with an average depth of 27.0 cm.[10] Franklin Bog not only satisfies *G. muhlenbergii* muck depth requirement of 15-45 cm, but also houses a mosaic of wet and dry areas that are necessary basic bog turtle needs and life stages.[4]

Bog turtle tracking. Research colleagues at Warren Wilson College tagged and tracked six bog turtles over a seven-month period from May to December of 2015. Each bog turtle was initially found using a wooden stick that was gently prodded into the muck layer. When a bog turtle was struck, the stick and the turtle's carapace made a distinguishable "thud." The age, sex, and habitat condition were recorded, and their carapaces were docked according to the order in which each specific turtle was found. For example, turtle 1.4 was docked at the first marginal scute to the left of the nuchal scute, and four marginal scutes to the right of the nuchal scute. Once docked, a small tracking device was glued onto the carapace of each turtle so they could be found and identified later (Figure 1). The turtles were tracked using telemetry at irregular intervals (depending on the availability of the researchers) between May and December (Figure 2).

Figure 1. Bog turtle (*Glyptemys muhlenbergii*) with tracking device attached to carapace

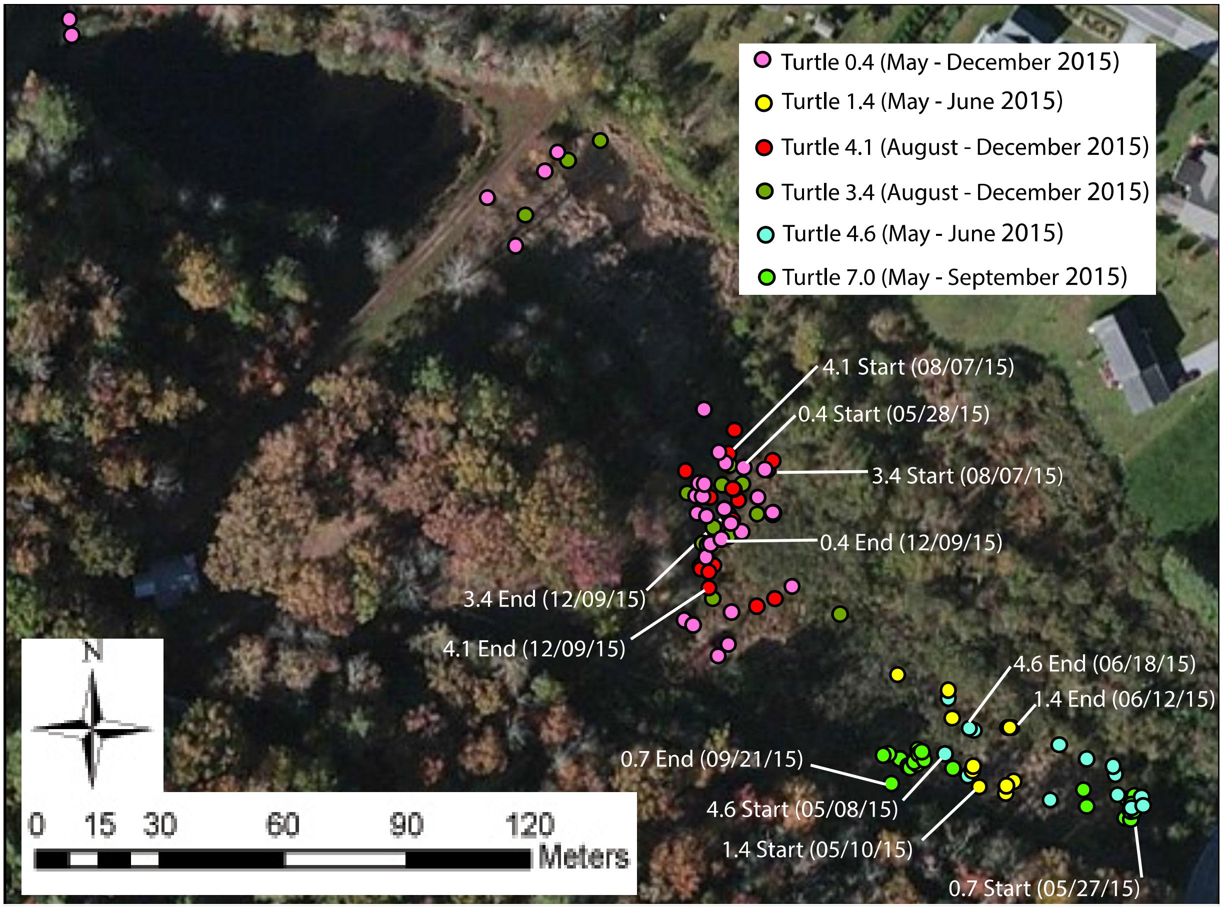

Figure 2. Locations of six telemetry tracked bog turtles (*Glyptemys muhlenbergii*) ranging between May – December 2015 at Franklin Bog, western NC

Hydrologic and soil analysis. Nine plot points representing a transect across the fen were evaluated for hydrologic and soil properties (Figure 3). Points 1, 2, 3, 6, and 7 were installed near areas of high recorded bog turtle activity, and points 4, 5, 8 and 9, were installed near areas of little to no recorded activity. Water samples were collected, and water temperature and conductivity were recorded from each of the nine points. Once the samples were transferred to the lab, each was filtered and injected the through an ion chromatograph to measure variances in major ions across the fen.

