# Habitat selection, movements, and home range of bog turtles (*Glyptemys muhlenbergii*) in southeastern PA and investigation of grazing as a management tool

Report to the United State Department of Agriculture

Natural Resources Conservation Service

Chesapeake Watershed CESU

Award 68-7482-16-565

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September 2018

The bog turtle (Glyptemys muhlenbergii)

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## Introduction

Reptiles and amphibians are vulnerable to extinction worldwide, mostly due to anthropogenic impacts (Gibbon et al. 2000). Pennsylvania is home to one of the world's rarest and smallest turtles that is facing the threat of extinction. The bog turtle (*Glyptemys muhlenbergii*) is a federally threatened species native to the eastern United States. The range of the bog turtle is broken into two geographically distinct areas. A southern segment occurs in Georgia, North Carolina, South Carolina, Virginia, and Tennessee and the northern segment occurs in Massachusetts, New York, Connecticut, Delaware, New Jersey, Maryland, and Pennsylvania. Most individuals are thought to reside in New Jersey and Pennsylvania, especially in highly fragmented populations within 15 southeastern and eastern Pennsylvania counties (Drasher and Pluto 2010).

Bog turtles are habitat specialists that rely on early successional, spring-fed emergent wetlands where sedges and low grasses dominate (Tesauro and Ehrenfeld 2007; Drasher and Pluto 2010). These habitats are often groundwater supplied, which saturates surface soils but does not deeply inundate them (Chase et al. 1989, Ernst and Lovich 2009, Feaga 2010). Bog turtles use a mix of dry grasses (usually tussocks within the wetland) for basking and nesting, and wet areas with soft, muddy soils. Chase et al. (1989) found that 78% of their turtle captures were found next to low grasses and sedges. In Pennsylvania, the most common plants associated with bog turtle habitat include sedges (*Carex* sp.), skunk cabbage (*Symplocarpus foetidus*), cattail (*Typha latifolia*), sphagnum moss (*Sphagnum* sp.), cinquefoil (*Potentilla fruticosa*), poison sumac (*Rhus vernix*), swamp magnolia (*Magnolia virginiana*), alder (*Alnus* sp.), jewelweed (*Impatiens* sp.), swamp honeysuckle (*Lonicera oblongifolia*), and serviceberry (*Amelanchier spicata*) (Ernst and Lovich 2009; Drasher and Pluto 2010).

One of the largest threats to the bog turtle, and all amphibians and reptiles in Pennsylvania, is the combined effect of habitat destruction, fragmentation, and degradation (Maret 2010). Over 400,000 acres of wetland exists in Pennsylvania (DCNR 2015), which is less than 2% of Pennsylvania's land area (Tiner 2009). Pennsylvania is among the many states that have lost more than 50% of their estimated original wetland area. It is estimated that in the 200 years after the American Revolution, wetlands were lost at a rate of 60 acres per hour in the 48 contiguous states (Dahl 1990). Although wetlands have shown a net gain in recent years (DCNR 2015), the specialist nature of the bog turtle means that much of those additional wetlands are unsuitable for bog turtles, whose limited habitat is still in danger.

Bog turtle habitats are often small, isolated wetlands on privately owned land (Lee and Norden 1996). Development and soil disturbance often lead to the introduction of invasive species that threaten bog turtle habitat. Vegetation like purple loosestrife (*Lythrum salicaria*), multiflora rose (*Rosa multiflora*), reed canary grass (*Phalaris arundinacea*), and common reed (*Phragmites australis*) degrades bog turtle habitat by eliminating the open, sunny conditions required by the bog turtle (Tesauro 2001). Reed canary grass, cattails (*Typha* sp.), purple loosestrife, and common reed are weedy species that spread rapidly and can replace native plant communities (Zedler 2003). Succession of species, like red maple (*Acer rubrum*), can transform open-canopy fens into closed-canopy swamps (USFWS 2010). The rate at which open canopy wetlands turnover to closed-canopy swampland exceeds the rate at which the bog turtle can expand and maintain gene flow (Rosenbaum et al. 2007). Development in regions where these specialized habitats exist threaten the survival of the species and have led to protection by federal and state agencies. The bog turtle was listed as federally threatened under the Endangered Species Act in 1997. This status means that the bog turtle is in danger of becoming extinct in the foreseeable future (USFWS 2015b). In 2000, Gibbon et al. estimated that bog turtles had experienced a 50% population decline in the previous 20 years, earning it a critically endangered status from the International Union for Conservation of Nature (IUCN) and a listing in Appendix I of the Convention on International Trade in Endangered Species (CITES). The bog turtle is one of the most endangered turtles on the planet (Rosenbaum et al. 2007, Turtle Conservation Fund 2002).

It is assumed that in the past, as habitat became unsuitable, bog turtles migrated to other suitable habitat maintained by beavers and fire (Carter et al. 2000). Beavers created nonpermanent, vegetated wetlands by naturally damming the numerous, anabranching streams in the region (Walter and Merritts 2008). Beavers, fire, and grazing by bison and elk presumably maintained open, early successional fen habitats (Lee and Norden 1996) before colonial settlement reduced these activities and replaced native grazers with domesticated livestock (Tesauro 2001).

Because most remaining wetlands that contain bog turtles are small (<2 ha), turtles have relatively little area to meet specific microhabitat requirements (Lee and Norden 1996). With limited connectivity to suitable habitat, it is critical to identify and maintain the microhabitat structure required by the bog turtle. Understanding the specific microhabitat requirements, attributes, movements, and home range use of bog turtles is critical to understanding their ecology. Understanding how these components respond to grazing is critical in devising strategies for conservation and management.

Numerous studies have described general bog turtle habitat by characterizing the overall wetland where bog turtles are found (Ashley 1948, Barton and Price 1955, Bury 1979, Taylor et al. 1984, Chase et al. 1989). Only recently have studies examined habitat use versus availability to show habitat selection (Carter et al. 1999, Morrow et al. 2001a) and none, to our knowledge, have examined overall habitat selection in the bog turtle's range of southeastern Pennsylvania.

Morrow et al. (2001a) found that in Maryland, turtles chose thick sedges and rushes that were low to the ground and formed cover. They noted that low vegetation was typically associated with wetter areas, suggesting that turtles may be selecting for habitat structure rather than specific plant species. Characteristics of bog turtle habitat differ slightly across its range (Ernst and Lovich 2009). Though many characteristics exist in all locations, it is important to understand the specific microhabitat changes happening in southeastern Pennsylvania, as this region holds great potential for bog turtle recovery. Understanding habitat selection of bog turtles is essential to effectively managing and conserving habitat.

*Biology and life history*

As Pennsylvania's smallest turtle, the bog turtle averages around 10 cm in length, with males reaching larger sizes (11.5 cm straight carapace length) than females (9.6 cm straight carapace length). Males have longer, thicker tails and convex plastrons whereas females have flatter plastrons, shorter tails, and often a taller, higher domed carapace (Ernst and Lovich 2009, Barton and Price 1955). Bog turtles are often confused with the spotted turtle (Clemmys guttata); however they can be distinguished by the large orange spot on both sides of the head.

Bog turtles commonly eat invertebrates but also feed on vegetation, seeds, and berries (Barton and Price 1955, Hulse et al 2001). Seasonal activity begins in late-March and peaks when breeding occurs from April through mid-June (Barton and Pierce 1955). Nesting then occurs mid-June through early July. Turtles remain active in the summer and early fall before seeking hibernacula in late September through November (Ernst and Lovich 2009).

The bog turtle has a long lifespan (estimated 25-35 years) and generation time. Both males and females reach sexual maturity between four and six years of age (Barton and Price 1955), with most individuals maturing at six years in Pennsylvania (Ernst 1977). Females lay one clutch (1-6 eggs) per nesting season and may only nest once every 2-3 years (Somers et al 2000). Hatching commonly occurs in late August to September (Drasher and Pluto 2010).

Hatchlings typically overwinter near the nest location. Adult and juvenile turtles may hibernate together or alone in groundwater seeps that consist of widespread underground tunnels, frequently around shrubs with extensive root systems (Ernst et al. 1989, Sirois et al. 2014). Juveniles less than three years old may hibernate in shallower habitats; however adults will burrow deeper (Holub and Bloomer 1977). Bog turtles often show fidelity to nesting sites and hibernacula year after year (Sirois et al. 2014). Bog turtles are capable of long distance movements; however Carter et al. (2000) reported that 75% of movements (measured every 1-9 days) were less than 20m. Chase et al. (1989) reported that individual bog turtles often remain within an area of less than 4 $m^2$. Smith and Cherry (2016) reported much larger daily movements (14.09 m/day) in North Carolina; however other studies have shown smaller daily movements between 1 and 3 m/day (Lovich et al. 1992, Morrow et al. 2001b). While turtles may appear to only move a short distance they may still be active within a small area (Chase et al. 1989). Straight line measurements can underestimate actual distances traveled by as much as 6.5 times (Carter et al. 2000). Population size is not easily quantified as these animals are difficult to locate and often occur in very low numbers in fragmented, suitable areas. Bog turtle populations in Pennsylvania are extremely low in genetic variability, owing to a historical bottleneck and rapid post-Pleistocene expansion into the north from southern populations (Rosenbaum et al. 2007). Life history traits like long life span, low reproductive output, and delayed sexual maturity along with small population sizes, also contribute to low genetic diversity (Rosenbaum et al. 2007, USFWS 2001). These animals are also popular in the pet trade, where the illegal collection and removal of individuals can be detrimental to small, isolated populations, leading to inbreeding and loss of genetic diversity (Hulse et al 2001). Low genetic variability is a historical characteristic of this species, however, and is likely not as large of a threat as the fragmentation and loss of suitable habitat (Rosebaum et al. 2007).

*NRCS and wetland grazing*

The Natural Resources Conservation Service (NRCS), through Working Lands for Wildlife and the Wetlands Reserve Easement (WRE) program, purchases wetland easements in several states to assist private landowners in promoting conservation efforts; preventing habitat degradation and restoring bog turtle habitat (USDA 2014). Habitat management often includes removal of nonnative and invasive plants and control of woody succession by reducing cover of shading trees and shrubs.

Prescribed grazing is used as a management tool on some wetland easements (USFWS 2010), though the implications are poorly understood. While overgrazing can contribute to wetland degradation (e.g., through nutrient loading and erosion), a low density of grazing cattle may help maintain open, sunny conditions (Tesauro and Ehrenfeld 2007), slow natural plant succession, and prevent the invasion of nonnative and invasive vegetation. When cattle graze, they break up dense rhizomes and improve the quality of the soil, potentially helping the bog turtle to tunnel and move among habitats (Tesauro 2001).

Changes in vegetative height and cover are particularly important to the bog turtle. Tesauro and Ehrenfeld (2007) demonstrated that cattle grazing decreased the height of invasive species and increased cover of native species that bog turtles depend on. In their study, cattle effectively reduced the canopy closing ability of purple loosestrife, a common invasive wetland species.

*Home range and estimation*

Home range estimation is an important component in understanding how bog turtles utilize available habitat. Ernst (1977), using the minimum convex polygon (MCP) method, reported a mean home range for males of 1.33 ha and 1.26 ha for females in Pennsylvania. Eichelberger (2005), also using MCP, found that at one location in Pennsylvania, home ranges averaged 1.34 ha and turtles utilized a total area of 4.44 ha. Studies in Maryland using harmonic mean measure of animal activity have reported mean home ranges of 0.066 ha in females and 0.176 ha in males (Chase et al. 1989). Morrow et al. (2001b), using 95% kernel density estimates (KDE), have shown home ranges to range from 0.003 to 3.12 ha. A study in Massachusetts, at the northernmost edge of the bog turtle’s range, using the MCP technique, found much larger home ranges of 2.69-6.69 ha, which varied between sites and years (Sirois et al. 2014). Smith and Cherry (2016) note that their calculated home ranges were highly variable based on technique but found that more than 80% of the calculated home ranges were below 1.55 ha. These differences in home range size may be due in part to the choice of estimator. Byer et al. (2017) found significant differences between 95% KDE estimates and 95% MCP (a conventional reduction of MCP) but found no significant difference between 50% KDE estimates and 95% MCP.

Minimum convex polygon home range is an early, parametric technique that is determined by constructing a polygon around the coordinate points of each animal where lines form exterior angles greater than or equal to 180 degrees (Bolstad 2016). MCP gives a simple outline of an animal’s home range. However, it includes areas that an animal was never observed using and equally weighs all areas that animals use (Row and Blouin-Demers 2006, Powell 2000). Because of this, the MCP technique does not answer interesting ecological questions regarding the contribution of different areas and habitat selection (Nilsen et al. 2007). Polygons also vary with the number of tracking events and generally increase as capture points increase (Jennrich and Turner 1969). Nevertheless, MCP is useful for comparing the maximum home range for herpetofauna and can be used for comparative purposes (Row and Blouin-Demers 2006).

Advances in tracking technology (e.g. radio telemetry) have necessitated the use of new methods in estimating home range. Kernel density estimation (KDE) is an increasingly common technique often used in conjunction with MCP. This nonparametric method uses kernels that create a more biologically relevant home range by emphasizing areas of greater use and is a much more useful technique to examine habitat selection (Worton 1989, Row and Blouin-Demers 2006). Using this method, a kernel is placed over each observation of an individual. Each kernel represents a probability density with a volume equal to 1. When kernels overlap on a two-dimensional surface this increases the density. Choosing the smoothing parameter (bandwidth selection) is an important parameter in using this method and is often a controversial topic among ecologists and mathematicians. The bandwidth is the radius of a circle within which locations are counted, and it controls the contribution of each point to the overall density. Therefore, the bandwidth, often symbolized as *h*, defines the spread of the density distribution. Considerable conflicting information exists regarding "best" practices for estimating kernel density and, unfortunately, there is no universally accepted method for choosing a bandwidth (Bolstad 2016, Gitzen et al. 2006).

Wide kernels (large bandwidths) allow for greater influence of distant observations and will reveal a general shape of the point distribution, but tend to spread, or oversmooth, resulting in an overestimate in home range size. Narrow kernels are most affected by nearby observations and will show finer detail, but may underestimate home range size and may fragment the estimated home range (Seaman and Powell 1996, Gitzen et al. 2006). Sample size (i.e., number of tracking events) is another consideration and, in general, small sample sizes cannot determine fine structure and will overestimate home range size. Some common methods for bandwidth estimation include reference (default) bandwidth, least squares cross validation (LSCV), and plug-in methods.

The reference bandwidth is often the default in many statistical software packages. However, because it treats distributions as unimodal, this tends to overestimate home range size and oversmooth the density estimate. Relying on the default bandwidth is not recommended for use with multimodal data, which is typical of mobile species (Walter et al. 2011, Seaman and Powell 1996, Naef-Daenzer 1993).

The LSCV method calculates multiple values by leaving out one location each time and chooses the bandwidth that produces the lowest error between the true density and the kernel density estimate. Seaman and Powell (1996) found that LSCV produced home ranges with the least bias when compared with other bandwidth methods. Their study used sample sizes of 50 and 150 observations, considerably more than this study. LSCV is considered a reliable bandwidth (Worton 1989), especially when the data has tight clusters of points. However, if the data are too clustered (e.g. same location is observed more than once) the LSCV becomes less reliable and may fail (Gitzen et al. 2006, Row and Blouin-Demers 2006).

The solve-the-equation plug-in method, further referred to as plugin, is considered a second-generation bandwidth selector and may offer an alternative to the previous, first-generation methods, which often have poor tradeoffs between variance and bias. This method approximates the second derivative of the density through numerous iterations (Jones et al. 1996, Troudi et al. 2008). The plugin method is recommended for less mobile species that utilize patchy habitat and small geographic areas. It results in less smoothing, and thus less overestimation of home range size than the LSCV method (Gitzen et al. 2006, Walter et al. 2011). We used this method in our kernel density estimates of home ranges.

*Purpose*

The purpose of this study is to 1) assess structural changes in vegetation within habitats where grazing is applied as a management tool for the enhancement of bog turtle habitat, 2) to determine how these changes affect microhabitat use and movement of bog turtles, and 3) compare methods of home range estimation. This information will improve our understanding of this species' needs and help agencies, like NRCS, make informed decisions regarding bog turtle conservation and habitat management.

## Methods

*Study sites*

Study sites were located in Chester, York, and Berks counties in southeastern, Pennsylvania. This study was conducted at two grazed (GRZ1 and GRZ2 sites) and three ungrazed (UGR1, UGR2, and UGR3 sites) Natural Resource Conservation Service (NRCS) wetland easements. All sites were known to be occupied by bog turtles. Despite considerable effort, we were unable to find additional grazed and ungrazed NRCS easements occupied by bog turtles in southeastern Pennsylvania.

The GRZ1 site is a 27.4 acre (11.1 ha) easement located in York County. Approximately 15 cattle had intermittent access throughout the entire study period, with plans to reduce this herd. The property contains a stream that runs the length of the easement, pasture, scrub-shrub, and forested wetland. The easement contains a mosaic of emergent wetland and upland. There are multiple areas of core habitat, including areas with woody species like alder (*Alnus sp.*), red maple (*Acer rubrum*), and multiflora rose (*Rosa multiflora*).

GRZ2 is a 30.3 acre (12.3 ha) easement located in Chester County. Approximately 22 cattle had grazing access beginning in July 2017. Reed canary grass (*Phalaris arundinacea*) is dominant in the core habitat. The wetland at the GRZ2 site extended into an adjacent, ungrazed site that was only surveyed for turtles in spring 2018; however no turtles were located originally on this property. Fencing separates the two properties and turtles were observed traveling between the two sites. When a turtle was observed in the ungrazed site, the microhabitat data was considered ungrazed for analysis.

The UGR1 site is a 29.2 acre (11.8 ha) easement located in Chester County. Much of this site has been historically altered and contains spring-fed wetlands that were ditched. The site contains patches of common reed (*Phragmites australis*), reed canary grass, and areas of scrub-shrub mix, as well as emergent habitat dominated by rushes, sedges, and grasses. This habitat stretches between two fields, one of which is continually grazed by two horses. All turtles were initially found in the field that excluded grazers. Because the horses were not witnessed entering the wetland and were excluded by fencing in June 2017, this site was considered ungrazed.

UGR2 and UGR3 are 5.2 and 6 acre (2.1 and 2.4 ha) easements, respectively, located in Berks County. UGR2 contains a wetland area dominated by reed canary grass, wooded wetlands, a pond, and a creek. UGR3 contains open emergent, scrub-shrub dominated by cattail, and forested wetland. Several springs feed a creek that connects these two sites, which are less than 1 km apart but separated by a four-lane highway.

An additional grazed site, Stolzfus located in northern Chester County, was surveyed with crews from MACHAC three times in April and May 2017. No turtles were ever found at this site although the site contains suitable bog turtle habitat. Surveyors who had previously visited the site mentioned turtles found on an adjacent property years ago. We were unable to survey that property and could not confirm the presence of bog turtles or suitable bog turtle habitat.

Total dissolved solids and pH measurements at each site were collected using an Oakton® PC450 multimeter. Measurements were recorded at turtle locations on one day of tracking in April 2018 in shallow, standing water (<5 cm). These data can be found in Table A1.

*Collection and tracking*

During the 2017 season, we affixed transmitters to each of 24 bog turtles (11 males, 13 females) (Table 1, Table A2). Not all turtles were tracked for equal length of time. During the 2017 season, three turtles (1 male from GRZ2, 1 male from UGR1, and 1 male from UGR2) were lost due to transmitter detachment, though the turtle at UGR1 was recovered at a later time. One female turtle at GRZ2 was found dead (stepped on by a cow) and another (1 male from GRZ1) was lost due to premature transmitter battery failure during the 2017 season and recovered in October 2017. In October 2017, all turtles with transmitters were caught and the transmitters were replaced to ensure adequate battery life so that the turtles could be rapidly located in the spring. Other turtle species encountered during surveys or tracking can be found in Table A3.

In April 2018, we again replaced transmitters to ensure adequate battery life for the 2018 field season. We also caught and affixed transmitters to an additional 4 bog turtles (2 males, 2 females) at UGR3, 1 female at GRZ2, and recovered the previously lost male at UGR2. This resulted in a total of 27 turtles (12 males, 15 females) tracked in 2018 and 29 different turtles (13 males, 16 females) tracked overall (Table 1).