Muck samples were collected at each of the nine points and analyzed for soil pH and carbon content. To test for pH, 5.0 g of soil was measured out for each sample and placed into a plastic cup (except sample 6 which only had 4.0 g of soil). For samples 1, 4, 8 and 9, 1.00 mL of water was added for every gram of soil. For samples 2, 3 and 7, 2.00 mL of water was added per gram of soil, and for samples 5 and 6, 3.00 mL of water was added per gram of soil. Discrepancies in water ratios per sample were determined by the ease of saturation of each soil sample. Samples were then left to sit for 30 minutes, after which a calibrated pH meter was swirled around in the saturated muck until the ready was steady. The pH probe was rinsed and the process was repeated for each sample.

In testing for carbon content, roughly 5g of soil of each sample was weighed out into 15-mL ceramic crucibles, except for samples 5 and 6 where only 2-3g could fit in the crucible. All nine samples were oven dried at 105°C for at least one hour and then transferred to a desiccator for drying. Each sample was weighed, recorded and then placed back in the oven for combustion at 360°C for two hours. The oven was then turned down to 105°C for one additional hour, and then transferred to the desiccator. Samples were weighed one last time, recorded and Loss-on-Ignition (LOI) (1) was calculated to provide percent (%) of organic carbon in each soil sample.

$$\text{LOI (\%)} = (105°\text{C soil weight}) – (360°\text{C soil weight}) / (105°\text{C soil weight}) \times 100 \qquad (1)$$

Soil temperature analysis. A total of 140 soil temperature readings were collected in the field on February 29, 2016 using a soil temperature probe. GPS coordinates of each point were recorded.

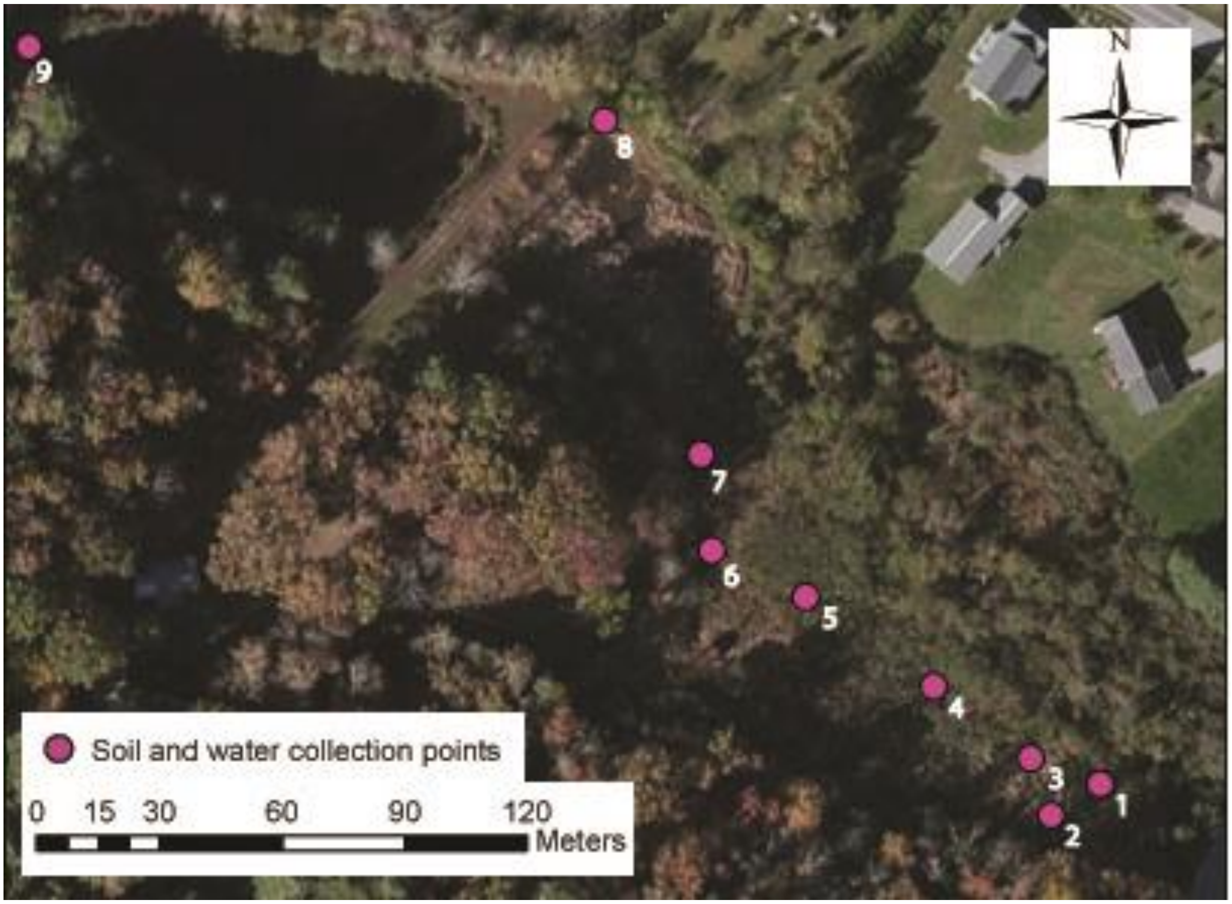

Figure 3. Locations of nine soil and water collection points from Franklin Bog, western NC

3. Results and Discussion

Bog turtle tracking. Turtle 0.4 was successfully tracked for the entirety of May – December 2015. Signals for turtles 1.4 and 4.6 were lost in June; the signal for turtle 7.0 was lost in September. The tracking devices, however secure, were not permanent fixtures on the bog turtle's carapaces and are assumed to have fallen off. Turtles 3.4 and 4.1 were tracked through December but were not initially tagged until August (Figure 2). Thus, the turtle movement data set is admittedly incomplete. If the study were to be duplicated, telemetry tracking should occur consistently, at least twice weekly for the duration of the study. Nevertheless, the data collected for this study was analyzed in an initial effort to identify trends between turtle movement and abiotic properties of the study site.

Bog turtles and soil properties. There was no apparent correlation between bog turtle distribution and soil pH as soil pH remained within 4.50 – 4.85 across all nine points (Table 1). For points classified as having frequent bog turtle activity (1, 2, 3, 6 and 7) organic carbon percentage ranged from 9.8% to 34.8% with a mean of 22.9±9.3%. For points classified as having little to no bog turtle activity (4, 5, 8 and 9) organic carbon percentage ranged from 4.7% to 26.9% with a mean of 12.6±10.0% (Table 1). These data suggest that high bog turtle activity may be associated with higher organic carbon, the relatively large standard deviations and two outliers (points 2 and 5) indicate more than nine soil samples would be necessary to show whether this relationship is statistically significant.

Table 1. Soil pH and percent of organic carbon (OC) from nine soil samples collected from Franklin Bog, NC

Sample	1	2	3	4	5	6	7	8	9
Soil pH	4.56	4.65	4.72	4.83	4.76	4.59	4.48	4.85	4.84
OC (%)	22.2	9.8	20.2	12.0	26.9	39.8	27.7	4.7	6.7

Bog turtles and water properties. Water pH was relatively consistent (6.3-7.3) across all nine-plot points, and therefore is not correlated with turtle activity. Likewise, water conductivity did not appear to be correlated with the movement of the studied bog turtles. Points of high turtle activity had recorded conductivity levels ranged between 23.0 uS/cm to 35.2 uS/cm with a mean of 30.5±4.9 uS/cm, while points of infrequent or no use had recorded levels between 16.5 uS/cm to 61.2 uS/cm and a mean of 32.1±20.1 uS/cm (Table 2).

Table 2. Temperature (°C), Conductivity (uS/cm), and pH of nine water samples collected from Franklin Bog, Western NC

Sample	1	2	3	4	5	6	7	8	9
Water Temp (°C)	0.6	1.0	0.5	2.3	5.1	6.4	5.0	2.5	5.7
Conductivity (uS/cm)	34.1	23.9	26.8	21.3	29.3	32.7	35.2	62.1	16.5
Water pH	7.2	6.3	7.3	7.0	6.8	6.9	7.0	6.9	6.7

Eight of the nine water samples were analyzed for the cations magnesium (Mg^{2+}), calcium (Ca^{2+}), ammonium (NH_4^+), sodium (Na^+) and potassium (K^+), and anions chloride (Cl^-) sulfate (SO_4^{2-}), nitrate (NO_3^-) and bicarbonate (HCO_3^-) (Table 3). On a Durov Diagram (Figure 4), cations plotted on a line ranging from Na/K water type for points 2 and 7 to a more Ca/Mg water type for points 1, 3, 4, 5, 6 and 8. HCO_3^- was the dominant anion for all samples, although points 2 and 7 have slightly higher sulfate concentrations (Figure 4). Although there is clear geochemical heterogeneity at the site, it does not appear to be correlated with points of high or low bog turtle activity. With more information about bog turtle movements in future field seasons, a trend may become more obvious.