Table 1. Total bog turtles tracked during the 2017 and 2018 seasons.

| | 2017 Turtles | | | 2018 Turtles | | |
|---|---|---|---|---|---|---|
| **Site** | Male | Female | **Total** | Male | Female | **Total** |
| GRZ1 | 3 | 5 | **8** | 3 | 5 | **8** |
| UGR1 | 3 | 3 | **6** | 3 | 3 | **6** |
| UGR2 | 2 | 1 | **3** | 2 | 1 | **3** |
| GRZ2 | 1 | 2 | **3** | 0 | 2 | **2** |
| UGR3 | 2 | 2 | **4** | 4 | 4 | **8** |
| **Total** | 11 | 13 | **24** | 12 | 15 | **27** |

We surveyed most sites with the help of Mid-Atlantic Center for Herpetology and Conservation (MACHAC) staff and volunteers. We searched visually and by probing in soft muck and in tussocks. All field equipment was disinfected with chlorhexidine between sites following Northeast Partners in Amphibian and Reptile Conservation protocol (NEPARC 2014). Upon finding a turtle, it was sexed, photographed, weighed, and, if unmarked, marked with a unique notch in the carapace. Turtles were also measured for straight carapace length, straight plastron length, carapace width, plastron width, and height to the nearest 0.1 mm. Because many of these sites were previously surveyed for turtles by personnel from MACHAC, marking of turtles was coordinated with MACHAC personnel to avoid duplicating codes. The age of each individual was determined by counting annuli on plastral scutes. The oldest turtles we could age were approximately 15 years old, as the burrowing behavior of bog turtles causes the plastron to become smooth, making it impossible to accurately age (Ernst 1977). Each turtle was fitted with a transmitter (Wildlife Materials SOP-2190). Juvenile turtles (<70mm straight carapace length) were not affixed with transmitters but all other data were collected. In 2017, the right, rear pleural scute was used as the transmitter attachment site except for two turtles, one of which had previous damage to the carapace that created a good attachment site and another which had damage to the right, rear leg. In this case the transmitter was attached on the left side to reduce weight on the damaged leg. In 2018, many of the replacement transmitters were attached to the left, rear pleural scute to avoid potential damage from repeated attachment to the previous attachment site. The attachment area was gently roughed using a wire brush and scour pad, then cleaned thoroughly with water and alcohol and allowed to dry. Epoxy gel was used to attach the transmitter, allowed to dry, and colored with a black marker to reduce visibility. Turtles were released at point of capture. Transmitter antennae trailed to the rear of the turtle and total transmitter and epoxy did not exceed 10% of the body weight. Weather conditions were recorded during each survey.

Turtles were tracked using radio telemetry (Wildlife Materials receiver model TRX-2000S) and were occasionally handled during tracking to examine transmitter attachment. Our scientific collecting permit from the Pennsylvania Fish and Boat Commission restricted radio-tracking to once per week, except for the nesting season from June 15 through September 15, when tracking was restricted to twice per month. Turtles were tracked an average of 10.9 times (range 5-16) during the 2017 study period. During spring 2017 (April-mid June), turtles were tracked roughly weekly, with a mean of 9.15 days (range 4-17 days) between tracking events. In summer 2017 (mid-June to early August), turtles were tracked biweekly with a mean of 14.06 days (range 11-18 days) between tracking events. During fall (mid-August through October), turtles were tracked less frequently (mean 17.88 days, range 9-29 days). In 2018, turtles were tracked during the spring and early summer (April-June), with a mean of 7.49 days (range 3-12 days) between tracking events. Turtles were tracked an average of 7.7 times (range 4-9) during the 2018 study period). These results exclude periods of time when turtles were lost and recovered at a later date or were not located during a tracking event.

GPS coordinates were recorded at each turtle location using a Garmin GPSMAP® 64s unit and downloaded using the DNRGPS application version 6.1.0.6 (Minnesota Department of Natural Resources 2014). Animals determined to be underground were not unearthed. New transmitters were affixed to remaining turtles in October 2017 to guarantee a full transmitter battery life for the winter, and again in April 2018. Upon completion of tracking in late June 2018, transmitters were removed, and turtles were released at final point of capture.

Because of the difficulty involved in finding turtles, in spring 2017 many turtles were not fitted with a transmitter until late April, May, or even June. Consequently, unlike data from summer and fall 2017, data on turtle habitat use and movements for spring 2017 were incomplete. Therefore, our top priority for 2018 was to track as many turtles as possible for the entire spring season. By attaching a fresh transmitter to previously captured turtles in October 2017, we were able to locate these turtles as soon as the weather warmed in April 2018 and to begin tracking movements and habitat use immediately. In addition, we visited sites more frequently in spring 2018 than in spring 2017 (approximately every 7 days instead of every 9 days). We were thus about to obtain a complete dataset for spring 2018. A consequence of the earlier attachment of transmitters was that several transmitters began to fail by late June. We therefore decided to remove transmitters from turtles at that point. The combined tracking from spring 2017 through early summer 2018 therefore provides a thorough estimate of turtle habitat use and movements through the entire year.

*Vegetation/Habitat*

Previous studies have investigated habitat use by bog turtles by examining habitat characteristics (e.g., soil moisture, vegetation, etc.) in the immediate vicinity around where turtles were found. However, to determine habitat selection, characteristics of other locations within the wetland that could potentially be used by turtles must also be determined and compared to those sites actually used by turtles. We used an innovative study design (Myers 2011) to determine habitat selection at two spatial scales by sampling habitat characteristics not only at turtle sites but also at two other locations: nearby random sites located 5-6 m away and far random sites located 15-18 m away. The comparison between turtle locations and nearby random sites allowed for determination of habitat selection at a fine special scale (i.e., within habitat patches), while the far random comparison allowed for a determination at a larger spatial scale (i.e., between habitat patches).

At each turtle location, we delineated a 2 m radius circular plot (~12.6 $m^2$) using turtle location as center. A 2 m radius was chosen based on daily bog turtle movements (Chase et al. 1989, Lovich et al. 1992). Within each plot, visual percent cover estimates were determined and ranked (Table 2) using 16 variables modified from Macey (2015), Myers (2011), Zimmerman et al. (2008), Tesauro and Ehrenfeld (2007), and United States Fish & Wildlife Service Bog Turtle Habitat Monitoring Form (Table 3, Appendix D). The categories are based on typical floristic composition associated with bog turtle habitat in the Northeast. Canopy cover was measured using a spherical crown densitometer (Forestry Suppliers). Refugia were defined as areas in which a bog turtle can retreat under substrate via tunnel/submersion, and were measured by visually surveying the plot and probing soft muck for areas a turtle could submerge.

Table 2. Height, percent cover, distance to standing water, woody stem density, and refugia availability rank classes of microhabitat characteristics used in vegetation surveys. Ranks were estimated within 2-meter radius plots at turtle locations, nearby random plots, and far random plots. Modified from modified from Macey (2015), Myers (2011), and Zimmerman et al. (2008). Refugia is an area in which a bog turtle can retreat under substrate via tunnel/submersion.

| Rank Class | Maximum vegetation height (m) | Percent cover (%) | Distance (m) | Woody stem density (WSD) | Index of refugia availability |
|---|---|---|---|---|---|
| **1** | No veg | < 1 | 0.00 | None | None |
| **2** | 0.01 ≤ 0.50 | 1 ≤ 5 | 0.01 ≤ 0.50 | Very few WS | Very little (~20%) |
| **3** | 0.60 ≤ 1.00 | 6 ≤ 10 | 0.51 ≤ 1.00 | Few WS | Little (~40%) |
| **4** | 1.01 ≤ 2.00 | 11 ≤ 25 | 1.01 ≤ 2.00 | Moderate WS | Moderate (~60%) |
| **5** | > 2.00 | 26 ≤ 50 | 2.01 ≤ 5.00 | Dense WS | Frequent (~80%) |
| **6** | - | 51 ≤ 75 | 5.01 ≤ 10.00 | - | Consistent (~100%) |
| **7** | - | 76 ≤ 100 | > 10.00 | - | - |

Table 3. List of microhabitat variables. Modified from Macey (2015), Myers (2011), Zimmerman et al. (2008), Tesauro and Ehrenfeld (2007), and USFWS Bog Turtle Habitat Monitoring Form. Ranks were estimated for each variable within 2-meter radius plots at turtle locations, nearby random plots, and far random plots. Canopy cover was measured using a spherical crown densitometer. Refugia is an area in which a bog turtle can retreat under substrate via tunnel/submersion. See Table 2 for rank classes

| | Variable |
|---|---|
| **1** | Percent cover reed canary grass (*Phalaris arundinacea*) |
| **2** | Percent cover cattail (*Typha spp.*) |
| **3** | Percent cover common reed (*Phragmites australis*) |
| **4** | Percent cover moss |
| **5** | Percent cover sedges/other graminoids (*Carex sp.,* grasses, rushes) |
| **6** | Percent cover woody vegetation, forbs, ferns (WFF) |
| **7** | Percent cover saturated soil |
| **8** | Percent cover standing water |
| **9** | Percent vegetation > 1m |
| **10** | Percent woody vegetation > 1m |
| **11** | Percent forbs/ferns > 1m |
| **12** | Woody stem density (WSD) |
| **13** | Distance from plot center to standing water/saturated soil |
| **14** | Max height of combined woody vegetation, forbs, ferns |
| **15** | Index of refugia availability |
| **16** | Canopy cover |

We also surveyed vegetation in a paired circular plot of the same size located in a random, cardinal direction 5-6 meters away center to center (nearby random). Beginning in July 2017 and for the remainder of the study period, random plots were also surveyed 15-18 meters away center to center (far random) (Figure 1). Nearby and far random plots represent habitat that is immediately and generally available to a bog turtle, respectively (Myers 2011). All random plots were surveyed on the same day of tracking to guarantee the same weather and resource conditions (Compton et al. 2002).

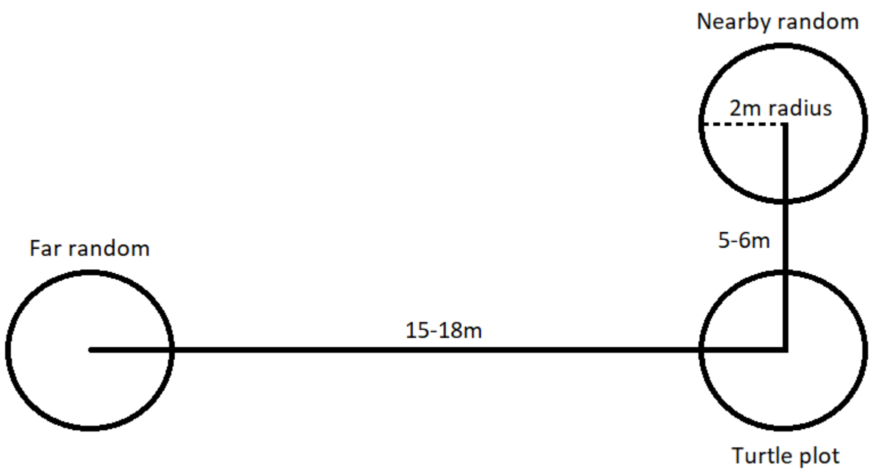


Figure 1. Illustration of turtle microhabitat and paired random vegetation plots. Nearby random and far random plots are located 5-6 m and 15-18 m away, respectively, from turtle plots center to center. Random cardinal direction was chosen for each random plot.

*Home range and movements*

Turtle locations were mapped using ArcGIS® 10.3 (ESRI). GPS coordinates obtained in decimal degrees were projected into the North American Datum 1983 (NAD83) and State Plane Pennsylvania South coordinate system.

To determine the distance moved by each turtle between tracking events, the ‘Point to Line’ tool in ArcMap™ (ESRI) was used to create lines sorted by date for each turtle. The ‘Split Line at Point’ tool was then used to separate each line into successive segments (length between tracks) with length measured in meters using a search radius of 0.01 m (ESRI).

Minimum convex polygon (MCP) home range was calculated using the ‘Minimum Bounding Geometry’ tool in ArcMap™ (ESRI). Points for an individual turtle were used as input and the convex hull geometry type was selected to create the MCP. Areas calculated in square meters were converted to hectares.

MCP overlap was determined using a method presented by Millspaugh et al. (2004):

$$Overlap = \frac{A_{1,2}}{(A_1 + A_2) - A_{1,2}}$$

where $A_1$ is the home range area of animal 1, $A_2$ is the home range area of animal 2 and $A_{1,2}$ is the intersected area of animals 1 and 2.

Kernel density estimates (KDE) were calculated using Geospatial Modeling Environment (GME; www.spatialecology.com), a program that uses ArcGIS® and R software to facilitate spatial analysis (Beyer 2015). Kernel density estimation was calculated using the method described by Worton (1989):

$$\hat{f}_h(x) = \frac{1}{nh^2} \sum_{i=1}^{n} K \left[\frac{x - X_i}{h}\right]$$

where X is a sample of n random points, the kernel K is the bivariate density function, and h is the bandwidth.

Shapefiles containing individual turtle locations created in ArcMap™ were used as input, the kernel was set as Gaussian, the cell size was set to 1m, and the bandwidth method set to 'PLUGIN' as defined by Sheather and Jones (1991). Because the bog turtle tends to use fragmented patches in small geographic areas, the plugin method was chosen as the most appropriate method for this study (Walter et al. 2011). The resulting raster was added to ArcMap.

Isopleths were created within GME to represent 50% and 95% of the density function. These are conventional percentiles used to represent the core home range and overall home range area, respectively. Isopleths were added to ArcMap™ and the 'Feature to Polygon' tool was used to convert the contour lines to polygons. Areas calculated in square meters were converted to hectares.

*Wetland estimation*

Wetland areas were delineated in spring 2018 by walking along the edge of each wetland area while recording a track using a Garmin GPSMAP® 64s unit. The track recording method was set at 'Auto' and the track recording interval was set at 'Most Often'. The edge of the wetland was estimated based on a combination of hydrology (i.e., saturated or inundated soils) and the presence of wetland vegetation. If the wetland area extended beyond a defined property border, such as a fence or No Trespassing signs (i.e., UGR1, GRZ2, UGR2), the delineation did not include areas beyond the edge of the easement/property. If the wetland area included heavily wooded areas (e.g, UGR3), the delineation extended about five meters into the wooded area. A shapefile of the recorded track was downloaded using the DNRGPS application version 6.1.0.6 (Minnesota Department of Natural Resources 2014).

*Statistical analysis*

All statistical analyses were performed using R version 3.4.2 (R Core Team 2017).

*Vegetation/Habitat analysis*

The variables percent common reed and percent moss were removed due to rarity of observations. Common reed was observed in only three plots and was accounted for within another category (percent sedges/graminoids). Moss was observed in less than 7% of plots, the majority of which were rank 2 (1 ≤ 5% cover). Maximum height was removed due high correlation with woody stem density (WSD). After removing these three variables, any records with missing data were omitted resulting in a total of 639 plots (140 far random, 249 nearby random, 250 turtle plots) for the 2017 season. Missing records were due to recorder error and resulted in the removal of 18 nearby random and 17 turtle plots. During 2018, an additional 630 plots were surveyed (210 far random, 210 nearby random, 210 turtle). The total number of plots collected during this study was 1269 plots (350 far random, 459 nearby random, and 460 turtle plots; 504 grazed, 765 ungrazed plots) across four season types (Table 4).

In conducting statistical analysis of vegetation and habitat use, the year was divided into spring (April through June 14), summer (mid-June through early August), and fall (mid-August through October) seasons. Data for spring 2017 were incomplete for two reasons. First, many of the turtles were not captured until May or June so early spring (i.e., April) was underrepresented. Second, we did not start gathering data on far random plots until July 2017. Therefore, in order to obtain a balanced study design that contained adequate numbers of turtle, nearby, and far random plots for rigorous statistical analysis of all three seasons, we used data from spring 2018 with data from summer and fall 2017. To further investigate, all four seasons were added to a model that was similarly balanced by season type.

Table 4. Plot type counts by season after omitting correlated variables and missing data. The following numbers of plots were used in vegetation analysis. Far random plots were collected beginning in Summer 2017.

| Plot type | Spring 2017 | Summer 2017 | Fall 2017 | Spring 2018 | Total plots by type |
|---|---|---|---|---|---|
| **Turtle** | 87 | 83 | 80 | 210 | 460 |
| **Nearby random** | 86 | 83 | 80 | 210 | 459 |
| **Far random** | 0 | 60 | 80 | 210 | 350 |
| **Total plot by season** | 173 | 226 | 240 | 630 | 1269 |

A principal components analysis (PCA) was conducted using the 13 variables in order to reduce the number of variables to principal components. Trends are shown in biplots that were created using the package ggbiplot in R (Vu 2011).

Pairwise comparisons of variables were conducted between all random and turtle plots. The following variables were removed from all modelling analysis due to high correlation with other variables ($r_s \geq 0.6$); percent woody vegetation >1m, percent forbs/ferns >1m, percent woody forbs and ferns (WFF), refugia index, and distance to standing water (Table A4).

Mixed effects models predicting habitat use/availability were run as logistic regressions using glmer (lme4) in R (family = binomial) (Bates et al. 2015). Turtle plots were coded as 1 and random plots coded as 0. All models included nested random effects season, site, and turtle ID to account for multiple measurements. Akaike's information criterion (AIC) values, as calculated by glmer in R, were used to compare and rank models. In the case where AIC values differed by less than 2, the most parsimonious model was chosen. $R^2$ values were computed for each model using r2beta (r2glmm) in R (Jaeger 2017). Type II analysis of variance and subsequent Tukey comparisons were performed when necessary using Anova (car) (Fox and Weisberg 2011) and glht (multcomp) (Hothorn et al. 2008) in R.

*Movements and home range comparisons*

Distance measurements calculated over a missed event (i.e. not found during a tracking event or lost and recovered later) were excluded from analysis. Distance was normalized by day for each segment and length of time to determine mean distance per day assuming a constant rate of movement. A linear mixed effects model was performed using lme (nlme) in R (Pinheiro et al. 2017) to test the effects of season, sex, and site on log transformed distances per day using turtle ID as a random effect. Type II analysis of variance and subsequent Tukey comparisons were performed using Anova (car) (Fox and Weisberg 2011) and glht (multcomp) (Hothorn et al. 2008) in R.

Differences by sex in MCP, 50% KDE, and 95% KDE home range were analyzed by linear mixed effects models using lme (nlme) in R (Pinheiro et al. 2017). Data were log transformed to meet assumption of normality in all instances. Home ranges were not computed for turtles tracked less than 10 times in 2017, resulting in home range estimates for 12 females and 7 males. A linear mixed effects model was performed using lme (nlme) in R (Pinheiro et al. 2017) to test the effect of estimation method on log transformed home range size for 19 turtles for which home range was calculated using all three methods, accounting for turtle ID as a random effect. Type II analysis of variance and subsequent comparisons were performed using Anova (car) (Fox and Weisberg 2011) and glht (multcomp) (Hothorn et al. 2008) in R.

## Results

### *Principal components analysis of Vegetation/Habitat*

Principal components analysis (PCA) results indicated that sedges/graminoids positively loaded onto principal component 1 (PC1), while negatively loading variables were associated with woody and tall vegetation. These variables included woody vegetation/forbs/ferns, total vegetation over 1m, woody vegetation over 1m, woody stem density, and canopy cover. PC1 explained 32.8% of the variance (Figure 2, Table 5). Principal component 2 (PC2), conversely, was negatively associated with sedges/graminoids and positively associated with the woody and tall vegetation variables (Table 5). PC2 explained 27.0% of the variance. Overall, PCA indicated that vegetation type varied similarly within all three plot types (Figure 2).

The ‘moisture’ axis, composed of the variables, saturated soil, standing water, refugia index, and distance to standing water, loaded relatively equally onto PC1 and PC2 (negative association with distance to standing water; positive association with other variables). This relationship showed a clear gradient among plot types with turtle plots grouped toward higher percent cover of saturated soil, standing water, refugia index, and a low distance to standing water. Far random plots, conversely, grouped toward less saturated soil, standing water, refugia index, and larger distance from standing water. Nearby random plots fell between these two plot types (Figure 2).

Figure 3 shows results grouped by grazing and site. Study sites vary considerably along the vegetation axis, but vary similarly along the moisture axis. The two grazed sites (GRZ2 and GRZ1) vary most along the vegetation axis and are substantially different from each other.