Table 3. Chemical properties of nine water samples collected from Franklin Bog in western North Carolina.

Sample	Na	K	Mg	Ca	HCO_3	NO_3	SO_4	Cl	Charge Balance (%)
1	2.5	2.1	0.8	3.7	16.7	0.0	0.7	1.0	13.1
2	2.1	1.4	0.0	0.6	5.6	0.0	0.8	0.9	9.1
3	2.1	2.4	0.9	3.6	17.8	0.0	0.3	0.0	15.16
4	2.1	1.7	0.4	1.8	10.5	0.0	0.7	0.9	10.0
5	2.7	2.7	1.2	6.3	29.3	0.0	0.7	1.7	5.1
6	2.1	2.0	1.8	7.3	33.9	0.0	1.4	0.7	3.9
7	1.7	1.8	0.0	0.7	6.1	0.0	3.1	0.9	-9.8
8	1.5	1.3	0.6	3.0	14.4	0.0	0.0	0.6	7.7

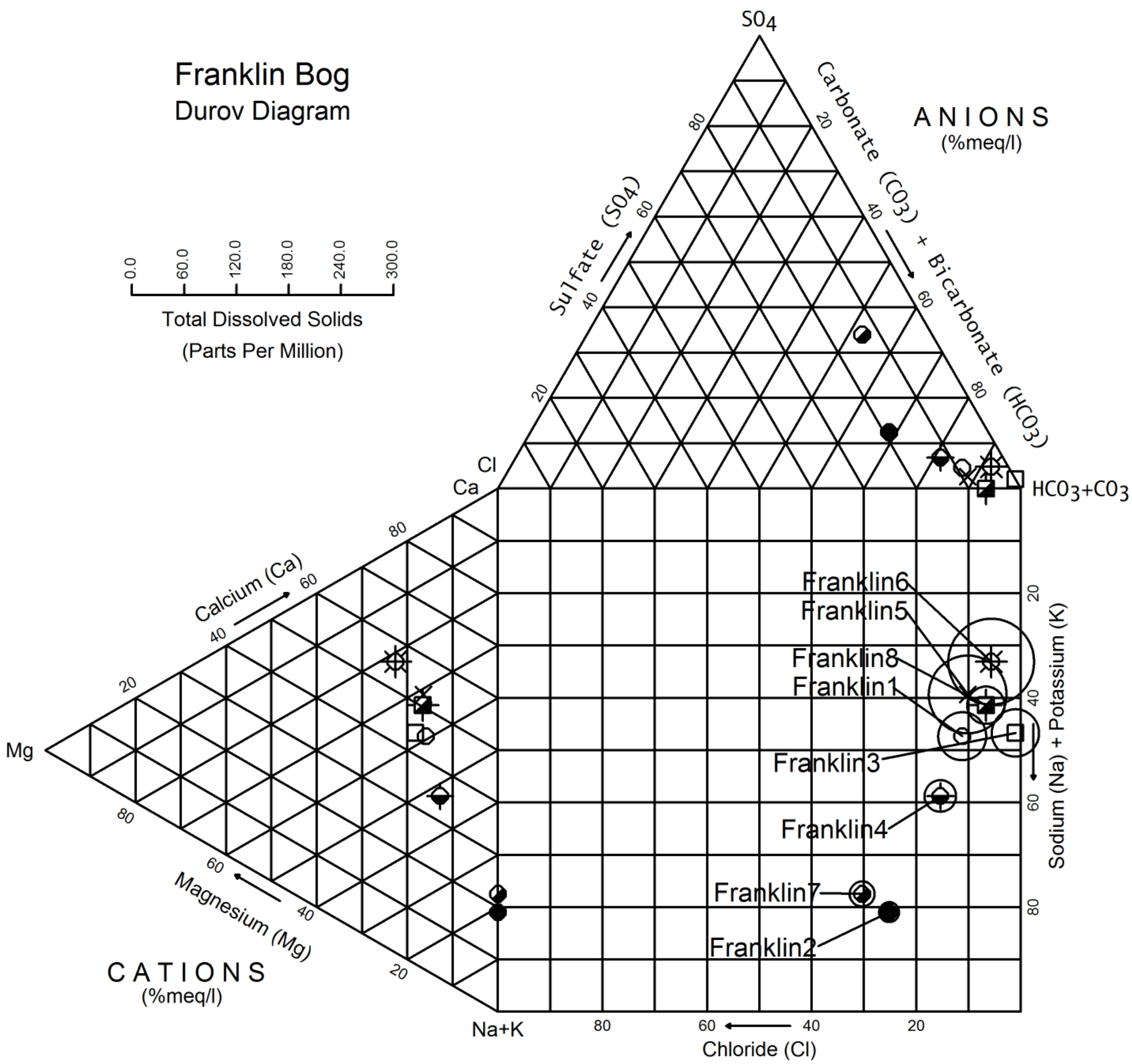

Figure 4. Durov Diagram illustrating the chemical composition of eight water samples collected from Franklin Bog, Western NC

Bog turtles and water table fluctuations. As turtles 0.4 and 3.4 both exhibited periods of wide-spread movement from bog habitat to pond-edge habitat, water table fluctuations were examined for a possible correlation with bog turtle movement. Turtle 0.4 moved North West from the central part of Franklin Bog – also known as the area it was most frequently located when tracked – to the terminal end of the first pond on the study site between 05/28/15 and 06/03/2015 (Figure 5). Between 06/03/15 and 06/29/16, turtle 0.4 continued moving West from the first pond to the terminal end of the second pond also located on the study site. Turtle 0.4 stayed at the terminal end of the second pond until 07/03/15, and was found to have moved back South East to first pond on 07/06/15. Almost 15 days later, turtle 0.4 was found back at the central location of Franklin Bog (Figure 5). Turtle 3.4 migrated North West from the central location of Franklin Bog to the terminal end of the first pond between 08/07/15 and 08/12/15, and remained there until at least 08/17/15. Turtle 3.4 was found back at the central location of Franklin Bog – where it was typically observed on days tracked – on 08/28/15 (Figure 6).

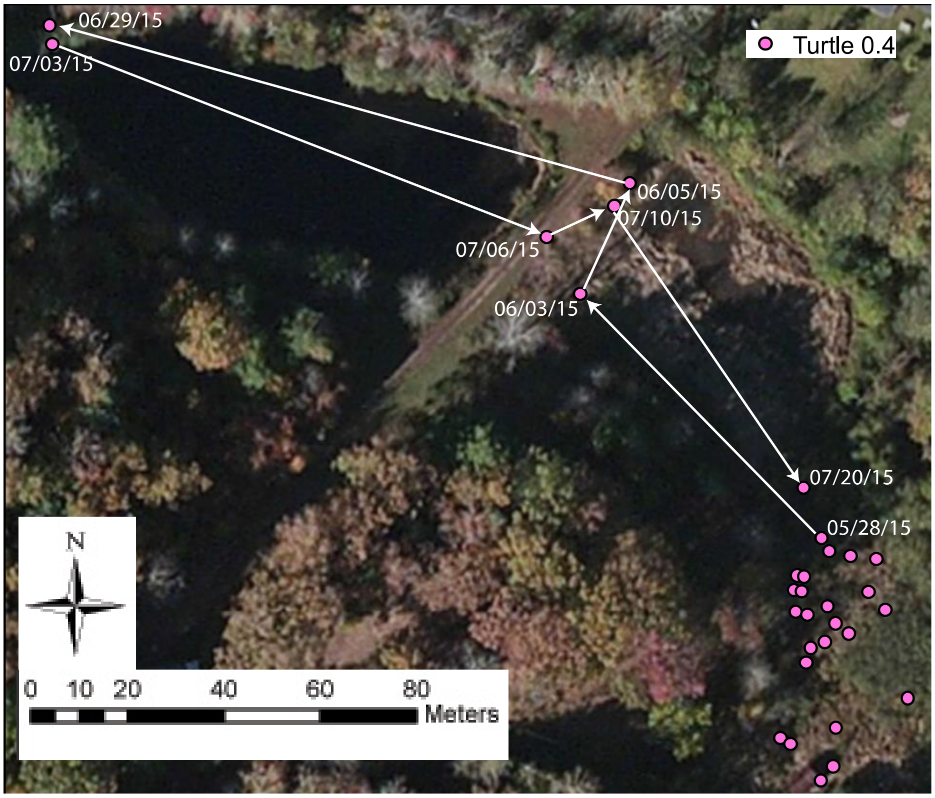

Figure 5. Mapped movement of turtle 0.4 in correlation to water table fluctuations at Franklin Bog, Western NC