Table 5. Principal components analysis variable loadings and variance explained by each principal component for vegetation plots collected 2017-2018 (turtle *n* = 460, nearby random *n* = 459, far random *n* = 350) in wetlands in southeastern PA.

| | **PC1** | **PC2** | **PC3** | **PC4** |
|---|---|---|---|---|
| Proportion of variance | 0.3284 | 0.2695 | 0.1003 | 0.0748 |
| Cumulative variance | 0.3284 | 0.5979 | 0.6982 | 0.7730 |
| **Variable** | | | | |
| Reed canary grass | 0.0776 | -0.1045 | 0.0416 | 0.3227 |
| Cattail | 0.0473 | 0.0694 | 0.2137 | -0.1576 |
| Sedges/graminoids | 0.3057 | -0.3161 | -0.1204 | 0.4689 |
| Woody veg/forbs/ferns (WFF) | -0.2993 | 0.2954 | 0.1832 | -0.4141 |
| Saturated soil | 0.3919 | 0.3912 | 0.2699 | 0.2201 |
| Standing water | 0.2913 | 0.2571 | -0.1502 | -0.0710 |
| Total vegetation >1m | -0.2979 | 0.3268 | 0.2717 | 0.4002 |
| Woody vegetation >1m | -0.2274 | 0.2522 | -0.3871 | 0.0060 |
| Forbs/ferns >1m | -0.1346 | 0.1472 | 0.5771 | 0.2065 |
| Distance to standing water | -0.3906 | -0.3621 | 0.1515 | 0.0871 |
| Refugia index | 0.3780 | 0.3300 | -0.0388 | -0.1025 |
| Woody stem density (WSD) | -0.1915 | 0.1960 | -0.3268 | 0.0079 |
| Canopy Cover | -0.2820 | 0.3277 | -0.3480 | 0.4530 |

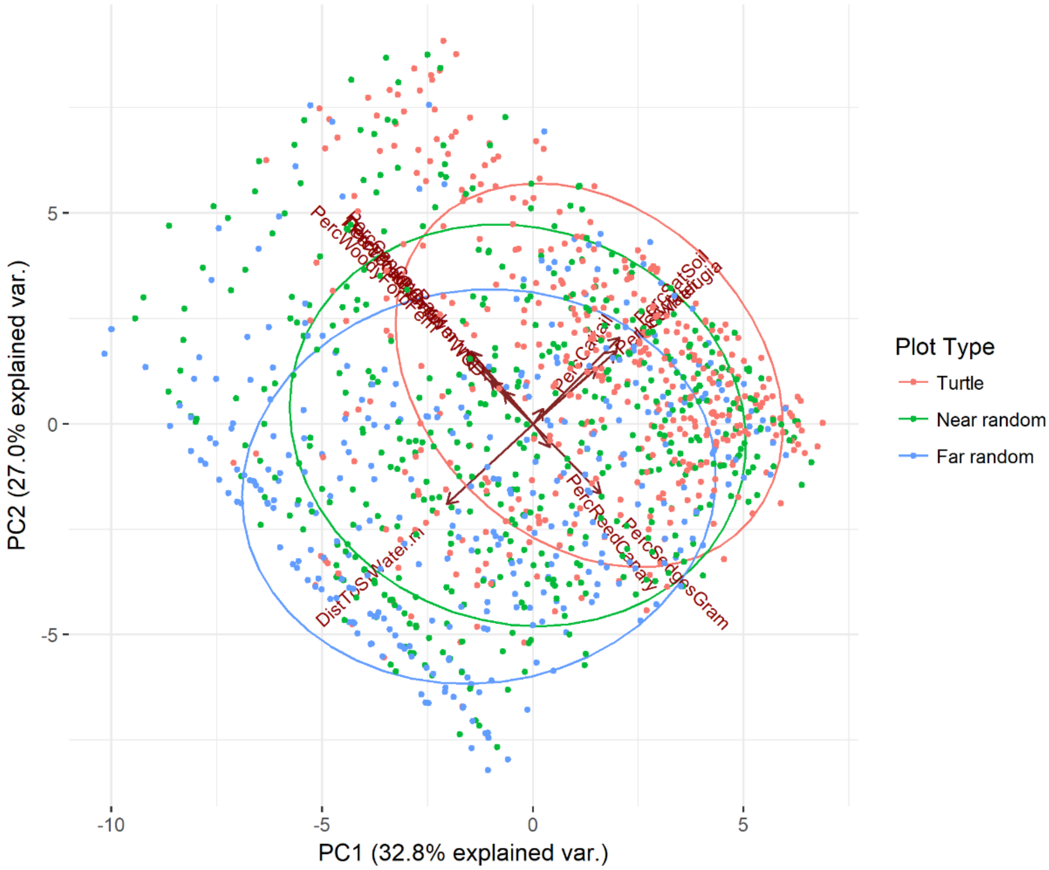


Figure 2. Principal components analysis biplot grouped by plot type. Points represent 2-meter radius plots measured at turtle locations, nearby random, and far random plots 2017-2018. Ellipses represent 1 standard deviation. All variable loadings in Table 5.

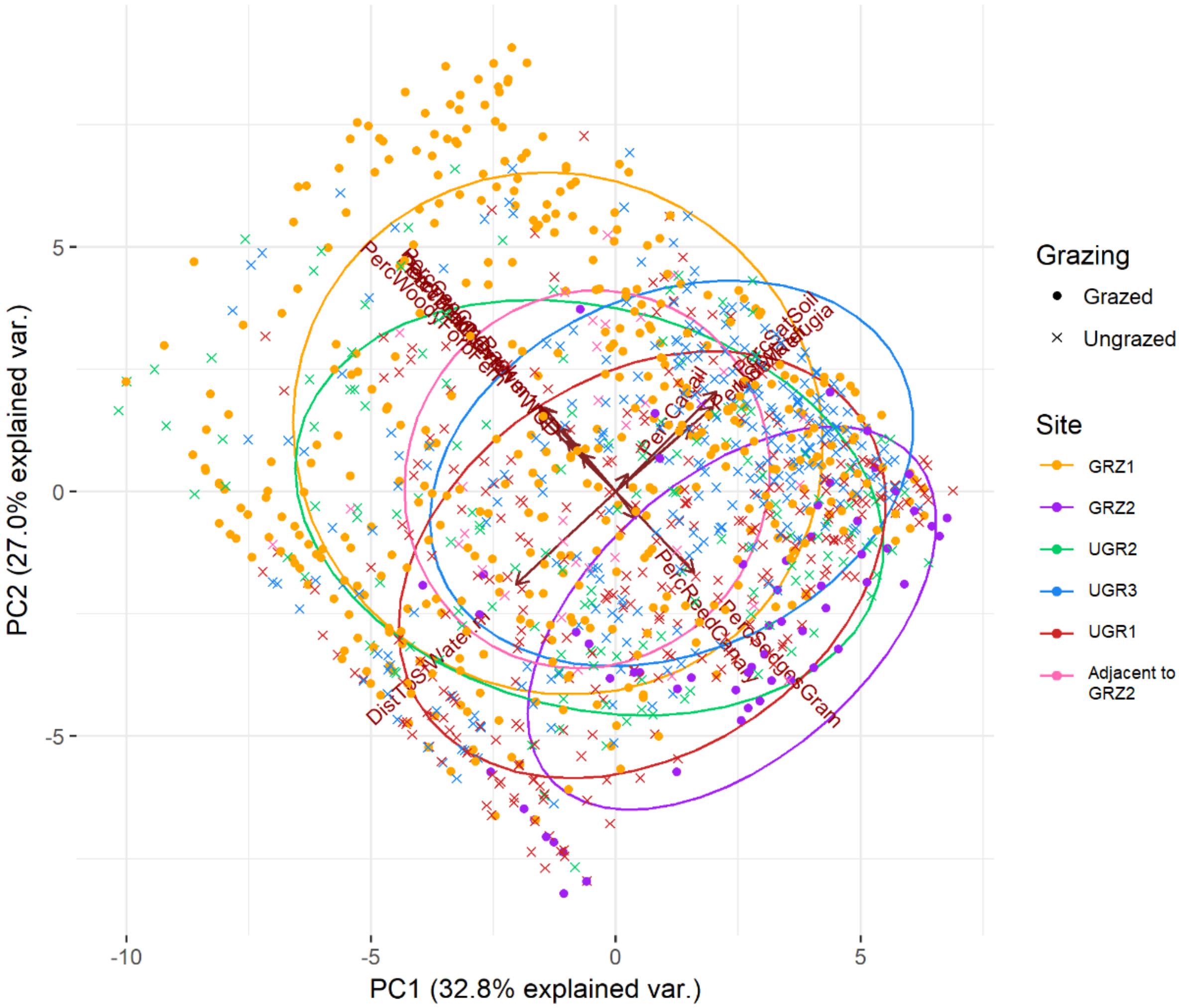


Figure 3. Principal components analysis biplot grouped by grazing and site. Points represent 2-meter radius plots measured at turtle locations, nearby random, and far random plots collected 2017-2018. Ellipses represent 1 standard deviation. All variable loadings in Table 5.

*Plot type comparison*

Overall, saturated soil, refugia index, and standing water all tended to decrease away from turtle locations (Figure 4A-D).

About 60% of turtle plots and 46.4% of nearby random plots contained over 75% saturated soil (rank 7), whereas only 28.3% of far random plots contained as much saturated soil. Saturated soil in turtle plots significantly differed from nearby random ($p$ < 1.0e-16) and far random ($p$ < 1.0e-16) (Figure 4A, Table 6).

Approximately 72% of turtle locations contained a moderate index of refugia availability (60% or more, rank >3), whereas only 25.4% of far random plots contained moderate refuge. Refugia index differed among plot types, with turtle plots containing more refugia than nearby random ($p$ < 1.0e-16) and far random ($p$ < 1.0e-16) plots (Figure 4B, Table 6).

Over 25% cover of standing water (rank > 3) was present in 26.5% of turtle plots, versus 13.9% and 6.6% of nearby and far random plots. Percent standing water differed by plot type with turtle plots containing more standing water than nearby random ($p$ < 1.0e-16) and far random plots ($p$ < 1.0e-16) (Figure 4C, Table 6).

Distance to standing water increased away from turtle locations (Figure 4D). Only 8.7% of turtle plots and 14.4% of nearby random plots occurred more than 5m from standing water (rank > 5), whereas 33.1% of far random plots occurred more than 5m from standing water. Turtle plots were significantly closer to water than both nearby random ($p$ < 1.0e-16) and far random plots (p < 1.0e-16) (Table 6).

Turtles were found in plots containing greater than 50% cover of sedges/graminoids 57.4% of the time, whereas 47.7% and 51.7% of nearby and far random plots, respectively, contained over 50% cover. Sedge and graminoid cover differed among plot types, with turtle and nearby random plots differing significantly ($p$ = 0.017) but no significant differences existing between turtle and far random plots ($p$ = 0.55) (Figure 4E, Table 6).

Woody stem density (WSD) differed among plots (Figure 4F). Nearly 23% of turtle plots and 18.5% of nearby random plots contained moderate to dense WSD (rank > 3), while only 13.6% of far random plots had similar WSD. WSD was greater in turtle plots compared to far random plots ($p$ = 0.0056) but turtle and nearby random plots did not differ significantly ($p$ = 0.95) Table 6).

The percentage of plots containing any cattail decreased slightly away from turtle plots (Figure 4G). Approximately 22.2% of turtle plots, 19.8% of nearby random, and 16.6% of far random plots contained any cattail (rank > 1). Percent cover of cattail marginally differed between turtle and nearby random plots ($p$ = 0.09) and differed significantly between turtle and far random plots ($p$ = 0.017) (Table 6).

Percent cover of reed canary grass decreased slightly away from turtle plots (Figure 4H). Approximately 5% of turtle plots, 4.4% of nearby random, and 3.4% of far random plots contained more than 50% cover of reed canary grass (rank > 5). Turtle and nearby random plots significantly differed ($p$ = 0.02), however turtle and far random plots did not differ significantly ($p$ = 0.17). Percent cover of woody vegetation, forbs, and ferns marginally differed between turtle and nearby random plots ($p$ = 0.07) but did not differ between turtle and far random plots ($p$ = 0.67), with turtle plots containing more woody vegetation, forbs, and ferns than nearby random plots (Table 6).

Percent woody vegetation over 1m and canopy cover tended to be higher in turtle plots when compared to far random plots, whereas forbs/ferns over 1m tended to be lower in turtle plots compared to far random locations. Percent cover of forbs/ferns over 1m, woody vegetation over 1m, and canopy cover did not significantly differ between turtle and nearby random plots, but marginally differed between turtle and far random plots (Table 6). Percent cover of total vegetation over 1m did not differ between plot types (Table 6).

In summary, differences in physical characteristics (i.e., soil moisture and standing water) between turtle locations and random plots appear to be greater than differences in vegetation. Turtles utilized microhabitats with saturated soils and access to refugia that were either partially inundated or close to standing water. Turtle plots were more different from far random plots than from near random plots. In addition, microhabitats used by turtles had higher woody stem densities and higher percent cover of grasses, sedges, cattails, and short forbs and ferns than other sites within the wetland. In addition, differences between turtle-nearby random and turtle-far random comparisons for several of the vegetation variables (e.g., sedges and graminoids, woody stem density) suggest that both fine scale (microhabitat) and large scale (habitat patches) characteristics are important.

We were unable to statistically examine differences in plot types between grazed and ungrazed sites due to the small sample size of sites. Overall, however, the grazed plots (grazed turtle plots, grazed nearby random, and grazed far random) had lower percent sedges/graminoids (Figure 5A-B), higher percent canopy cover (Figure 5C-D), lower cover of reed canary grass (Figure 5E-F), and higher woody stem density (Figure 5G-H) than plots at ungrazed sites. These differences, however, are almost exclusively accounted for by the GRZ1 site (Figure 5), where turtles spent much of the time near a large stand of alders. There was considerable variation between all sites, which limited our ability to attribute any of the variation to grazing.

Table 6. Results of linear mixed effects models comparing variables between turtle and nearby random plots, and between turtle and far random plot types. NR = nearby random plots, FR = far random plots. Model: Variable ~ Plot type, random = ~1|Site/TurtleID. Models were run as linear mixed effects models using lme (nlme) in R with the following syntax: Response variable ~ fixed effects, random = ~1|random effects. Significance codes: **.** = P < 0.1, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Variable | Intercept | SE | Sig. | Turtle-NR estimate | SE | Sig. | Turtle-FR estimate | SE | Sig. | Fig. |
|---|---|---|---|---|---|---|---|---|---|---|
| **Saturated soil** | 6.1263 | 0.20 | *** | -0.8571 | 0.13 | *** | -2.0065 | 0.14 | *** | 4A |
| **Refugia index** | 4.3758 | 0.20 | *** | -1.1561 | 0.11 | *** | -1.9895 | 0.11 | *** | 4B |
| **Standing water** | 3.3910 | 0.15 | *** | -0.9006 | 0.09 | *** | -1.3736 | 0.10 | *** | 4C |
| **Dist. to standing water** | 2.1101 | 0.18 | *** | 1.1844 | 0.12 | *** | 2.0752 | 0.13 | *** | 4D |
| **Sedges/graminoids** | 5.5517 | 0.30 | *** | -0.2790 | 0.12 | * | -0.0744 | 0.13 | | 4E |
| **Woody stem density** | 1.8617 | 0.21 | *** | -0.0053 | 0.08 | | -0.2326 | 0.08 | *** | 4F |
| **Cattail** | 1.4899 | 0.19 | *** | -0.0957 | 0.06 | **.** | -0.1438 | 0.06 | * | 4G |
| **Reed canary grass** | 2.2510 | 0.41 | *** | -0.1782 | 0.08 | * | -0.1155 | 0.08 | | 4H |
| **Woody veg/forbs/ferns** | 4.1644 | 0.42 | *** | 0.1996 | 0.11 | **.** | -0.0501 | 0.12 | | |
| **Forbs/ferns >1m** | 1.8964 | 0.23 | *** | 0.0800 | 0.10 | | 0.2508 | 0.11 | * | |
| **Woody vegetation >1m** | 1.7923 | 0.23 | *** | 0.0429 | 0.10 | | -0.1910 | 0.10 | **.** | |
| **Canopy cover** | 2.338 | 0.45 | *** | 0.0126 | 0.11 | | -0.2129 | 0.12 | **.** | |
| **Total vegetation >1m** | 3.2211 | 0.34 | *** | 0.0224 | 0.12 | | -0.1288 | 0.13 | | |

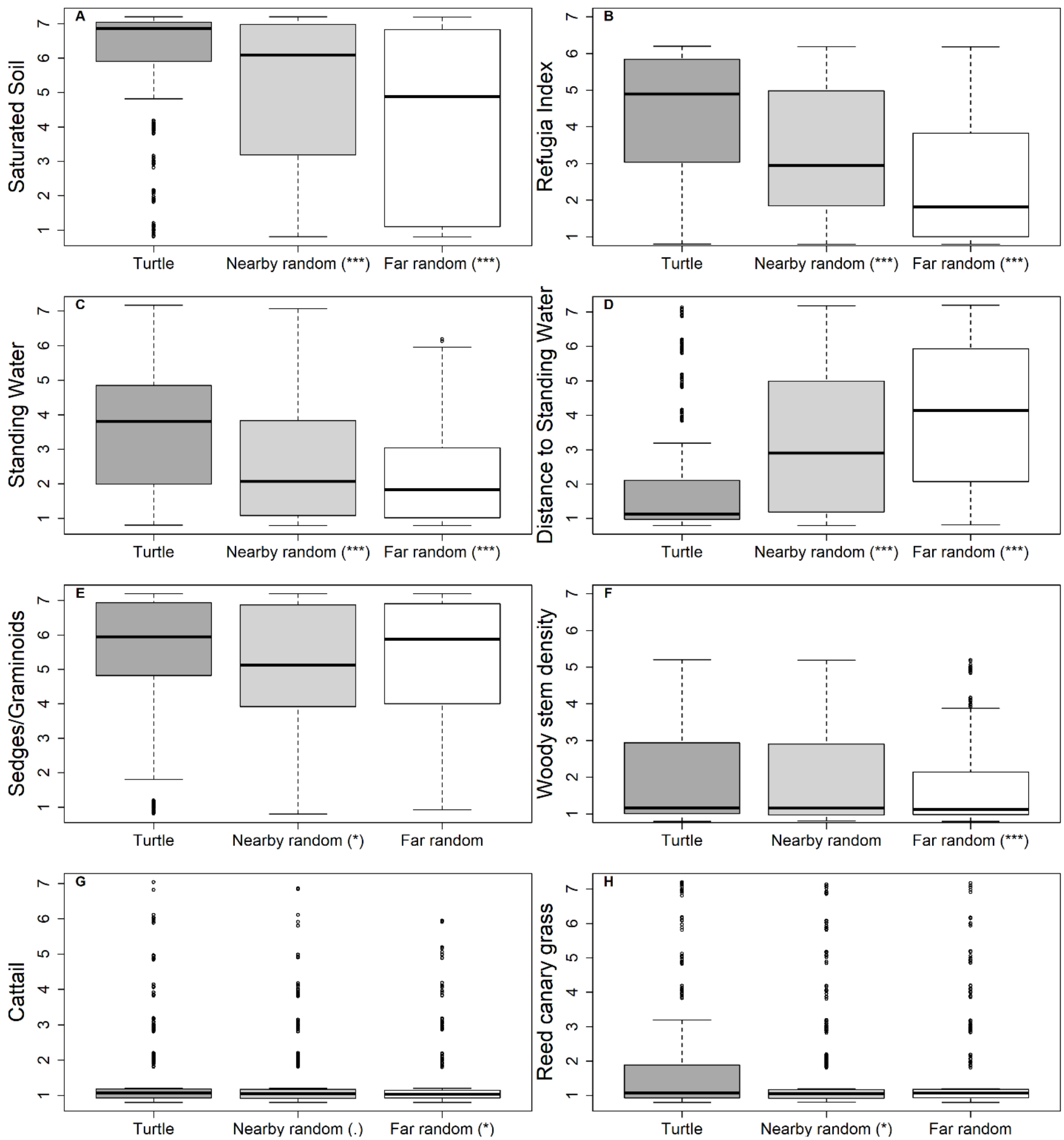


Figure 4. Boxplots showing rank class for variables by plot type. See Table 2 for rank divisions. Plots represent 2-meter radius plots measured at turtle locations, nearby random, and far random plots. Asterisks denote statistical difference between random plot type to turtle plots (see Table 6 for results). Significance codes: **.** = P < 0.1, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

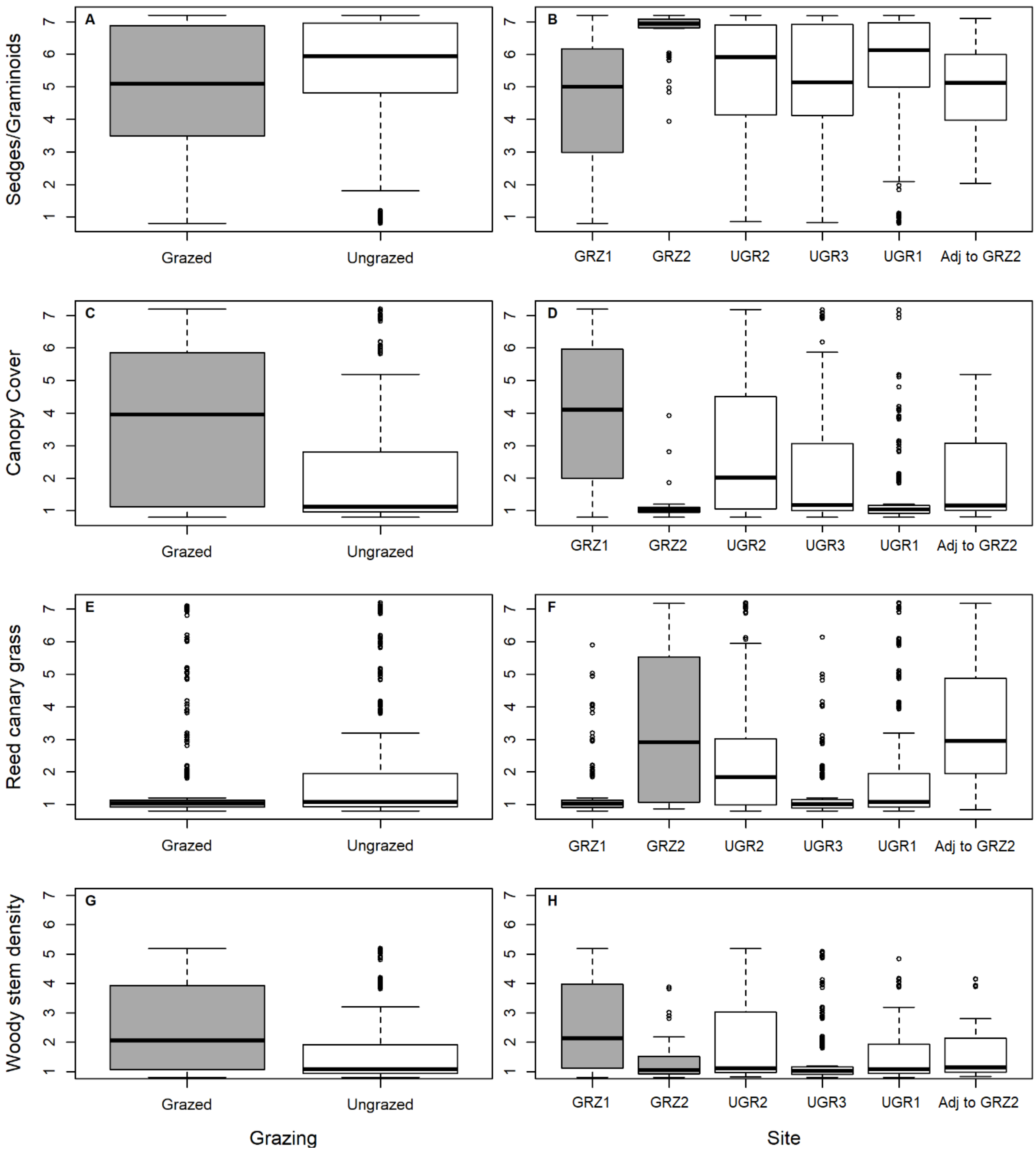


Figure 5. Boxplots showing rank class for variables by grazing (A, C, E, G) and the same variables by site (B, D, F, H respectively). Gray boxes are grazed sites in all plots and white boxes are ungrazed. See Table 2 for rank divisions. There was considerable variation between all sites, which limited my ability to attribute any of the variation to grazing.

*Multivariate mixed effects modelling*

Determining the variables that affect habitat selection is complicated by correlations among variables. For example, by choosing an area with saturated soils, a turtle may appear to be choosing other variables associated with saturated soils. Multivariate mixed effects models consider all habitat variables in a single model, thus partially accounting for correlations among variables, and therefore providing a better indicator of turtle habitat selection than the univariate plot type comparisons above. The variable season was included in the models to examine whether habitat selection changed over the course of the year. A change in selection by season is indicated by the presence of a season by habitat variable interaction. Statistical tables for the most parsimonious models are shown below; tables of all models are shown in Appendix A.

Multivariate models also provide a more detailed representation of habitat selection through examination of the relationship between turtle locations and nearby and far random plots. Comparisons between turtle locations and nearby random plots give an indication of fine scale habitat selection (i.e., microhabitat choice among locations in close proximity), while comparison between turtle locations and far random plots give an indication of larger scale habitat selections (i.e., choice among larger habitat patches).

*Seasons: Spring 2018 + Summer 2017 + Fall 2017*

The likelihood that a plot was a turtle location compared with a nearby random location was strongly positively associated with standing water ($p$ = 6.45e-09) and marginally positively associated with saturated soil ($p$ = 0.05), woody stem density ($p$ = 0.07), and reed canary grass ($p$ = 0.10) (Table 7, Table A5).

Table 7. Final model predicting nearby random/turtle location where Season includes spring 2018, summer 2017, fall 2017 (Model 7, see Table A5 for all models). Models were run as logistic regressions using glmer (lme4) in R, where turtle plots were coded as 1 and nearby random plots as 0 with the following syntax: Response variable ~ fixed effects + (1|Random effects). Model: Plot type ~ Standing water + Reed canary grass + Saturated soil + Sedges/graminoids + WSD + Grazing + Season + (1|Season/Site/TurtleID). Significance codes: **.** = P < 0.1, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| **Parameter** | **Estimate** | **SE** | **P** | |
|---|---|---|---|---|
| (Intercept) | -2.7422 | 0.49 | 2.24e-08 | *** |
| Standing water | 0.3827 | 0.07 | 6.45e-09 | *** |
| Saturated soil | 0.0979 | 0.05 | 0.0501 | **.** |
| Sedges/graminoids | 0.0601 | 0.05 | 0.2454 | |
| Reed canary grass | 0.1024 | 0.06 | 0.0994 | **.** |
| Woody stem density | 0.1389 | 0.08 | 0.0679 | **.** |
| Grazing | 0.1822 | 0.18 | 0.3234 | |
| Season – Summer 2017 | 0.4504 | 0.23 | 0.0489 | **.** |
| Season – Fall 2017 | 0.2354 | 0.21 | 0.2586 | |

Compared with far random plots, turtle plots were positively associated with standing water ($p$ = 2.12e-14), saturated soil ($p$ = 0.0001), and woody stem density ($p$ = 0.013), and negatively associated with cattail ($p$ = 0.02) (Table 8, Table A6). There was also a marginally negative association of turtle plots with the interaction of total vegetation >1m and season, with summer differing from spring and fall ($p$ = 0.07). Turtles were more likely to be found in areas with tall vegetation in the spring and fall months.

Table 8a. Final model predicting far random/turtle location where Season includes spring 2018, summer 2017, fall 2017 (Model 6, see Table A6 for all models). Models were run as logistic regressions using glmer (lme4) in R, where turtle plots were coded as 1 and far random plots as 0 with the following syntax: Response variable ~ fixed effects + (1|Random effects). ':' denotes an interaction. Model: Plot type ~ Standing water + Saturated soil + Cattail + WSD + Grazing + Season + Season*Total veg > 1m + (1|Season/Site/TurtleID)) Significance codes: * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| **Parameter** | **Estimate** | **SE** | **P** | |
|---|---|---|---|---|
| (Intercept) | -3.4053 | 0.38 | <2e-16 | *** |
| Standing water | 0.6207 | 0.08 | 2.12e-14 | *** |
| Saturated soil | 0.2080 | 0.05 | 0.0001 | *** |
| Cattail | -0.2244 | 0.10 | 0.0218 | * |
| Woody stem density (WSD) | 0.2299 | 0.09 | 0.0125 | * |
| Total veg > 1m | 0.0528 | 0.09 | 0.5614 | |
| Grazing - Ungrazed | 0.3932 | 0.21 | 0.0624 | . |
| Season – Summer 2017 | 1.8317 | 0.58 | 0.0017 | ** |
| Season – Fall 2017 | -0.4435 | 0.61 | 0.4670 | |
| Total veg > 1m : Season - Summer 2017 | -0.2483 | 0.14 | 0.0699 | . |
| Total veg > 1m : Season - Fall 2017 | 0.0698 | 0.14 | 0.6247 | |

Table 8b. Analysis of deviance table (Type II Wald $X^2$ tests) to determine the overall effect Season :Total vegetation > 1m interaction within Model 6 predicting far random/turtle location, where Season includes spring 2018, summer 2017, fall 2017.

| **Parameter** | **$X^2$** | **df** | **P** | |
|---|---|---|---|---|
| Standing water | 58.4214 | 1 | 2.12e-14 | *** |
| Saturated soil | 14.8827 | 1 | 0.0001 | *** |
| Cattail | 5.2582 | 1 | 0.0218 | * |
| Woody stem density (WSD) | 6.2443 | 1 | 0.0125 | * |
| Total veg > 1m | 0.0008 | 1 | 0.9772 | |
| Grazing - Ungrazed | 3.4736 | 2 | 0.0624 | . |
| Season | 11.5203 | 2 | 0.0032 | ** |
| Total veg > 1m : Season | 4.5271 | 2 | 0.1040 | |

Modelling turtle microhabitat use vs overall availability by combining nearby and far random plots showed that turtle locations had strong positive associations with standing water ($p$ = 1.54e-14), saturated soil ($p$ = 0.0008), and woody stem density ($p$ = 0.0006). Turtles were marginally positively associated with reed canary grass ($p$ = 0.097) (Table 9, Table A7).

Table 9. Final model predicting overall random/turtle location, where Season includes spring 2018, summer 2017, fall 2017 (Model 7, see Table A7 for all models). Models were run as logistic regressions using glmer (lme4) in R, where turtle plots were coded as 1 and random plots as 0 with the following syntax: Response variable ~ fixed effects + (1|Random effects), ':' denotes an interaction. Model: Plot type ~ Standing water + Saturated soil + Sedges/graminoids + WSD + Reed canary grass + Grazing + Season + (1|Season/Site/TurtleID). Significance codes: * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Parameter | Estimate | SE | P | |
|---|---|---|---|---|
| (Intercept) | -4.0323 | 0.45 | <2e-16 | *** |
| Standing water | 0.4534 | 0.06 | 1.54e-14 | *** |
| Saturated soil | 0.1534 | 0.05 | 0.0008 | *** |
| Sedges/graminoids | 0.0667 | 0.05 | 0.1587 | |
| Woody stem density (WSD) | 0.2347 | 0.07 | 0.0006 | *** |
| Reed canary grass | 0.0900 | 0.05 | 0.0967 | . |
| Grazing | 0.1574 | 0.16 | 0.3259 | |
| Season - Summer | 0.5979 | 0.21 | 0.0037 | ** |
| Season - Fall | 0.1428 | 0.19 | 0.4415 | |

In summary, all three comparisons (turtle plots v. nearby random plots, turtle plots v. far random plots, and turtle plots v. all random plots) indicate a positive association between bog turtle locations and standing water, saturated soils, and woody stem density. These three variables were stronger predictors of turtle use in comparison with far random locations than with nearby random locations, indicating that turtles select microhabitats within larger patches containing standing water, saturated soils, and a high density of woody stems. The weaker association between turtle plots and reed canary grass suggests that turtles are not specifically choosing reed canary grass but rather that reed canary grass is growing in the microhabitats selected by turtles. When comparing turtle plots with far random plots, the negative association between turtle plots and cattail suggests that turtles avoid large patches of cattails. Finally, the significant interaction between total vegetation >1m and season in the far random comparison suggests that turtles are found in areas of taller vegetation in spring and fall and shorter vegetation in the summer, which is most likely a result of moving to and from hibernacula. The primary difference between the multivariate analysis and the (previous) univariate analysis is in relation to cattail. The univariate analysis indicates a positive association between turtle locations and cattail cover, whereas the multivariate analysis indicates selection by turtles for sites away from cattail patches. This suggests that the positive relationship in the univariate model is due to cattails growing in habitats preferred by turtles rather than a preference by turtles for cattails.

*Seasons: Spring 2017 + Summer 2017 + Fall 2017 + Spring 2018*

To test the robustness of the Spring 2018 + Summer 2017 + Fall 2017 models, we also constructed statistical models with all four survey seasons. When all four surveyed seasons were using in the model comparing turtle plots with nearby random plots, turtle plots were still strongly, positively associated with standing water ($p$ = 4.79e-09) and strongly, positively associated with saturated soil ($p$ = 0.0009). Turtle locations were also positively associated with woody stem density ($p$ = 0.04), reed canary grass ($p$ = 0.04), and marginally associated with sedges/graminoids ($p$ = 0.055). Cattail was positively associated with turtle plots but the relationship was not statistically significant ($p$ = 0.08) (Table 10, Table A8).

Table 10. Final model predicting nearby random/turtle location, where Season includes all four seasons (Model 8, see Table A8 for all models). Models were run as logistic regressions using glmer (lme4) in R, where turtle plots were coded as 1 and random plots as 0 with the following syntax: Response variable ~ fixed effects + (1|Random effects). Model: Plot type ~ Standing water + Saturated soil + Sedges/graminoids + WSD + Reed canary grass + Cattail + (1|Season/Site/TurtleID). Significance codes: * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Parameter | Estimate | SE | P | |
|---|---|---|---|---|
| (Intercept) | -2.6693 | 0.46 | 7.67e-09 | *** |
| Standing water | 0.2819 | 0.05 | 4.79e-09 | *** |
| Saturated soil | 0.1366 | 0.04 | 0.0009 | *** |
| Sedges/graminoids | 0.0921 | 0.05 | 0.0550 | . |
| Woody stem density (WSD) | 0.1383 | 0.07 | 0.0376 | * |
| Reed canary grass | 0.1056 | 0.05 | 0.0424 | * |
| Cattail | 0.0896 | 0.08 | 0.2536 | |

With all four seasons used in the model comparing turtle plots with far random plots, turtle plots were positively associated with standing water ($p$ = 1.98e-14), saturated soil ($p$ = 4.40e-05), and woody stem density ($p$ = 0.001), and negatively associated with cattail (p = 0.02) (Table 11, Table A9).

Table 11. Final model predicting far random/turtle location, where Season includes all four seasons (Model 5, see Table A9 for all models). Models were run as logistic regressions using glmer (lme4) in R, where turtle plots were coded as 1 and random plots as 0 with the following syntax: Response variable ~ fixed effects + (1|Random effects). Model: Plot type ~ Standing water + Saturated soil + WSD + Cattail + Grazing + (1|Season/Site/TurtleID). Significance codes: * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Parameter | Estimate | SE | P | |
|---|---|---|---|---|
| (Intercept) | -1.5679 | 1.39 | 0.2494 | |
| Standing water | 0.6128 | 0.08 | 1.98e-14 | *** |
| Saturated soil | 0.2154 | 0.05 | 4.40e-05 | *** |
| Woody stem density (WSD) | 0.2456 | 0.08 | 0.0011 | ** |
| Cattail | -0.2141 | 0.09 | 0.0234 | * |
| Grazing | 0.3357 | 0.21 | 0.1017 | |

Modelling turtle microhabitat use vs overall availability by combining nearby and far random plots while including all four seasons in the model showed that turtle locations had positive associations with saturated soil ($p$ = 0.0008), standing water ($p$ = 0.019), and sedges/graminoids ($p$ = 0.035) (Table 12a, Table A10). There was a significant interaction between standing water and season with spring 2018 significantly differing from spring 2017 in the model. There was also a significant interaction between woody stem density and season, with fall 2017 significantly differing from spring 2017 in the model.

Table 12a. Final model predicting overall random/turtle location, where Season includes all four seasons (Model 5, see Table A10 for all models). Models were run as logistic regressions using glmer (lme4) in R, where turtle plots were coded as 1 and random plots as 0 with the following syntax: Response variable ~ fixed effects + (1|Random effects), ':' denotes an interaction. Model: Plot type ~ Standing water + Saturated soil + Sedges/graminoids + WSD + Reed canary grass + Grazing + Season + Season:Standing water + Season:WSD + (1|Season/Site/TurtleID). Significance codes: * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Parameter | Estimate | SE | P | |
|---|---|---|---|---|
| (Intercept) | -2.3129 | 0.54 | 1.78e-05 | *** |
| Standing water | 0.2319 | 0.10 | 0.0191 | * |
| Saturated soil | 0.1405 | 0.04 | 0.0008 | *** |
| Sedges/graminoids | 0.0906 | 0.04 | 0.0346 | * |
| Woody stem density (WSD) | 0.0840 | 0.12 | 0.4837 | |
| Reed canary grass | 0.0727 | 0.05 | 0.1298 | |
| Grazing | 0.1950 | 0.15 | 0.1809 | |
| Season – Summer 2017 | -0.6783 | 0.51 | 0.1862 | |
| Season – Fall 2017 | -1.8293 | 0.57 | 0.0015 | ** |
| Season – Spring 2018 | -1.9685 | 0.49 | 5.15e-05 | *** |
| Standing water : Summer 2017 | 0.0823 | 0.15 | 0.2533 | |
| Standing water : Fall 2017 | 0.2080 | 0.16 | 0.1826 | |
| Standing water : Spring 2018 | 0.2701 | 0.12 | 0.0199 | * |
| WSD : Summer 2017 | 0.0557 | 0.16 | 0.7291 | |
| WSD : Fall 2017 | 0.2665 | 0.15 | 0.0799 | . |
| WSD : Spring 2018 | 0.1612 | 0.14 | 0.2533 | |

Table 12b. Analysis of deviance table (Type II Wald $X^2$ tests) to determine the overall effect of interactions with season within Model 5 predicting overall random/turtle location, where Season includes all four seasons.

| Parameter | $X^2$ | df | P | |
|---|---|---|---|---|
| Standing water | 59.0784 | 1 | 1.52e-14 | *** |
| Saturated soil | 11.2583 | 1 | 0.0008 | *** |
| Sedges/graminoids | 4.4667 | 1 | 0.0346 | * |
| Woody stem density (WSD) | 12.2334 | 1 | 0.0005 | *** |
| Reed canary grass | 2.2949 | 1 | 0.1298 | |
| Grazing | 1.7898 | 1 | 0.1809 | |
| Season | 19.5888 | 3 | 0.0002 | *** |
| Standing water : Season | 3.7301 | 3 | 0.2921 | |
| WSD : Season | 6.2483 | 3 | 0.1001 | |

The results of the four-season analyses are similar to those of the spring 2018 + summer 2017 + fall 2017 analysis, suggesting that the original models are robust. Both sets of models indicate standing water and saturated soils are crucial factors in microhabitat selection by bog turtles. The major difference between the two sets of analyses is that in two of the four-season models (turtle plots v. nearby random plots and turtle plots v. all random plots), turtle plots were positively associated with sedges/graminoids. This association is in agreement with the univariate analysis. In addition, there were significant interactions between season and woody stem density, with spring 2018 differing from spring 2017, and between season and standing water, with spring 2017 differing from fall 2017. Spring 2017 data included few early spring data points, and therefore represented drier habitat conditions (accounting for the season by standing water interaction) when turtles would have moved further from hibernacula (accounting for the season by woody stem density interaction).

*Movements and distance*

Mean distance traveled per day across the study was 3.39 m (± 5.12 m, range 0.04 m-53.3 m). During spring 2017 (April through June 14), mean distance traveled was 3.63 m/day (± 4.14 m, range 0.19 - 20.76 m). During summer 2017 (mid-June through early August), mean distance traveled was 4.84 m/day (± 8.27 m, range 0.06 - 53.29 m). During fall 2017 (mid-August through October), mean distance traveled was 1.20 m/day (± 1.32 m, range 0.05 - 6.13 m) (Figure 6). During spring 2018 (April through June 14), mean distance traveled was 3.21 m/day (± 3.54m, range 0.04 - 25.84 m).

Regression analysis showed no effect of sex or site on log transformed daily movements (Table A12). There was an overall effect of season on daily movements ($p$ = 1.33e-09) (Table 13a-b). Tukey comparisons showed that movements differed between seasons with fall 2017 movements being smaller than all other seasons ($p$ < 1e-05). No other seasons differed significantly (Table 13c) though movements were largest in the summer season (Figure 6).

Out of the 469 total points collected from 29 turtles over the course of the study, only 20 points were located outside of delineated wetland habitat on the easements. Five of these locations were still in wetland habitat but outside of the wetland within the easement, often on neighboring property. The remaining 15 points were located less than 10 m from delineated wetland, 87% of which were less than 5 m from delineated wetland.