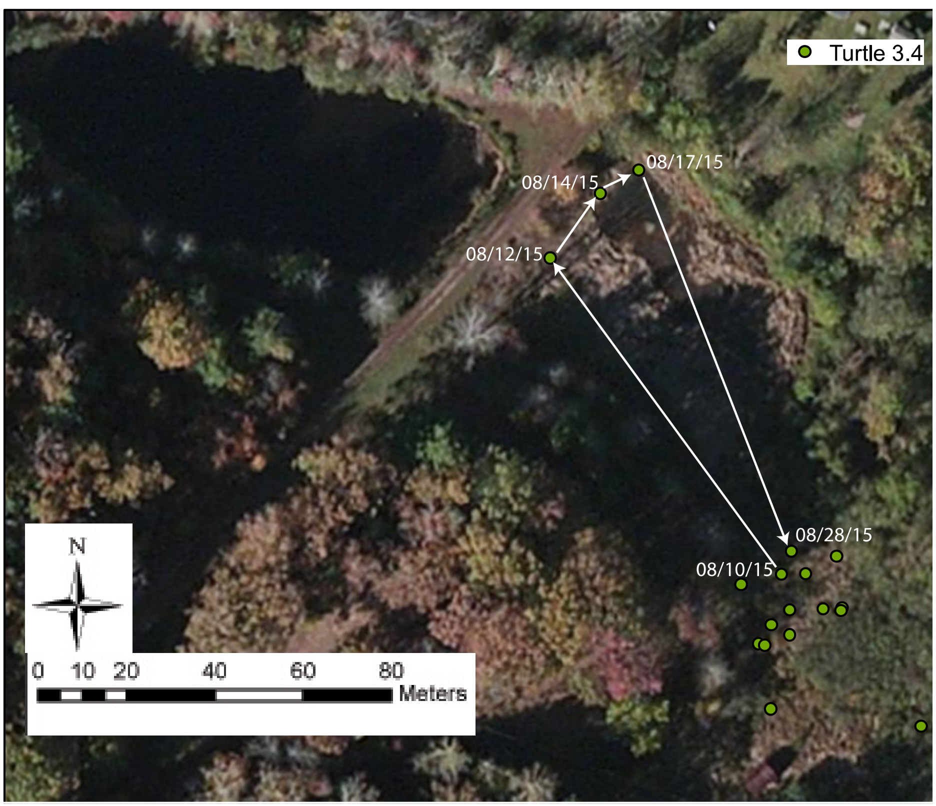

Figure 6. Mapped movement of turtle 3.4 in correlation to water table fluctuations at Franklin Bog, Western NC

Four groundwater monitoring wells that were installed prior to this study demonstrated several dramatic decreases in water table across the entire fen from the beginning of August through the end of September of 2015 (Figure 7). The data did not appear to support a correlation between turtle 0.4 movement and water table depth fluctuations as turtle 0.4 migrated to the ponds before the water table showed a significant decrease. Turtle 3.4 did migrate from the central region of Franklin Bog to the pond habitat in early August, and moved back by 08/28/15. Turtle 3.4 seemed to migrate back to the central region of Franklin Bog just as the water table appears to level out again, but also just before the most dramatic decrease recorded over the study period (September).