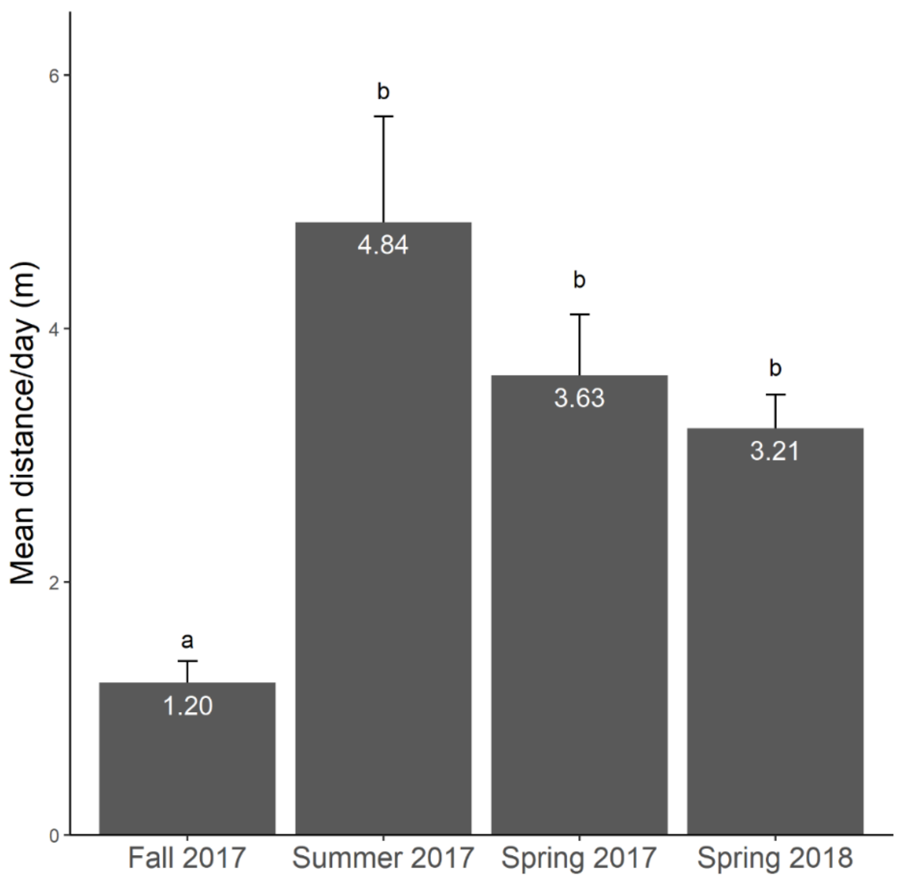


Figure 6. Mean distance/day (m) by season for bog turtles in southeastern PA. Movements significantly differed between seasons with fall movements being smaller than all other seasons ($p$ < 1e-05). Error bars represent one standard error.

Table 13a. Final model examining differences in log transformed distance per day by season (Model 3, see Table A12) (log transformed distance/day ~ season, random = ~1|TurtleID). Models were run as linear mixed effects models using lme (nlme) in R with the following syntax: Response variable ~ fixed effects, random = ~1|random effects. Significance codes: * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Parameter | Estimate | SE | P | |
|---|---|---|---|---|
| (Intercept) | 0.7152 | 0.14 | 0.0000 | *** |
| Season – Summer 2017 | -0.0311 | 0.18 | 0.86 | |
| Season – Fall 2017 | -1.1329 | 0.20 | 0.0000 | *** |
| Season – Spring 2018 | -0.0778 | 0.16 | 0.63 | |

Table 13b. Analysis of deviance table (Type II $X^2$ tests) to examine the overall effect of season within Model 3, examining differences in log transformed distance per day by season.

| Parameter | $X^2$ | df | P | |
|---|---|---|---|---|
| Season | 44.26 | 3 | 1.332e-09 | *** |

Table 13c. Tukey post-hoc comparisons of season within Model 3, examining differences in log transformed distance per day by season.

| Parameter | Estimate | SE | P | |
|---|---|---|---|---|
| Summer 2017 – Spring 2017 | -0.0311 | 0.18 | 1.00 | |
| Fall 2017 – Spring 2017 | -1.1329 | 0.20 | <1e-05 | *** |
| Fall 2017 – Summer 2017 | -1.1017 | 0.19 | <1e-05 | *** |
| Spring 2017 – Spring 2018 | -0.0778 | 0.16 | 0.96 | |
| Summer 2017 – Spring 2018 | -0.0467 | 0.15 | 0.99 | |
| Fall 2017 – Spring 2018 | 1.0551 | 0.17 | <1e-05 | *** |

*Minimum convex polygon (MCP) home range*

Median MCP home range size calculated over 2017-2018 was 0.24 ha in males and 0.27 ha in females for an overall median of 0.26 ha across all sites. Mean MCP home range was 0.31 (± 0.25) ha in males and 1.01 (± 1.63) ha in females, which was greatly affected by two outliers. A female at the UGR1 site had a considerably larger home range than any other individual (MCP 5.19 ha, 50% KDE 0.83 ha, 95% KDE 4.91 ha) and a female at GRZ2 had a very large home range (MCP 3.57, 50% KDE 1.04 ha, 95% KDE 5.26 ha) (Figure 7, Table A11), which were greatly increased in size by a single point. All other MCP home ranges were less than 1 ha. Overall mean MCP home range was 0.76 (± 1.33) ha across all sites (Table 14). There was no significant difference in logged MCP home range size between males and females ($p$ = 0.40 (Table 15) or between sites ($H(4)$ = 4.09, $p$ = 0.39). MCP home ranges within each site overlapped by a mean of 25.5%.

*Kernel density estimate (KDE) home range*

Mean 50% KDE was 0.21 (± 0.28) ha overall (Table 14, Figure 7) and did not significantly differ between males and females (log transformed, $p$ = 0.50) (Table 15) or between sites ($H(4)$ = 5.27, $p$ = 0.26). Mean 95% KDE was 1.07 (± 1.50) ha overall (Table 14) and did not significantly differ between males and females ($p$ = 0.38) (Table 15) or between sites ($H(4)$ = 5.01, $p$ = 0.29).

Mean log transformed home range size differed by estimation technique ($p$ < 2.2e-16) (Table 16a, Table 16b) with 95% KDE being significantly larger than both MCP ($p$ < 2e-16) and 50% KDE ($p$ < 2e-16), and MCP being larger than 50% KDE ($p$ < 1e-10) (Table 16c). Figure 7 shows home range sizes for all turtles.

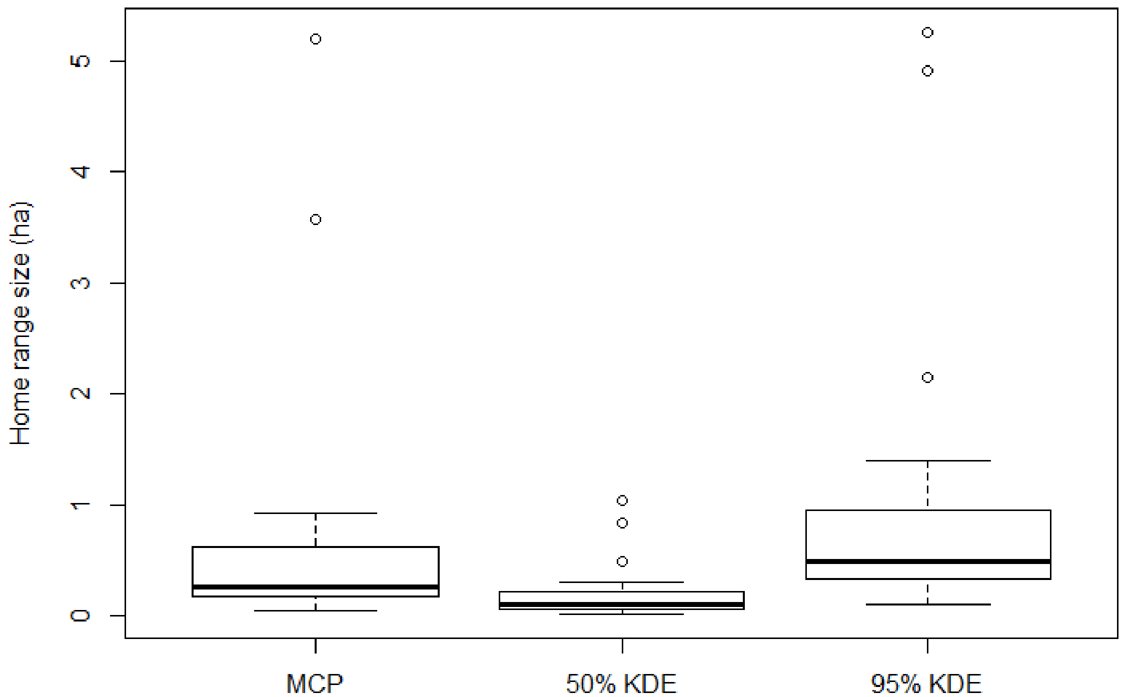


Figure 7. Bog turtle home range size (n = 19) for three estimation methods. Mean log transformed home range size differed by estimation technique ($p < 2.2e-16$) (Table 16a, Table 16b).

Table 14. 2017-2018 home range size mean, median, and range for bog turtles (*n* = 19) in five wetlands in southeastern PA calculated using minimum convex polygon (MCP), 95%, and 50% kernel density estimation (KDE). All units in hectares.

| **MCP** | **Male (*n* = 7)** | **Female (*n* = 12)** | **Overall (*n* = 19)** |
|---|---|---|---|
| mean | 0.31 (± 0.25) | 1.01 (± 1.63) | 0.76 (± 1.33) |
| median | 0.24 | 0.27 | 0.26 |
| range | 0.052 - 0.83 | 0.065 - 5.19 | 0.052 - 5.19 |
| | | | |
| **50% KDE** | **Male (*n* = 7)** | **Female (*n* = 12)** | **Overall (*n* = 19)** |
| mean | 0.11 (± 0.07) | 0.27 (± 0.34) | 0.21 (± 0.28) |
| median | 0.088 | 0.11 | 0.10 |
| range | 0.035 - 0.22 | 0.017 - 1.04 | 0.017 - 1.04 |
| | | | |
| **95% KDE** | **Male (*n* = 7)** | **Female (*n* = 12)** | **Overall (*n* = 19)** |
| mean | 0.51 (± 0.33) | 1.40 (± 1.82) | 1.07 (± 1.50) |
| median | 0.33 | 0.55 | 0.49 |
| range | 0.13 - 1.07 | 0.10 – 5.26 | 0.10 – 5.26 |

Table 15. Results of models examining differences in log transformed home range size by sex for each home range estimation method (log transformed home range area ~ sex, random = ~1|Site), Models were run as linear mixed effects models using lme (nlme) in R with the following syntax: Response variable ~ fixed effects, random = ~1|random effects. Significance codes: * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| **Estimation method** | **Parameter** | **Estimate** | **SE** | **P** | |
|---|---|---|---|---|---|
| MCP | (Intercept) | -0.9015 | 0.37 | 0.0306 | * |
| | Sex - Male | -0.4886 | 0.56 | 0.4002 | |
| 50% KDE | (Intercept) | -1.9058 | 0.38 | 0.0002 | ** |
| | Sex - Male | -0.3327 | 0.48 | 0.4993 | |
| 95% KDE | (Intercept) | -0.3250 | 0.36 | 0.3888 | |
| | Sex - Male | -0.4482 | 0.49 | 0.3803 | |

Table 16a. Model examining differences in log transformed home range by estimation method (log transformed home range ~ method, random = ~1|TurtleID). Models were run as linear mixed effects models using lme (nlme) in R with the following syntax: Response variable ~ fixed effects, random = ~1|random effects. Significance codes: * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Parameter | Estimate | SE | P | |
|---|---|---|---|---|
| (Intercept) | -1.1159 | 0.26 | 1e-04 | *** |
| Method – 50% KDE | -1.0139 | 0.06 | 0 | *** |
| Method – 95% KDE | 0.5508 | 0.06 | 0 | *** |

Table 16b. Analysis of deviance table (Type II tests) to examine the overall effect of estimation method on log transformed home range size.

| Parameter | $X^2$ | df | P | |
|---|---|---|---|---|
| Method | 702.7 | 2 | <2.2e-16 | *** |

Table 16c. Tukey post-hoc comparisons of methods within model examining effect of estimation method on log transformed home range size.

| Parameter | Estimate | SE | P | |
|---|---|---|---|---|
| MCP – 50% KDE | 1.0139 | 0.06 | <2e-16 | *** |
| 95% KDE – 50% KDE | 1.5648 | 0.06 | <2e-16 | *** |
| 95% KDE – MCP | 0.5508 | 0.06 | <2e-16 | *** |

Discussion

The primary goal in this study was to assess effects of grazing on the microhabitat structure of bog turtles. Due to the lack of available grazed sites, we were unable to utilize statistical analysis in comparing sites. PCA results demonstrate how variable microhabitat characteristics were at all sites. Within site variability is expected as bog turtle habitat tends to be heterogenous, with pockets of wet and dry area that fluctuate throughout the season (Chase et al. 1989, Carter et al. 1999). The vegetation differed more between the two grazed sites, GRZ2 and GRZ1, than between grazed and ungrazed sites (Figure 3). In addition, the two grazed sites varied in stocking density and frequency of grazing. Site variability was also exacerbated by ongoing chemical treatment of cattail and multiflora rose at some of the study sites. These differences along with small sample size of sites made it difficult to ascertain any effects of grazing on the microhabitat.

A previous study on the effects of cattle grazing indicated that grazed sites had greater cover of graminoids, ferns, and forbs, and decreased height of invasive species like purple loosestrife, Japanese stilt grass (*Microstegium vimineum*), and reed canary grass (Tesauro and Ehrenfeld 2007). These authors hypothesized that grazing initially catalyzed growth and establishment of invasive plants by the addition of nutrients from manure and run-off, but continual grazing prevented these species from dominating. The authors found more turtles in grazed sites than formerly grazed sites. However, as they note, the number of turtles found was correlated with habitat area. Population size is most likely related to habitat area as well as other factors, such as historical population size, historical habitat area, and land use history. History of land use can be difficult to obtain, particularly as smaller farming operations are lost, and land is developed into a suburban landscape (Ferry and Brock 2003, Alter 2017). Even with land use information, differences in grazing history may be difficult to compare.

Stocking density and frequency may be important components to understanding the effects of grazing. It is also important to consider the existing vegetation and whether grazing might benefit the plant species composition. Studying sites with similar densities and cattle access, or an increased number of study sites, would allow for better comparison. Without statistical basis, we hypothesize that limiting the number of cattle, portion of a wetland grazed, grazing frequency and duration, or seasonal access will be crucial parts of a management scheme. We also hypothesize that the plant composition, particularly the types of invasive species, at each site will necessitate different management practices.

Few studies have examined the effects of habitat alterations on bog turtle populations (Tesauro and Ehrenfeld 2007, Sirois et al. 2014). None of these studies attempted to examine microhabitat selection in response to habitat alterations, as was attempted in this study. With the addition of more grazed sites, valuable information could be obtained about habitat selection in response to grazing. It may also be beneficial to intensively examine a small number of populations before and after the application of grazing as a management tool.

*Microhabitat selection*

Turtle microhabitat observations in this study were very consistent with previous literature describing bog turtle habitat and behavior. Bog turtles were more likely to be in areas containing saturated soil, access to refugia, short grasses and sedges, high woody stem density, and that are wet but not entirely inundated with water (Chase et al. 1989, Ernst and Lovich 2009, Myers 2011, Tesauro and Ehrenfeld 2007). Chase et al (1989) and Tesauro and Ehrenfeld (2007) examined differences among wetlands, and found that wetlands with the above characteristics had higher densities of turtles. Our study and Myers (2011) examined habitat selection by turtles within wetlands by comparing turtle locations to nearby and far random locations. It is interesting that studies conducted at both the landscape scale and at the microhabitat scale converge on the same (or similar) set of habitat characteristics that appear to be essential to bog turtles. It is also worth noting that these studies were performed in different states throughout the Mid-Atlantic region (Maryland, Pennsylvania, New Jersey, and New York), suggesting that habitat needs throughout this region are similar.

Compared with other areas in the wetland, there was a clear selection by bog turtles for standing water and saturated soils. Differences in standing water and saturated soil were greater between turtle plots and far random plots than between turtle plots and near random plots, indicating that bog turtles are selecting for wet patches within the larger habitat. Bog turtle habitat is often heterogenous and contains wet and dry pockets of habitat. Vegetation characteristics in sites selected by bog turtles had greater coverage of sedges/graminoids and higher density woody stems than unselected sites. Selection for sedges/graminoids appeared to be stronger at the microhabitat scale (i.e., between turtle and nearby random plots), indicating that turtles are selecting for sedges/graminoids within larger patches of suitably wet habitat. Selection for high woody stem density appeared to be stronger at a larger spatial scale (i.e., between turtle sites and far random patches), indicating that turtles were selecting between larger patches of habitat. The interactions between season and woody stem density/tall vegetation in models of turtle vs random plots can be attributed to turtles moving to and from hibernacula. Because hibernacula are often in shrub thickets where turtles use elaborate root tunnels, habitat use by turtles includes extensive use of areas with high woody stem density, particularly in early spring and fall. The importance of woody stems and sedges/graminoids to bog turtles is illustrated in a landscape-level study by Myers and Gibbs (2013). They found that wetlands occupied by bog turtles had about 1.5 times greater proportional area of scrub-shrub vegetation and 3.5 times greater proportional area of emergent vegetation than random unoccupied wetlands. Although this study and our study were performed at vastly different spatial scales, they both indicate the importance of particular habitat types.

We often found bog turtles in or around standing water in areas covered by low vegetation (i.e., turtles were hidden from view). On average, turtle plots contained less than 25% standing water. Turtles may not always use standing water, but having water available is a major component of bog turtle habitat selection. Feaga et al. (2013) found that wetlands used by bog turtles did not differ from unused wetlands in soil attributes like organic carbon or particulate size; however unused wetlands lacked areas that were continuously saturated. It is worth noting that in our analyses standing water and refugia index were highly correlated, meaning that the water itself may not be the most important factor but that it means a turtle may find refuge from predators, heat, etc. (Pittman and Dorcas 2009).

Tesauro and Ehrenfeld (2007) reported 45% of their bog turtle observations occurred in hoofprints of large grazers, leading them to suggest that hooprints serve as an important microhabitat for turtles. We did not observe anything like this at grazed site used in this study. We suspect that hoofprints may have been searched more often as bog turtle surveyors tend to return, even if unconsciously, to areas of successful previous captures. Although these authors did not report the site area or stocking densities at any of their sites, their result might also be attributed to larger densities of cattle covering more of the available wetland in hoofprints. The use of radiotelemetry in our study provides more detailed information regarding habitat use and selection, and we do not feel that the use of hoofprints is a strong component of bog turtle habitat selection.

At larger spatial scales (i.e., in comparison to far random plots), turtles were found at sites with low cattail densities. However, at smaller spatial scales, turtle presence was positively associated with cattail densities. This apparent contradiction is likely due to cattail's need for moist soils. It appears that turtles are avoiding dense stands of cattails but that their preference for wet microhabitats blurs this relationship at smaller spatial scales. Bog turtles may choose cattails for shade or food, as slugs are known to inhabit the lower stems of the cattail (USWFS 2010). Cattail distribution within a wetland has important management implications as cattails can spread rapidly and create dense monocultures that are unsuitable bog turtle nesting habitat (Myers 2011, USFWS 2010).

Though we found turtles often associated with reed canary grass, we do not think that turtles are selecting for this species but rather for standing water or grasses and sedges. Reed canary grass has become an undesirable weed in many agricultural areas as it was (and, in some cases, still is) cultivated as forage (Wilkins and Hugh 1932). Present throughout North America, it has become a dominant plant creating dense stands in many US wetlands (Schooler et al. 2006). Reed canary is highly adaptable to water level and soil moisture fluctuations, grows rapidly, and spreads laterally (Schilling and Kiniry 2007). The sheer biomass and leaf surface area in dense stands of reed canary result in higher transpiration rates than other plant species that can alter the hydrology of wetlands resulting in low stream flow or lowering of the water table (Gebauer 2013). Invasion by reed canary is known to decrease plant diversity, floristic quality, and insect abundance and diversity, causing general declines in biodiversity in invaded areas (Spyreas et al. 2010).

Throughout the study no turtle was ever observed in stream habitat although a stream was available at every study site, which is consistent with other studies that report that bog turtles seldom use or even avoid stream habitat (Chase et al. 1989, Carter et al. 1999). However, Pittman and Dorcas (2009) found that stream habitat was used regularly at their study site in North Carolina, even when other suitable habitat was available. Many turtles in our study crossed a stream to travel between suitable habitats. Some streams were deeply incised, potentially impeding bog turtle movements.

*Movements*

Daily movements of bog turtles reported in the literature range from as low as 0.1-1.32 m/day at two sites in Maryland (Byer et al. 2017) to approximately 13-14 m/day at a site in North Carolina (Smith and Cherry 2016). Lovich et al. (1992) reported daily movements of approximately 1-2 m/day at a site in North Carolina. Daily movements of turtles in this study (3.39 ± 5.12 m/day) are consistent with a study by Morrow et al. (2001b) that reported daily mean movements of 3.3 (± 0.2) m/day at two study sites in Maryland.

Movements may be dependent on seasonal factors, habitat size, or time between observations. In this study, bog turtle tracking was limited by our Pennsylvania Fish & Boat Commission permit which allowed weekly tracking before June 15$^{th}$ and twice per month thereafter. Every published study that reports daily movements of bog turtles has used a different tracking protocol (i.e. tracking duration, tracking frequency).

Distances moved by males and females did not differ in this study consistent with previous reports on bog turtle movements (Pittman and Dorcas 2009, Carter et al. 2000, Morrow et al. 2001b, Smith and Cherry 2016).

Several studies have proposed a bimodal pattern in bog turtle activity, suggesting that they are most active when emerging from hibernation and before entering hibernacula in the fall (Arndt 1977, Bury 1979, Collins 1990). Conversely, we found that turtles made the smallest movements during the fall. Morrow et al. (2001b) suggests that if this bimodal pattern exists, it is not noticeable. The choice by the researcher as to which dates constitute the different seasons may also affect whether a bimodal distribution is detected. Straight line distances normalized by day make it difficult to track actual distances moved by turtles. While a bog turtle may appear to move only a short distance, straight line measurements can underestimate actual distances traveled by as much as 6.5 times (Carter et al. 2000, Chase et al. 1989). A more valid, though difficult, way to measure this is to use thread spooling to compare daily “activity areas” and length of thread extended several times throughout the season.

*Home range*

We calculated home ranges using three techniques, minimum convex polygon (MCP), 50 percent kernel density estimate (50% KDE), and 95 percent kernel density estimate (95% KDE). Each of these measures provides different information on home range. The MCP encloses all locations at which a turtle was located but provides no information on where the turtle went within this area or how much time it spent in different areas within that range. The 50% KDE describes an area where a turtle would be expected to spend roughly 50% of its time and is often used as an estimate of core habitat for that individual. Because it estimates core habitat, the 50% KDE may also indicate areas that should receive top priority for habitat management. The 95% KDE describes where a turtle would be expected to spend 95% of its time, which is often used as an estimate of total area likely to be used. Because it is an estimate based solely on turtle locations and does not incorporate actual habitats, the 95% KDE ends up including areas that are highly unlikely to be used by turtles. For example, if a turtle spends a large amount of time near a wetland edge, the estimate may extend into upland areas never used by the turtle. The 50% and 95% KDE can also result in estimated home ranges being fragmented into two distinct areas, in which case it is important to recognize that that turtles move between the fragments.

All minimum convex polygon (MCP) and 50% kernel density estimate (KDE) home ranges were below 1 ha except for two individuals: one female at UGR1 (MCP 5.19 ha, 50% KDE 0.83 ha) and one female at GRZ2 (MCP 3.56 ha, 50% KDE 1.04 ha) (Table A11). For both turtles, home range size was greatly increased by a single, outlying data point. Home range sizes in our study are consistent with those of many previous studies (Chase et al. 1989, Morrow et al. 2001b, Smith and Cherry 2016, Byer at al. 2017); however, home ranges were smaller than those reported in some other studies (Eichelberger 2005, Ernst 1977). This difference might be due to differences in the size of available habitat within study sites; however, this is difficult to define and often not reported.

It is important to recognize that home ranges may fluctuate between years due to local conditions (e.g. rainfall, temperature) and that data collected over one year may miss specific trends present in other conditions. Long term differences in home range size may indicate changes in habitat quality. It has been suggested that an increase in home range size across years may be due to a decrease in the quality of available habitat, possibly due to increases in invasive species (Byer et al. 2017, Morrow et al 2001b). To make comparisons across years, home ranges must be calculated using the same technique and similar sample sizes, as these can have substantial effects on calculations of home range size.

Both MCP and 95% KDE seemed to overestimate home range in this study by including vast areas of land never used by a turtle. The 50% KDE appears to be a good method for identifying important, or “core”, habitat area and critical areas for intense management. Even though it does not identify the most utilized habitat, MCP may be a better method of estimating home range if the goal is to understand the entire area within where a turtle moves. In addition, unlike KDE, MCP creates a boundary around the outermost points and thus removes some of the uncertainty that arises from uneven sample size, bandwidth selection, and the distribution of points that create high variability with kernel estimates.

The 95% KDE includes all locations where a turtle was found and may offer a good option for identifying total habitat requirements for the bog turtle. Although this estimate may include area never visited by a turtle, it may be important to include a buffer around areas of use. Therefore the 95% KDE may be an appropriate measure of home range from a land acquisition or protection standpoint. Because 50% and 95% KDE may fragment the estimated home range into two or more areas, MCP may be most useful for identifying corridors between fragmented areas of use (Figure 8). These corridors may not include characteristics often associated with bog turtle habitat and may be overlooked in initial surveys. In many cases the 95% KDE includes area that crosses roads or other developed areas. No turtle was ever found to have crossed a paved road in this study, so paved roads may act as an appropriate boundary for easements in many cases. It is critical to consider all areas of use, corridors, and buffers when acquiring or protecting land for the preservation of the bog turtle. More than one method of estimation may thus be required to estimate bog turtle home range.

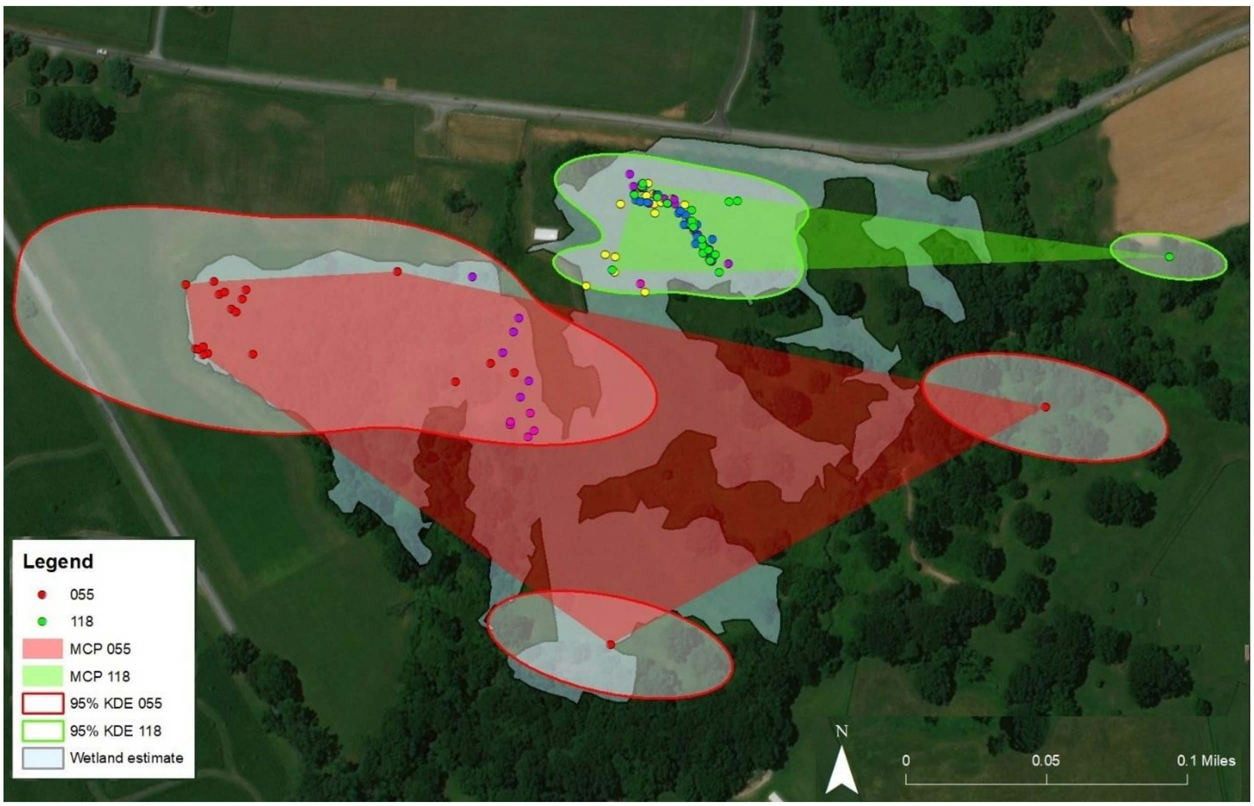


Figure 8. MCP and 95% KDE home ranges of two selected turtles. Note that MCP may identify important corridors between fragmented areas of use.

Finally, it is important to emphasize that home range estimation is dependent on several factors including the duration of observation, number of sample points collected, correlation of sample point data, and for some methods the choice of bandwidth (Walter et al. 2011). Despite our best efforts to predict home ranges, a turtle may still travel outside any calculated home range on occasion, which has implications for habitat protection and acquisition. Unless entire wetland complexes are preserved, there is no guarantee that a turtle won’t occasionally wander beyond the boundaries of a protected area.

Minimum convex polygon home ranges within each site overlapped by a mean of 25.5 percent, indicating that turtles at a particular site often utilized different areas of the wetland. As with home range estimation, home range overlap requires the choice of an appropriate method based on several factors (i.e. distribution of points, number of locations, expected overlap). In addition, home range overlap studies that measure home range overlap using one method may be not be comparable to studies that measure overlap differently (Millspaugh et al. 2004). Because kernel densities likely overestimated home range in this study, home range overlap was not calculated using KDE home ranges. The method used with MCP in this study is considered a static interaction analysis, meaning it measures overall association over a span of time without accounting for proximity of the animals at any particular time (Kernohan et al. 2001, Millspaugh et al. 2004). This method has been criticized because conclusions may be misleading regarding the probability of finding two animals in the same area (Fieberg and Kochanny 2005). The method used here does not take into account habitat selection and use within the home range and therefore does not make predictions about where turtles will be found within the home range but rather gives a general description of association between animals.

*Microhabitats, Turtle Movements, and Easement Boundaries*

Bog turtles in the study showed extremely high fidelity to microhabitats with saturated soil and access to standing water. This is born out in their movements and home ranges, with none of the turtles ever straying more than 10 m beyond the edge of a wetland. Out of the 469 total points collected from 29 turtles over the course of the study, only 15 points were located outside of wetlands. and only 2 of these 15 points were further than 5 m from the wetland edge. On the other hand, on several occasions, at 3 of the 5 study sites (UGR1, UGR2, and particularly UGR3), turtles traveled to wetland habitat straying as far as 80 m (UGR2) to 100 m (UGR1) off the NRCS easement. At the UGR3 site, the NRCS easement (6 acres) sits within a much larger wetland, and turtles frequently moved off the easement. These findings have implications for habitat protection and management. If the goal is to maximize long term protection for as many turtles in a wetland as possible, along with the habitats they use, protected areas for bog turtles should include as much of the wetland as possible. Large wetlands often span multiple properties with different ownership, greatly complicating protection efforts.

There are many valid reasons for preserving upland habitats surrounding wetlands. Removing uplands from agricultural use, both farming and grazing, will reduce inputs of nutrients and sediments to nearby wetlands, thereby improving water quality and reducing the spread of invasive species (Kercher and Zedler 2004, Woo and Zedler 2002). Protecting uplands surrounding wetland also provides a buffer against encroaching development and associated threats such as invasive species, poaching, and mesopredators (e.g., domestic pets, racoons, skunks, and opossums). However, our research suggests that bog turtles will rarely, if ever, stray more than a few m into upland habitat.

*Long Term Conservation at Landscape Scales*

Despite the relatively recent listing, bog turtle populations have been reported as declining for many years (Bury 1979). Even in 1861, these turtles were recognized as being in imminent danger (Ennis 1861). At least one study has shown positive outcomes of population monitoring at small scales. Chase et al. (1989) reported that in Maryland, the bog turtle population was not in immediate danger. Even though these small populations are persisting, the long-term sustainability of small populations is limited. Many studies have found loss of genetic variability in small populations, but report that population viability of long-lived species is more threatened by habitat loss and degradation than by loss of genetic diversity (Rosenbaum et al. 2007, Kuo and Janzen 2004). Recruitment will not be enough to sustain a population in the event of rapid decline in adult population. Proximity to humans may increase the likelihood and severity of population threatening events. Regional connectivity of wetlands can increase dispersal ability that may protect against stochastic events.

Maintaining habitat and connectivity among populations is crucial, as it will allow gene flow that can prevent harmful effects of inbreeding (Shoemaker and Gibbs 2013). Shoemaker and Gibbs (2013) used genetic markers to investigate the dispersal rates of bog turtles in a region of New York/Massachusetts. They found a dispersal rate of approximately 0.33 individuals per year (or approximately 1% per year) in recent centuries, which could be high enough to reduce maladaptive genetic drift (Mills and Allendorf 1996). These authors stressed the need for conservation and connectivity at a regional scale, which would include “stepping stone” wetlands that may not include turtles.

*On Grazing in Wetlands, Invasive Plant Species, and Bog Turtles*

Surprisingly little is known about the effects of grazing in wetlands on invasive vegetation. Tesauro (2001) and Tesauro and Ehrenfeld (2007) indicate that grazing by cattle, goats, and sheep can reduce the height of invasive plant species and increase the cover of native wetland vegetation. It is worth noting, however, that one of the invasive species with the greatest response to grazing in their studies, purple loosestrife, was absent at our study sites. Livestock grazing can also have detrimental effects on wetland vegetation, as manure can cause excess nutrient loading (Tesauro and Ehrenfeld 2007), especially if supplemental feed is provided to livestock. Excess nutrients can stimulate the invasion and growth of unwanted species at the expense of native wetland species (Kercher and Zedler 2004, Woo and Zedler 2002). Livestock grazing can also impact the streams that run through many wetlands, primarily through increased erosion due to removal of streamside vegetation and trampling of the banks. This can cause channel downcutting, or incision, which, in turn, can cause a lowering of the water table and a replacement of riparian plant species by upland species (Armour et al. 1991, Belsky et al. 1999).

Even less is known about the effect of invasive plant species on bog turtles. Although invasive species are frequently cited as a major cause of bog turtle decline (e.g., USFWS 2001, 2010) and USFWS (2010) promotes the control invasive species in bog turtle habitats, there are almost no studies that document negative effects of invasive species on bog turtles. Succession to forested wetland and the accompanying increases in canopy cover reduce the suitability of a habitat for bog turtles (Myer and Gibbs 2013), but that succession often involves native species such as red maple. There is some evidence that invasive reed canary grass can alter the hydrology of wetlands (Gebauer 2013) which, in turn, could potentially affect their suitability as habitat for bog turtles. Dense stands of reed canary and cattail can decrease heterogeneity in wetlands (Werner and Zedler 2002) and can potentially affect bog turtles by reducing light transmission to the ground (Tesauro and Ehrenheld 2007). However, the detrimental effects of most wetland invasive plants are more hypothetical than based on actual evidence. Tesauro and Ehrenfeld (2007) performed the only study that documents the negative effects of invasive plant species, and positive effects of livestock grazing, on bog turtles. In a comparison of grazed and formerly grazed sites, they found greater cover of low-growing native vegetation and lower heights of tall growing invasive vegetation at grazed sites. They also found that grazed sites contained greater numbers of turtles, greater turtle density, and greater frequency of occurrence for juvenile turtles. A potential confounding factor is that the shorter vegetation and the absence of litter at the grazed sites may have made it easier to find turtles, thus inflating the perceived benefits of grazing on bog turtles. In addition, almost half of the turtles found at grazed sites were found in hoof prints, which raises the possibility that the presence of hoof prints also made it easier to find turtles. Interestingly, Tesauro and Ehrenfeld found that cover of woody saplings, although low, was actually over 3x higher at grazed sites (although the difference was not statistically significant), which suggests that grazing may not be effective at preventing succession to forested wetland. Note that we are not claiming that invasive plants are not a threat to bog turtles, but rather that the evidence is generally circumstantial (e.g., Tesauro 2001) or lacking. Although we believe that high densities of invasive species can negatively impact bog turtles, more research on this topic is needed.

It is likely that the effects of invasive species will be complex and vary by plant density, soil characteristics, and environmental conditions. For example, multiflora rose is considered to be a species that degrades bog turtle habitat (USFWS 2010). However, at low densities multiflora rose may provide shade and shelter to bog turtles, which we occasionally observed under multiflora rose bushes.

Finally, grazing can directly impact bog turtle populations if large grazers (i.e., cattle) step on and injure or kill turtles or disturb or destroy nests. The likelihood of such occurrences increases at high densities of large grazers and when grazers have access to nesting areas during the bog turtle nesting season (USFWS 2010). During our study, one of our tracked turtles at a grazed site was stepped on and crushed by a cow.

Because of the potential for both beneficial and detriment effects, the USFWS promotes the use of grazing as a management tool for invasive plant species in wetlands occupied by bog turtles but also recommends caution in its implementation. The USFWS Service determined that "light to moderate livestock grazing that prevents or minimizes the encroachment of invasive native and exotic plant species" is not in violation of section 9 of the Endangered Species Act. In addition, the USFWS (2010) defined "light to moderate grazing":

For the purpose of this opinion, “light to moderate grazing” is defined as grazing using a stocking density of less than 0.75 animal units per acre of “grassland” within the fenced enclosure. “Grassland” is defined as open, grassy areas such as areas with emergent wetland vegetation (e.g., sedges, rushes); upland pasture grasses (e.g., fescue, timothy); or invasive, exotic plants (e.g., Phragmites, reed canary grass). This stocking density is equivalent to one dairy cow per two acres, four sheep per acre, or five goats per acre of grassland within the fenced enclosure. Grazers have access to both upland and wetland areas, and large grazers are excluded from known nesting areas during the bog turtle nesting season (June 1 to September 30).

Our limited knowledge on grazing, invasive species, and bog turtles means that there are many critical areas in need of further investigation, including:

- What effects, both positive and negative, do various invasive plant species have on bog turtles? How do these effects vary with plant density, soil type, and environmental conditions?
- How do various grazers (e.g., cattle, goats, sheep) differ in their effects on invasive wetland plants, wetland hydrology, and bog turtles?
- What are the effects of differences in stocking density, frequency and duration of grazing, and season during which grazing occurs on invasive wetland plants, wetland hydrology, and bog turtles?

Providing answers to these questions will be difficult, as combinations of the questions above are almost limitless – Which invasive species? What environmental conditions? Which grazer(s)? What grazing regimen? Given the limited number of grazed NRCS easements in southeast Pennsylvania with an adequate population of turtles, we highly recommend that future studies include sites other than NRCS easements and locations outside of southcentral Pennsylvania. In addition, there is the question of study design. Field surveys such as the one performed by Tesauro and Ehrenfeld (2007) must deal with the inherent issue of turtles being easier to find in habitats with low vegetation, i.e., grazed sites. An experimental study may be the most effective way to study the problem. Several sites could be selected with similar vegetational characteristics, and grazers could be stocked at the same density and with the same grazing regimen at half the sites (or, if all sites were already being grazed, grazers could be removed from half the sites). To truly determine the effects of grazers on turtles would require multiple years to evaluate the effect of grazing on recruitment and mortality (and potentially migration if turtles move into or out of treated sites). A radiotelemetry study would be preferred, as it would allow monitoring of individual turtles on a regular basis.

Because of all the issues and questions mentioned above, we are hesitant to recommend grazing as a management tool unless it is also linked to a study of its effect on vegetation, wetland hydrology, and turtles. At a minimum, we recommend that if grazers are stocked on NRCS wetland easements containing bog turtles, that USFWS (2010) recommended practices should be followed, i.e,. grazers should not be stocked at densities above the recommended level (e.g., 1 dairy cow/2 acres) and large grazers should be excluded from nesting areas from June 1 through September 30. If nesting areas are not known, we recommend that livestock be excluded from potential nesting areas (i.e., areas of the wetland with appropriate habitat) during these months until a proper study to determine nesting areas is performed. Although not included in the recommendations by USFWS, we also recommend that supplemental feeding of grazers be halted or minimized during periods in which they are grazing in the wetland and associated upland areas in order to minimize nutrient additions. At the two grazed sites in our study, stocking density was above the recommended level, there was no exclusion of grazers from potential nesting areas during the nesting season. In addition, both grazed sites had streams with highly incised channels running through the wetlands. Since stream incision can cause a lowering of the water table (Armour et al. 1991, Belsky et al. 1999), potentially impacting wetland hydrology, we recommend that streams running through bog turtle habitat be fenced to exclude livestock.