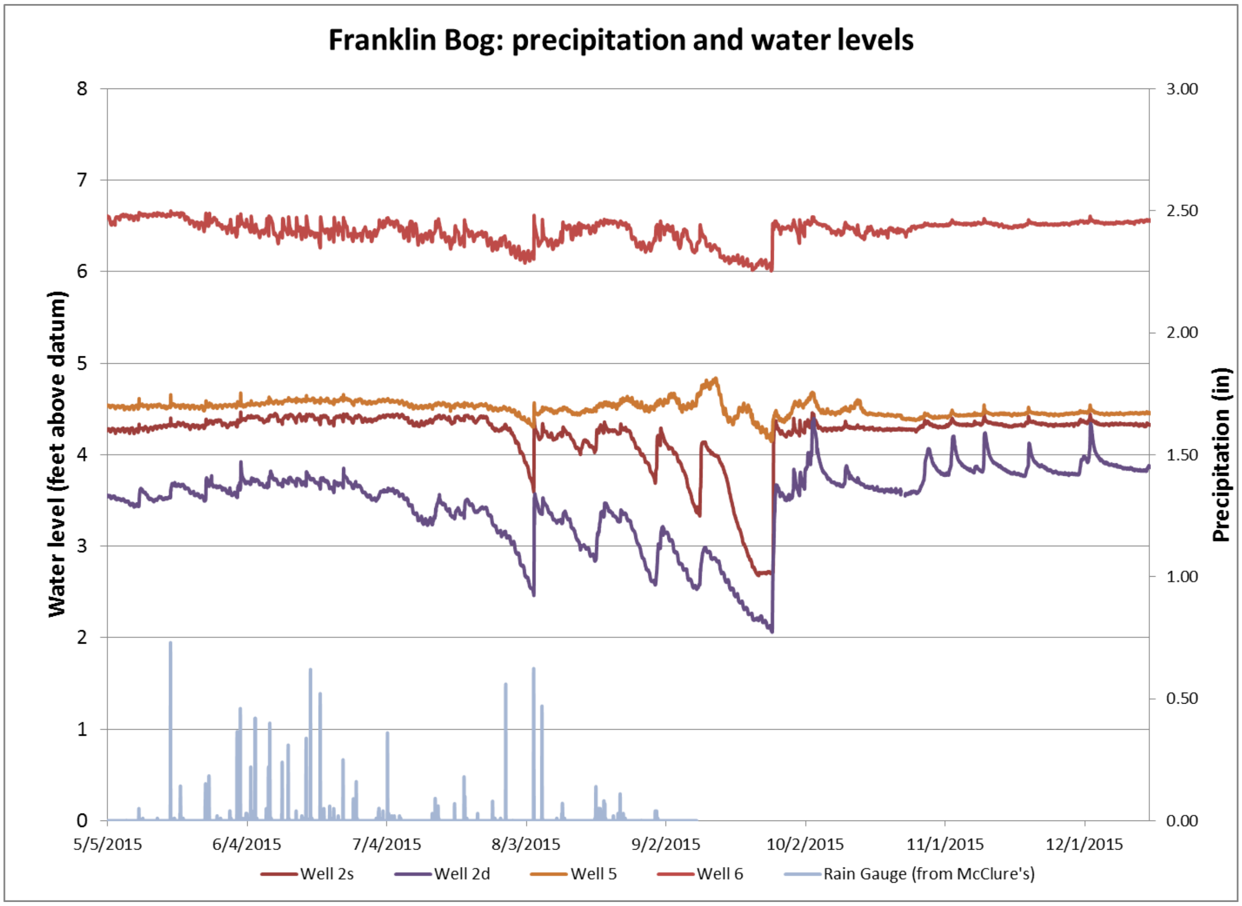

Figure 7. Water table depth fluctuations and precipitation changes at Franklin Bog of western North Carolina between 05/05/2015 and 12/15/2015

Bog turtles and soil temperature variance. Points of groundwater discharge could be spotted on February 14, 2016 by the presence of unfrozen, flowing water surrounded by stagnant ice, and were heavily concentrated on the south western edges of the fen. At ground water discharge points, water – and thus saturated soil – is geothermally regulated, so it can be assumed that the water coming out of the ground will be warmer than surrounding water in winter and cooler than surrounding water in summer.

The data suggests that for turtles 7.0 and 4.6 there was little relationship between bog turtle distribution and the presence of seeps, especially as they were often plotted in the far eastern corner of the fen with very little geothermal activity. Turtle 1.4 was consistently found at locations with higher geothermally heated soils than both turtles 7.0 and 4.6, but was still not assumed to be directly associated with groundwater seeps. For turtles 4.1, 3.4 and 4.0 there appeared to be direct a correlation with their distribution and the presence of groundwater seeps. Additionally, the three turtles tracked into December (4.1, 3.4, 4.0) also demonstrated a pattern between their potential hibernacula and high soil temperature (Figure 8). A more consistent data set of turtle locations and additional temperature points to increase accuracy of temperature gradient across the fen could potentially influence the trend between the two variables. Regardless of trends between the two variables, the data suggests that the soil temperature gradient across Franklin bog remains within a range that is suitable for bog turtle activity and success year round.