*Specific Site Observations and Recommendations*

*GRZ1*

Reed canary grass is present in patches mainly along the stream. Japanese stilt grass is also encroaching mainly along the stream at this site. Multiflora rose is present throughout the wetland and occasionally utilized by bog turtles. Autumn olive and mile a minute are also present but uncommon. A large alder thicket serves as an important hibernaculum. Red maple is a concern as it is growing within the alder thicket. This site supports a healthy breeding population of bog turtles with 8 males, 7 females, and 3 juveniles found during surveys or tracking. As far as we can tell, surveys have never been conducted to determine nesting areas.

Approximately 15 cattle had access at the beginning of the study, with plans to reduce the herd. Field 1 is divided with a smaller paddock located close to the barn. The cattle are occasionally moved between the two paddocks but otherwise have grazing access to core habitat year-round. Because these cattle are given supplemental forage when in the barn, the addition of nutrients on the property should be of concern. The stream running through the easement is deeply incised.

Our recommendations for management at this site include:

- Surveys should be conducted to determine nesting areas.
- Grazers should be excluded from known nesting areas from June 1 through September 30. Until surveys to determine nesting areas are completed, we recommend that grazers be excluded from all potential nesting areas (i.e., regions of the wetland with appropriate habitat) during these months
- Fencing should be installed along the creek to prevent further stream incision.
- The alder thicket should be maintained as a hibernaculum. However, maple trees within the thicket should be girdled to prevent excessive shading.
- Invasive species should be monitored and spot treated as necessary.

- Stocking density should be maintained below 0.75 animal units per acre (one cow or bull per 2 acres). The stocking density during our study was slightly above this level.

*UGR1*

Common reed is present in a patch toward the southern end of the wetland. UGR1 is the only site where common reed was observed. Reed canary grass is present at UGR1 but is not dominant. Tearthumb (*Persicaria sagittata*) is present and dominant in much of the western pasture. Mile a minute (*Persicaria perfoliata*) is present in spots. Multiflora rose is present throughout the wetland but most common in the southern portion of HMU 1. Canada thistle (*Cirsium arvense*) is growing in the upland close to the roadside within the easement fence, along the mowed path in the western pasture, and within the horse pasture.

In total, 3 males, 3 females, and 2 juveniles were located at the site during surveys or tracking. All turtles were originally located in the western pasture (HMU 1). Turtles were never located in the heavily wooded, central portion of wetland (much of HMU 2) where skunk cabbage dominates, though turtles may have traveled through this area when they traveled to the eastern edge of the wetland. Fencing was installed in the eastern portion of the site in June 2017 separating HMU 3, where horses graze, and HMU 2. The horses were never observed entering the wetland at any time before fence installation and the turtles were never observed in the evidently grazed portion of field.

Our recommendations for management of this site include:

- Invasive species should be monitored and spot treated as necessary.
- Two turtles left the site and wandered onto neighboring properties. We do not know whether these properties have been surveyed for bog turtles. Because turtles are utilizing areas within the wetland that fall outside of the easement, NRCS might want to consider surveys and potential easements on these neighboring properties.

*GRZ2*

GRZ2 is dominated by reed canary grass in both pastures. Multiflora rose is present and occasionally utilized by bog turtles. Canada thistle is present in the upland but very near the wetland and may require herbicides rated for use in wetlands.

Reed canary grass is also present at the neighboring site but nowhere near as dominant as at GRZ2. The neighboring site is a more diverse wetland. The main wetland is filled with cattail, ferns, and skunk cabbage, as well as woody species, including a large patch of multiflora rose that was treated in 2017 but returned in 2018. Reed canary grass is present in the southern part of the wetland but is not yet dominant.

Only 1 young male, 3 females, and 4 juveniles were found at the GRZ2 site. In 2018, one female was observed in the northern pasture (HMU 2b) of GRZ2. No turtle was observed in this pasture before and this pasture was not surveyed in either 2017 or 2018. It is possible turtles utilize this pasture more often than observed in this study.

The GRZ2 site contains approximately 22 cattle. Because this site is split into two pastures, at any time the cattle are enclosed in one pasture they are stocked at a rate much higher than the recommended 0.75 animal units per acre and did have grazing access during the nesting season. One of our monitored turtles was crushed and killed by a cow at this site, possibly because of the high stocking density.

Our recommendations for management of this site include:

- The 2014 USFWS habitat management plan for the GRZ2 property called for the installation of fencing around core bog turtle habitat and along the entire length of the stream by March 2015 and the exclusion of grazers from this area from June-September. However, the fencing was never installed and cattle continue to graze and trample this area throughout the summer months. We strongly recommend that fencing be installed around core bog turtle habitat and along the stream before June 2019 and that cattle be excluded from this area from June 1 through September 30.
- Invasive species should be monitored and spot treated as necessary. Multiflora rose on the neighboring site was cut in 2017 but grew back almost entirely in 2018. Herbicide may be necessary to control multiflora rose on this site.
- To the best of our knowledge, the northern pasture of GRZ2 (HMU 2b) has never been surveyed for bog turtles. One of our monitored turtles wandered into the pasture in 2018, which does contain wetland habitat. We recommend that future surveys include this area of the property.

*UGR2*

The UGR2 site is dominated by reed canary grass. There is a small cattail patch often utilized by the bog turtles at the site. This site contained the smallest population of bog turtles with only 3 turtles (2 males, 1 female) and no juveniles found during surveys. One male turtle traveled to a wetland along a powerline to the south of the site. This habitat was never surveyed but contains suitable habitat and may contain more turtles. At least two turtles hibernated within a portion of the vegetated buffer between the wetland and the agricultural field to the east. A tunnel entrance was located at the base of a large shrub but otherwise this area contained little saturated soil.

Our recommendations for management of this site include:

- Invasive species should be monitored and spot treated as necessary.
- The UGR2 and UGR3 sites are part of a larger wetland complex that was disrupted by the construction of U.S. Route 222. As described above, one turtle wandered south of UGR2 onto neighboring property. Because turtles are utilizing areas within the wetland complex that fall outside of the easement, NRCS might want to consider surveys and potential easements on neighboring properties to the south of UGR2.

*UGR3*

Despite the proximity of this site to UGR2, UGR3 has little reed canary present. Much of the wetland utilized by bog turtles is dominated by cattail which was chemically treated during the study period. Much of this cattail dominated wetland extends into neighboring property not contained within in the easement, where turtles spend a significant amount of time and use portions as hibernacula. Cattail is not treated on this neighboring property, so expansion of cattails poses a continued threat to the site. UGR3 contains a healthy breeding population of bog turtles with 8 males, 7 females, and 3 juveniles found during surveys and tracking.

Our recommendations for management of this site include:

- Invasive species should be monitored and spot treated as necessary. Cattail at this site is dense and of special concern.
- The wetland in which the UGR3 easement is located is much larger than the easement, and turtles frequently wander onto neighboring properties. Because turtles are utilizing areas within the wetland that fall outside of the easement, NRCS might want to consider potential easements on neighboring properties.

*Conclusion*

The collection of bog turtle behavior and habitat use in this study is only a snapshot of the overall behavioral characteristics of the bog turtle species but will serve as a valuable tool in conserving the habitat at these study sites. Comparisons of grazing made in this study should be examined with caution because of the differing plant composition, grazing density, frequency, and duration. While turtles were rarely observed leaving wetlands in this study, bog turtles do occasionally make long distance movements, even if only rarely. This underscores the importance of protecting and maintaining entire wetland complexes. Surrounding upland habitat should also be protected when possible as it may shield wetlands from adverse effects of agriculture and development.

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## Appendix A

Table A1. Total dissolved solids (TDS) and pH recorded at turtle locations in April 2018. All measurements were taken in shallow, standing water (< 5 cm).

| Site | Date | pH | TDS (ppm) |
|---|---|---|---|
| UGR2 | 4/26/2018 | 6.76 | 242.4 |
| UGR2 | 4/26/2018 | 6.84 | 122.5 |
| | | | |
| UGR1 | 4/29/2018 | 5.85 | 76.62 |
| UGR1 | 4/29/2018 | 6.06 | 76.51 |
| UGR1 | 4/29/2018 | 6.20 | 70.49 |
| UGR1 | 4/29/2018 | 6.24 | 72.05 |
| UGR1 | 4/29/2018 | 6.27 | 693.9 |
| UGR1 | 4/29/2018 | 6.45 | 66.06 |
| | | | |
| UGR3 | 4/26/2018 | 6.52 | 239.3 |
| UGR3 | 4/26/2018 | 6.74 | 233.8 |
| UGR3 | 4/26/2018 | 6.84 | 242.4 |
| UGR3 | 4/26/2018 | 6.84 | 242.4 |
| | | | |
| GRZ1 | 4/28/2018 | 5.85 | 24.73 |
| GRZ1 | 4/28/2018 | 5.89 | 23.87 |
| GRZ1 | 4/28/2018 | 6.55 | 20.07 |
| GRZ1 | 4/28/2018 | 9.47 | 31.79 |
| GRZ1 | 4/28/2018 | 9.56 | 20.5 |
| GRZ1 | 4/28/2018 | 9.82 | 34.97 |
| GRZ1 | 4/28/2018 | 9.97 | 20.07 |

Table A2. Individual turtle data from turtles tracked during 2017 and 2018. All measurements were recorded on original date found (2017 - Start). SCL = straight carapace length, SPL = straight plastron length, CW = carapace width, PW = plastron width. Age was measured (when possible) by counting annuli on plastron scutes. Worn refers to a turtle with a plastron that was over 50% worn and age could not be determined. KDE was not determined for turtles tracked less than 10 times in 2017. 246 was found dead and 615 was lost due to transmitter detachment. 885 was lost in 2017 due to transmitter detachment but recovered in 2018..

| Turtle | | | 2017 Season | | 2018 Season | | SCL | SPL | CW | PW | Height | Weight | Age | Total # |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Site | Sex | Start | End | Start | End | (mm) | (mm) | (mm) | (mm) | (mm) | (g) | (yrs) | Tracks |
| 885 | UGR2 | M | 5-27-17 | 7-6-17 | 5-7-18 | 6-25-18 | 96.5 | 80.9 | 70.1 | 46.7 | 37.0 | 136 | >8 | 11 |
| 765 | UGR2 | M | 5-15-17 | 10-4-17 | 4-14-18 | 6-25-18 | 105.1 | 82.4 | 72.9 | 49.0 | 39.5 | 154 | >9 | 21 |
| 315 | UGR2 | F | 4-28-17 | 10-4-17 | 4-14-18 | 6-25-18 | 98.2 | 83.5 | 69.6 | 48.6 | 41.4 | 152 | 9 | 22 |
| 685 | UGR1 | M | 7-17-17 | 10-17-17 | 4-22-18 | 6-27-18 | 100.7 | 79.5 | 75.4 | 47.5 | 37.2 | 159 | 6 | 11 |
| 176 | UGR1 | M | 4-21-17 | 10-17-17 | 4-22-18 | 6-27-18 | 102.7 | 83.1 | 72.1 | 46.9 | 38.1 | 154 | worn | 19 |
| 055 | UGR1 | F | 4-30-17 | 10-17-17 | 4-22-18 | 6-27-18 | 87.2 | 75.6 | 65.7 | 45.9 | 38.4 | 112 | 11 | 20 |
| 226 | UGR1 | F | 4-30-17 | 10-17-17 | 4-22-18 | 6-27-18 | 93.8 | 82.4 | 68.8 | 48.4 | 40.9 | 152 | >12 | 20 |
| 118 | UGR1 | M | 4-30-17 | 10-17-17 | 4-22-18 | 6-27-18 | 92.2 | 72.8 | 64.1 | 42.1 | 34.3 | 104 | 8 | 21 |
| 398 | UGR1 | F | 4-21-17 | 10-17-17 | 4-22-18 | 6-27-18 | 97.6 | 84.9 | 75.6 | 51.1 | 42.0 | 160 | worn | 22 |
| 246 | GRZ2 | F | 5-16-17 | 7-17-17 | | | 94.0 | 78.2 | 67 | 47.5 | 40.1 | 138 | worn | 7 |
| 615 | GRZ2 | M | 4-21-17 | 7-5-17 | | | 71.9 | 60.7 | 57.2 | 38.2 | 31.3 | 56 | 4 | 8 |
| 135 | GRZ2 | F | 6-8-17 | 10-17-17 | 4-22-18 | 6-27-18 | 100.6 | 86.3 | 75.7 | 52.8 | 41.7 | 163 | 13 | 15 |
| 733 | GRZ2 | F | | | 5-15-18 | 6-27-18 | 96.7 | 83.6 | 73.6 | 50.7 | 43.6 | 156 | >12 | 5 |
| 536 | UGR3 | M | 6-19-17 | 10-4-17 | 4-14-18 | 6-25-18 | 98.4 | 79.9 | 69.8 | 46.2 | 36.3 | 124 | 8 | 14 |
| 447 | UGR3 | F | 6-1-17 | 10-4-17 | 4-14-18 | 6-25-18 | 94.7 | 80.1 | 68.3 | 46.7 | 38.6 | 133 | 7 | 19 |
| 097 | UGR3 | M | 6-1-17 | 10-4-17 | 4-14-18 | 6-25-18 | 102.8 | 84.4 | 74.0 | 47.6 | 35.8 | 148 | worn | 19 |
| 665 | UGR3 | F | 5-27-17 | 10-4-17 | 4-14-18 | 6-25-18 | 93.8 | 79.5 | 66.1 | 47.5 | 37.8 | 139 | worn | 20 |
| 215 | UGR3 | M | | | 4-14-18 | 6-25-18 | 102.3 | 81.2 | 73 | 48.2 | 37.9 | 146 | worn | 9 |
| 814 | UGR3 | F | | | 4-26-18 | 6-25-18 | 89.5 | 79.7 | 67.7 | 48.1 | 39.4 | 136 | 9 | 8 |
| 992 | UGR3 | F | | | 5-20-18 | 6-25-18 | 90.4 | 77.8 | 64.6 | 45.7 | 40.5 | 133 | 7 | 4 |
| 005 | UGR3 | M | | | 5-20-18 | 6-25-18 | 93.6 | 73.7 | 64.8 | 44 | 34.4 | 108 | 9 | 4 |
| 585 | GRZ1 | F | 5-31-17 | 10-1-17 | 4-13-18 | 6-26-18 | 93.7 | 79.5 | 69.8 | 50.0 | 42.7 | 150 | 11 | 19 |
| 825 | GRZ1 | M | 5-31-17 | 10-1-17 | 4-13-18 | 6-26-18 | 94.6 | 75.5 | 68.0 | 44.3 | 35.0 | 110 | 6 | 19 |
| 337 | GRZ1 | F | 5-18-17 | 10-1-17 | 4-13-18 | 6-26-18 | 92.6 | 77.4 | 69.6 | 48.5 | 40.4 | 138 | >9 | 21 |
| 466 | GRZ1 | M | 4-16-17 | 10-1-17 | 4-13-18 | 6-26-18 | 124.0 | 81.3 | 75.5 | 49.1 | 42.0 | 142 | >15 | 19 |
| 016 | GRZ1 | F | 4-29-17 | 10-1-17 | 4-13-18 | 6-26-18 | 95.3 | 80.0 | 67.8 | 48.2 | 42.3 | 142 | >14 | 22 |
| 155 | GRZ1 | F | 4-29-17 | 10-1-17 | 4-13-18 | 6-26-18 | 102.8 | 85.3 | 74.0 | 51.7 | 42.8 | 174 | >13 | 22 |
| 268 | GRZ1 | M | 4-29-17 | 10-1-17 | 4-13-18 | 6-26-18 | 103.1 | 82.7 | 74.9 | 50.8 | 39.2 | 154 | >8 | 23 |
| 705 | GRZ1 | F | 4-16-17 | 10-1-17 | 4-13-18 | 6-26-18 | 91.6 | 78.0 | 66.6 | 49.4 | 41.3 | 128 | >15 | 25 |

Table A3. Other turtle species encountered during surveys or tracking 2017-2018.

| Species | ID | Site | Date |
|---|---|---|---|
| Spotted | L8R10 M | UGR1 | 6/21/2017 |
| Box | R2 J | UGR2 | 6/3/2018 |
| Box | F | UGR1 | 5/23/2018 |
| Box | F | UGR2 | 5/30/2018 |

Table A4. Correlation matrix showing Spearman's rank correlation coefficients between turtle plots and all random plots collected 2017-2018. One variable was removed from analysis from a pair if $r_s \geq 0.6$.

| | **Reed canary** | **Cattail** | **Sedges/ graminoids** | **WFF** | **Saturated soil** | **Standing water** | **Total veg >1m** | **Woody veg >1m** | **Forbs/fern >1m** | **Dist. to standing water** | **Refugia index** | **WSD** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reed canary** | | | | | | | | | | | | |
| **Cattail** | -0.0833 | | | | | | | | | | | |
| **Sedges/graminoids** | 0.2881 | -0.1211 | | | | | | | | | | |
| **WFF** | -0.2741 | 0.1058 | -0.8501 | | | | | | | | | |
| **Saturated soil** | 0.0615 | 0.3063 | 0.0826 | -0.0782 | | | | | | | | |
| **Standing water** | -0.0112 | 0.2093 | 0.1291 | -0.1383 | 0.5007 | | | | | | | |
| **Total veg >1m** | -0.0719 | -0.0123 | -0.4591 | 0.4826 | -0.0004 | -0.0908 | | | | | | |
| **Woody veg >1m** | -0.1952 | -0.2395 | -0.4362 | 0.3999 | -0.2050 | -0.0521 | 0.4828 | | | | | |
| **Forbs/fern >1m** | -0.1035 | 0.2725 | -0.2974 | 0.3467 | 0.1555 | -0.0689 | 0.5883 | -0.0601 | | | | |
| **Dist. to standing water** | 0.0252 | -0.2040 | -0.1185 | 0.1208 | -0.5540 | -0.8416 | 0.1008 | 0.0708 | 0.0447 | | | |
| **Refugia index** | 0.0069 | 0.3248 | 0.1110 | -0.1217 | 0.6862 | 0.7969 | -0.1157 | -0.1274 | -0.0400 | -0.7932 | | |
| **WSD** | -0.2057 | -0.2507 | -0.4179 | 0.4009 | -0.1966 | -0.0644 | 0.4113 | 0.8991 | -0.0784 | 0.0746 | -0.1136 | |
| **Canopy cover** | -0.2466 | -0.1204 | -0.3689 | 0.4214 | -0.0441 | -0.0242 | 0.4351 | 0.4645 | 0.2526 | 0.0205 | -0.0832 | 0.4517 |