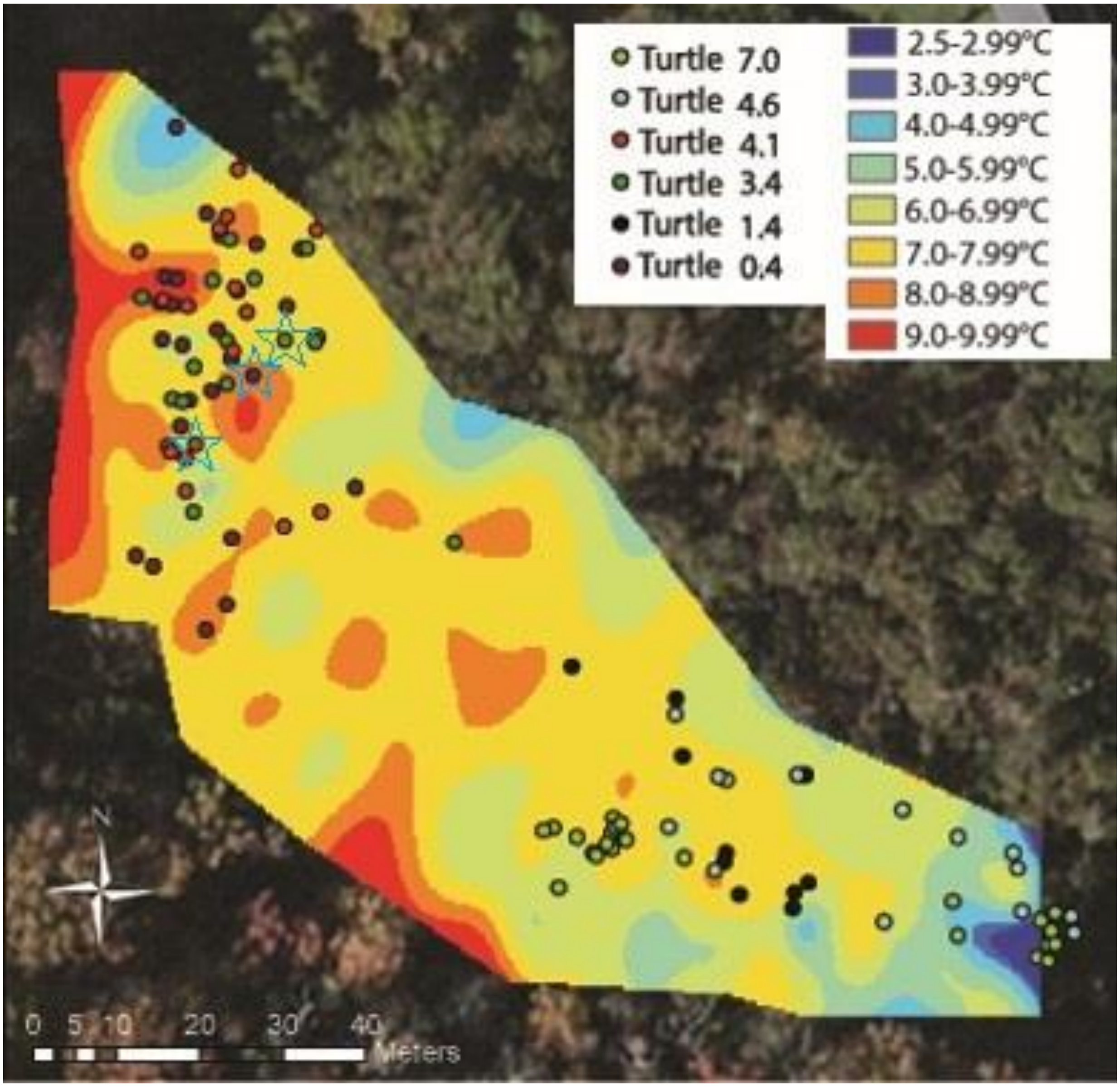

Figure 8. The position of geothermally regulated groundwater seeps in Franklin Bog, Western NC, in correlation with the distribution of six telemetry tracked bog turtles (*Glyptemys muhlenbergii*) between May – December 2015. The potential hibernation points are marked with blue stars for the three bog turtles (0.4, 3.4, 4.1) successfully tracked through December

4. Conclusion

This goal of this project was to examine the relationship between several abiotic variables of a mountain fen such as water chemistry and conditions, soil properties, water table fluctuations and soil temperature variance, and the distribution of the threatened bog turtle over a seven month period ranging between May – December of 2015. The data suggests that there may have been a trend in high levels of organic carbon content in the soil for points of high bog turtle activity, and for points of infrequent bog turtle activity there may have been a trend of low organic carbon content, with exception of the two outliers – points 2 and 5 – which exhibited the opposite. Turtle 3.4 showed evidence of moving to pond habitat at the beginning of a period of low water table depth during August of 2015, however turtle 3.4 returned to its area of usual activity before the most significant decrease in water table occurred. Turtle 0.4 also migrated to pond habitat and back again, but before any decrease in water table was recorded.

For the three bog turtles that were successfully tracked into December, there was a trend of high soil temperatures (7.0 -8.99°C) with each turtle's potential point of hibernation, and correlation to their distribution patterns in regards to the presence of groundwater seeps. When examining all other abiotic factors such as soil pH, water chemistry, water temperature/conductivity/pH, the data suggested that there was no apparent correlation between the distributions of the six telemetry tracked bog turtles. However, with an increased availability to data and time for analysis, a trend may become evident in future studies.

Nearly 5,000 historically known acres of mountain wetlands within the greater area of North Carolina have dwindled to a remaining 500 acres today, and most in poor condition.[11] With an estimated one third of all endangered species belonging to mountain wetland habitats, it remains imperative that these fragile ecosystems are safe from further anthropogenic degredation.[11] This project's purpose was to develop a more thorough understanding of bog turtle habitat requirements and ecology, with hopes to aid land management teams and mountain wetland conservationists in preservation of the bog turtle and its unique habitat. It was determined that regardless of trends between bog turtle distribution and specific abiotic factors within the fen, that Franklin Bog as a whole represents a habitat that is highly successful in encouraging the proliferation of bog turtle populations. And in summary, Franklin Bog should be regarded as an excellent model for suitable bog turtle habitat for future land management projects.

5. Acknowledgements

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