Table A5. Results of mixed effects models predicting use/nearby availability of bog turtles, where season includes spring 2018, summer 2017, and fall 2017. Coefficient estimates and standard error are shown in parentheses for each fixed effect variable. All models were run as logistic regressions using glmer (lme4) in R (family = binomial). In all models, plot type was the response variable in which turtle plots were coded as 1 and nearby random plots coded as 0. All models included nested random effects; Season/Site/TurtleID, ‘:’ denotes an interaction. Significance codes: . = P < 0.1, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Variable | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -2.85 | *** | -2.84 | *** | -2.84 | *** | -2.77 | *** | -2.74 | *** | -2.66 | *** | -2.74 | *** |
| | (0.59) | | (0.58) | | (0.58) | | (0.54) | | (0.53) | | (0.50) | | (0.49) | |
| **Standing Water** | 0.41 | *** | 0.42 | *** | 0.42 | *** | 0.42 | *** | 0.42 | *** | 0.39 | *** | 0.38 | *** |
| | (0.08) | | (0.08) | | (0.08) | | (0.08) | | (0.08) | | (0.07) | | (0.07) | |
| **Sedges/graminoids** | 0.06 | | 0.06 | | 0.06 | | 0.06 | | 0.05 | | 0.05 | | 0.06 | |
| | (0.06) | | (0.06) | | (0.06) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | |
| **Woody stem density (WSD)** | 0.16 | | 0.16 | | 0.17 | | 0.16 | | 0.17 | * | 0.17 | . | 0.14 | . |
| | (0.14) | | (0.14) | | (0.12) | | (0.11) | | (0.09) | | (0.09) | | (0.08) | |
| **Reed canary** | 0.10 | | 0.10 | | 0.10 | | 0.10 | | 0.11 | . | 0.11 | . | 0.10 | . |
| | (0.07) | | (0.06) | | (0.06) | | (0.06) | | (0.06) | | (0.06) | | (0.06) | |
| **Cattail** | 0.03 | | 0.03 | | 0.03 | | | | | | | | | |
| | (0.10) | | (0.10) | | (0.10) | | | | | | | | | |
| **Saturated soil** | 0.09 | . | 0.09 | . | 0.09 | . | 0.09 | . | 0.09 | . | 0.09 | . | 0.10 | . |
| | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | |
| **Total vegetation > 1m** | -0.04 | | -0.04 | | -0.05 | | -0.05 | | -0.05 | | -0.04 | | | |
| | (0.10) | | (0.10) | | (0.06) | | (0.06) | | (0.06) | | (0.06) | | | |
| **Canopy cover** | 0.002 | | | | | | | | | | | | | |
| | (0.06) | | | | | | | | | | | | | |
| **Grazing - ungrazed** | 0.20 | | 0.20 | | 0.20 | | 0.22 | | 0.21 | | 0.21 | | 0.18 | |
| | (0.21) | | (0.20) | | (0.20) | | (0.19) | | (0.19) | | (0.19) | | (0.18) | |
| **Season - Summer** | 1.26 | . | 1.26 | . | 1.17 | * | 1.15 | . | 1.05 | * | 0.54 | * | 0.45 | * |
| | (0.67) | | (0.67) | | (0.59) | | (0.59) | | (0.46) | | (0.26) | | (0.23) | |
| **Season - Fall** | -0.04 | | -0.04 | | 0.03 | | 0.003 | | 0.18 | | 0.32 | | 0.24 | |
| | (0.72) | | (0.14) | | (0.64) | | (0.63) | | (0.52) | | (0.24) | | (0.21) | |
| **Standing water :** | -0.21 | | -0.21 | | -0.21 | | -0.21 | | -0.20 | | | | | |
| **Season - Summer** | (0.14) | | (0.14) | | (0.14) | | (0.14) | | (0.14) | | | | | |
| **Standing water :** | 0.06 | | 0.06 | | 0.06 | | 0.06 | | 0.06 | | | | | |
| **Season - Fall** | (0.16) | | (0.16) | | (0.15) | | (0.15) | | (0.15) | | | | | |
| **WSD : Season - Summer** | -0.04 | | -0.04 | | -0.06 | | -0.05 | | | | | | | |
| | (0.19) | | (0.19) | | (0.15) | | (0.15) | | | | | | | |
| **WSD : Season - Fall** | 0.07 | | 0.08 | | 0.07 | | 0.08 | | | | | | | |
| | (0.19) | | (0.18) | | (0.14) | | (0.14) | | | | | | | |
| **Total vegetation > 1m :** | -0.03 | | -0.03 | | | | | | | | | | | |
| **Season - Summer** | (0.14) | | (0.14) | | | | | | | | | | | |
| **Total vegetation > 1m :** | 0.01 | | 0.01 | | | | | | | | | | | |
| **Season – Fall** | (0.16) | | (0.16) | | | | | | | | | | | |
| **AIC** | 984.2 | | 982.2 | | 978.3 | | 976.4 | | 973.1 | | 971.6 | | 970.1 | |
| **df** | 21 | | 20 | | 18 | | 17 | | 15 | | 13 | | 12 | |
| **$R^2$** | 0.108 | | 0.108 | | 0.109 | | 0.109 | | 0.108 | | 0.105 | | 0.105 | |

Table A6. Results of mixed effects models predicting use/far availability of bog turtles, where season includes spring 2018, summer 2017, and fall 2017. Coefficient estimates and standard error are shown in parentheses for each fixed effect variable. All models were run as logistic regressions using glmer (lme4) in R (family = binomial). In all models, plot type was the response variable in which turtle plots were coded as 1 and far random plots coded as 0. All models included nested random effects; Season/Site/TurtleID, ':' denotes an interaction. Significance codes: . = P < 0.1, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| **Variable** | **1** | | **2** | | **3** | | **4** | | **5** | | **6** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -3.64 | *** | -3.42 | *** | -3.30 | *** | -3.46 | *** | -3.52 | *** | -3.41 | *** |
| | (0.65) | | (0.62) | | (0.43) | | (0.41) | | (0.40) | | (0.38) | |
| **Standing Water** | 0.66 | *** | 0.61 | *** | 0.61 | *** | 0.63 | *** | 0.62 | *** | 0.62 | *** |
| | (0.10) | | (0.08) | | (0.08) | | (0.08) | | (0.08) | | (0.08) | |
| **Sedges/graminoids** | 0.02 | | 0.02 | | | | | | | | | |
| | (0.07) | | (0.07) | | | | | | | | | |
| **Woody stem density (WSD)** | 0.18 | | 0.15 | | 0.15 | | 0.27 | ** | 0.25 | ** | 0.23 | * |
| | (0.17) | | (0.16) | | (0.16) | | (0.10) | | (0.09) | | (0.09) | |
| **Reed canary** | 0.04 | | 0.05 | | 0.05 | | 0.06 | | 0.07 | | | |
| | (0.07) | | (0.07) | | (0.07) | | (0.07 | | (0.07) | | | |
| **Cattail** | -0.20 | | -0.21 | . | -0.22 | * | -0.20 | * | -0.21 | * | -0.22 | * |
| | (0.11) | | (0.11) | | (0.10) | | (0.10) | | (0.10) | | (0.10) | |
| **Saturated soil** | 0.20 | *** | 0.21 | *** | 0.21 | *** | 0.20 | *** | 0.21 | *** | 0.21 | *** |
| | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | |
| **Total vegetation > 1m** | 0.12 | | 0.12 | | 0.12 | | 0.04 | | 0.04 | | 0.05 | |
| | (0.12) | | (0.12) | | (0.12 | | (0.09) | | (0.09) | | (0.09) | |
| **Canopy cover** | -0.06 | | -0.06 | | -0.06 | | | | | | | |
| | (0.06) | | (0.06) | | (0.06) | | | | | | | |
| **Grazing - ungrazed** | 0.30 | | 0.30 | | 0.30 | | 0.32 | | 0.36 | . | 0.39 | . |
| | (0.23) | | (0.22) | | (0.22) | | (0.22) | | (0.21) | | (0.21) | |
| **Season - Summer** | 1.97 | ** | 1.78 | ** | 1.78 | ** | 1.86 | ** | 1.82 | ** | 1.83 | ** |
| | (0.75) | | (0.61) | | (0.61) | | (0.59) | | (0.59) | | (0.58) | |
| **Season - Fall** | 0.21 | | -0.48 | | -0.46 | | -0.36 | | -0.38 | | -0.44 | |
| | (0.78) | | (0.63) | | (0.62) | | (0.62) | | (0.61) | | (0.61) | |
| **Standing water :** | -0.06 | | | | | | | | | | | |
| **Season - Summer** | (0.20) | | | | | | | | | | | |
| **Standing water :** | -0.23 | | | | | | | | | | | |
| **Season - Fall** | (0.17) | | | | | | | | | | | |
| **WSD : Season - Summer** | 0.10 | | 0.12 | | 0.12 | | | | | | | |
| | (0.23) | | (0.22) | | (0.22) | | | | | | | |
| **WSD : Season - Fall** | 0.27 | | 0.27 | | 0.27 | | | | | | | |
| | (0.22) | | (0.22) | | (0.22) | | | | | | | |
| **Total vegetation > 1m :** | -0.29 | . | -0.30 | . | -0.30 | . | -0.24 | . | -0.24 | . | -0.25 | . |
| **Season - Summer** | (0.17) | | (0.16) | | (0.16) | | (0.14) | | (0.14) | | (0.14) | |
| **Total vegetation > 1m :** | -0.05 | | -0.05 | | -0.05 | | 0.07 | | 0.07 | | 0.07 | |
| **Season – Fall** | (0.17) | | (0.17) | | (0.17) | | (0.14) | | (0.14) | | (0.14) | |
| **AIC** | 811.7 | | 809.5 | | 807.6 | | 805.2 | | 803.6 | | 802.5 | |
| **df** | 21 | | 19 | | 18 | | 16 | | 15 | | 14 | |
| **$R^2$** | 0.207 | | 0.214 | | 0.214 | | 0.215 | | 0.214 | | 0.214 | |

Table A7. Results of mixed effects models predicting use/overall availability of bog turtles, where season includes spring 2018, summer 2017, and fall 2017. Coefficient estimates and standard error are shown in parentheses for each fixed effect variable. All models were run as logistic regressions using glmer (lme4) in R (family = binomial). In all models, plot type was the response variable in which turtle plots were coded as 1 and random (both nearby and far) plots coded as 0. All models included nested random effects; Season/Site/TurtleID, ':' denotes an interaction. Significance codes: . = P < 0.1, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Variable | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -4.03 | *** | -4.02 | *** | -3.97 | *** | -3.99 | *** | -3.85 | *** | -3.90 | *** | -4.03 | *** |
| | (0.54) | | (0.54) | | (0.51) | | (0.51) | | (0.49) | | (0.47) | | (0.45) | |
| **Standing Water** | 0.51 | *** | 0.51 | *** | 0.51 | *** | 0.51 | *** | 0.46 | *** | 0.46 | *** | 0.45 | *** |
| | (0.07) | | (0.07) | | (0.07) | | (0.07) | | (0.06) | | (0.06) | | (0.06) | |
| **Sedges/graminoids** | 0.06 | | 0.06 | | 0.05 | | 0.05 | | 0.05 | | 0.05 | | 0.07 | |
| | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | |
| **Woody stem density (WSD)** | 0.22 | . | 0.25 | * | 0.25 | ** | 0.24 | ** | 0.24 | ** | 0.22 | ** | 0.23 | *** |
| | (0.13) | | (0.11) | | (0.08) | | (0.08) | | (0.08) | | (0.07) | | (0.07) | |
| **Reed canary** | 0.07 | | 0.07 | | 0.09 | | 0.09 | | 0.09 | | 0.08 | | 0.09 | . |
| | (0.06) | | (0.06) | | (0.06) | | (0.06) | | (0.06) | | (0.05) | | (0.05) | |
| **Cattail** | -0.06 | | -0.06 | | -0.06 | | -0.06 | | -0.07 | | -0.07 | | | |
| | (0.09) | | (0.05) | | (0.08) | | (0.08) | | (0.08) | | (0.08) | | | |
| **Saturated soil** | 0.15 | ** | 0.15 | ** | 0.15 | ** | 0.15 | ** | 0.15 | *** | 0.16 | *** | 0.15 | *** |
| | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | |
| **Total vegetation > 1m** | 0.003 | | -0.02 | | -0.03 | | -0.03 | | -0.03 | | | | | |
| | (0.09) | | (0.06) | | (0.06) | | (0.06) | | (0.06) | | | | | |
| **Forbs/ferns > 1m** | | | | | | | | | | | | | | |
| **Canopy cover** | -0.02 | | -0.02 | | -0.02 | | | | | | | | | |
| | (0.05) | | (0.05) | | (0.05) | | | | | | | | | |
| **Grazing - ungrazed** | 0.22 | | 0.21 | | 0.20 | | 0.22 | | 0.22 | | 0.20 | | 0.16 | |
| | (0.18) | | (0.18) | | (0.18) | | (0.17) | | (0.17) | | (0.17) | | (0.16) | |
| **Season - Summer** | 1.57 | ** | 1.34 | * | 1.14 | ** | 1.10 | ** | 0.64 | ** | 0.59 | ** | 0.60 | ** |
| | (0.60) | | (0.54) | | (0.43) | | (0.41) | | (0.24) | | (0.21) | | (0.21) | |
| **Season - Fall** | 0.02 | | 0.19 | | 0.40 | | 0.37 | | 0.19 | | 0.14 | | 0.14 | |
| | (0.66) | | (0.58) | | (0.48) | | (0.48) | | (0.22) | | (0.19) | | (0.19) | |
| **Standing water : Season - Summer** | -0.20 | | -0.19 | | -0.18 | | -0.18 | | | | | | | |
| | (0.13) | | (0.13) | | (0.13) | | (0.13) | | | | | | | |
| **Standing water : Season - Fall** | -0.06 | | -0.06 | | -0.05 | | -0.05 | | | | | | | |
| | (0.14) | | (0.14) | | (0.14) | | (0.14) | | | | | | | |
| **WSD : Season - Summer** | -0.04 | | -0.09 | | | | | | | | | | | |
| | (0.17) | | (0.14) | | | | | | | | | | | |
| **WSD : Season - Fall** | 0.11 | | 0.11 | | | | | | | | | | | |
| | (0.17) | | (0.13) | | | | | | | | | | | |
| **Total vegetation > 1m : Season - Summer** | -0.09 | | | | | | | | | | | | | |
| | (0.13) | | | | | | | | | | | | | |
| **Total vegetation > 1m : Season – Fall** | 0.02 | | | | | | | | | | | | | |
| | (0.14) | | | | | | | | | | | | | |
| **AIC** | 1253.7 | | 1250.5 | | 1248.3 | | 1246.5 | | 1244.3 | | 1242.5 | | 1241.2 | |
| **df** | 21 | | 19 | | 17 | | 16 | | 14 | | 13 | | 12 | |
| **$R^2$** | 0.132 | | 0.132 | | 0.129 | | 0.130 | | 0.132 | | 0.132 | | 0.131 | |

Table A8. Results of mixed effects models predicting use/nearby availability of bog turtles, where season includes all four seasons. Coefficient estimates and standard error are shown in parentheses for each fixed effect variable. All models were run as logistic regressions using glmer (lme4) in R (family = binomial). In all models, plot type was the response variable in which turtle plots were coded as 1 and nearby random plots coded as 0. All models included nested random effects; Season/Site/TurtleID, ‘:’ denotes an interaction. Significance codes: . = P < 0.1, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| **Variable** | **1** | | **2** | | **3** | | **4** | | **5** | | **6** | | **7** | | **8** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -2.22 | *** | -2.17 | *** | -2.21 | *** | -2.23 | *** | -2.63 | *** | -2.78 | *** | -2.75 | *** | -2.67 | *** |
| | (0.64) | | (0.63) | | (0.60) | | (0.59) | | (0.52) | | (0.49) | | (0.48) | | (0.46) | |
| **Standing Water** | 0.26 | * | 0.25 | * | 0.24 | * | 0.24 | * | 0.34 | *** | 0.29 | *** | 0.29 | *** | 0.28 | *** |
| | (0.10) | | (0.10) | | (0.10) | | (0.10) | | (0.06) | | (0.05) | | (0.05) | | (0.05) | |
| **Sedges/graminoids** | 0.09 | . | 0.09 | . | 0.08 | . | 0.08 | . | 0.09 | . | 0.10 | . | 0.10 | * | 0.09 | . |
| | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | |
| **Woody stem density (WSD)** | 0.09 | | 0.12 | | 0.18 | * | 0.17 | * | 0.17 | * | 0.13 | . | 0.12 | . | 0.14 | * |
| | (0.14) | | (0.13) | | (0.08) | | (0.08) | | (0.08) | | (0.07) | | (0.07) | | (0.07) | |
| **Reed canary** | 0.10 | . | 0.09 | . | 0.10 | . | 0.10 | . | 0.11 | * | 0.10 | . | 0.10 | * | 0.11 | * |
| | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | |
| **Cattail** | 0.08 | | 0.08 | | 0.08 | | 0.08 | | 0.09 | | 0.07 | | 0.09 | | 0.09 | |
| | (0.09) | | (0.09) | | (0.08) | | (0.08) | | (0.08) | | (0.08) | | (0.08) | | (0.08) | |
| **Saturated soil** | 0.09 | . | 0.09 | . | 0.09 | . | 0.09 | . | 0.10 | * | 0.13 | ** | 0.13 | ** | 0.14 | *** |
| | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.04) | | (0.04) | | (0.04) | | (0.04) | |
| **Total vegetation > 1m** | 0.02 | | -0.03 | | -0.03 | | -0.03 | | -0.02 | | 0.02 | | 0.03 | | | |
| | (0.10) | | (0.06) | | (0.05) | | (0.05) | | (0.05) | | (0.04) | | (0.04) | | | |
| **Canopy cover** | -0.01 | | -0.01 | | -0.009 | | | | | | | | | | | |
| | (0.05) | | (0.05) | | (0.05) | | | | | | | | | | | |
| **Grazing - ungrazed** | 0.16 | | 0.16 | | 0.14 | | 0.15 | | 0.15 | | 0.08 | | | | | |
| | (0.18) | | (0.18) | | (0.18) | | (0.17) | | (0.17) | | (0.17) | | | | | |
| **Season - Summer 2017** | 0.47 | | 0.26 | | 0.26 | | 0.25 | | 0.19 | | | | | | | |
| | (0.68) | | (0.56) | | (0.44) | | (0.44) | | (0.25) | | | | | | | |
| **Season - Fall 2017** | -0.87 | | -0.90 | | -0.58 | | -0.59 | | 0.01 | | | | | | | |
| | (0.76) | | (0.63) | | (0.53) | | (0.53) | | (0.25) | | | | | | | |
| **Season - Spring 2018** | -0.82 | | -0.88 | . | -0.77 | . | -0.77 | . | -0.27 | | | | | | | |
| | (0.53) | | (0.51) | | (0.41) | | (0.41) | | (0.21) | | | | | | | |
| **Standing water :** | -0.06 | | -0.05 | | -0.04 | | -0.04 | | | | | | | | | |
| **Season – Summer 2017** | (0.16) | | (0.16) | | (0.16) | | (0.16) | | | | | | | | | |
| **Standing water :** | 0.20 | | 0.21 | | 0.22 | | 0.22 | | | | | | | | | |
| **Season – Fall 2017** | (0.17) | | (0.17) | | (0.17) | | (0.17) | | | | | | | | | |
| **Standing water :** | 0.15 | | 0.16 | | 0.17 | | 0.17 | | | | | | | | | |
| **Season – Spring 2018** | (0.12) | | (0.12) | | (0.12) | | (0.12) | | | | | | | | | |
| **WSD : Season – Summer 2017** | 0.05 | | 0.004 | | | | | | | | | | | | | |
| | (0.19) | | (0.17) | | | | | | | | | | | | | |
| **WSD : Season – Fall 2017** | 0.18 | | 0.16 | | | | | | | | | | | | | |
| | (0.19) | | (0.16) | | | | | | | | | | | | | |
| **WSD : Season – Spring 2018** | 0.09 | | 0.06 | | | | | | | | | | | | | |
| | (0.19) | | (0.15) | | | | | | | | | | | | | |
| **Total vegetation > 1m :** | -0.08 | | | | | | | | | | | | | | | |
| **Season – Summer 2017** | (0.14) | | | | | | | | | | | | | | | |
| **Total vegetation > 1m :** | -0.03 | | | | | | | | | | | | | | | |
| **Season – Fall 2017** | (0.16) | | | | | | | | | | | | | | | |
| **Total vegetation > 1m :** | -0.05 | | | | | | | | | | | | | | | |
| **Season – Spring 2018** | (0.14) | | | | | | | | | | | | | | | |
| **AIC** | 1220.7 | | 1215.0 | | 1210.2 | | 1208.2 | | 1206.1 | | 1204.1 | | 1202.3 | | 1200.6 | |
| **df** | 25 | | 22 | | 19 | | 18 | | 15 | | 12 | | 11 | | 10 | |
| **$R^2$** | 0.104 | | 0.104 | | 0.102 | | 0.103 | | 0.097 | | 0.096 | | 0.095 | | 0.096 | |

Table A9. Results of mixed effects models predicting use/far availability of bog turtles, where season includes all four seasons. Coefficient estimates and standard error are shown in parentheses for each fixed effect variable. All models were run as logistic regressions using glmer (lme4) in R (family = binomial). In all models, plot type was the response variable in which turtle plots were coded as 1 and far random plots coded as 0. All models included nested random effects; Season/Site/TurtleID, ':' denotes an interaction. Significance codes: . = P < 0.1, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Variable | 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -1.65 | | -1.76 | | -1.71 | | -1.73 | | -1.57 | |
| | (1.45) | | (1.44) | | (1.37) | | (1.37) | | (1.39) | |
| **Standing Water** | 0.62 | *** | 0.61 | *** | 0.61 | *** | 0.61 | *** | 0.61 | *** |
| | (0.08) | | (0.08) | | (0.08) | | (0.08) | | (0.08) | |
| **Sedges/graminoids** | 0.005 | | 0.005 | | | | | | | |
| | (0.06) | | (0.06) | | | | | | | |
| **Woody stem density (WSD)** | 0.30 | ** | 0.27 | ** | 0.27 | ** | 0.26 | *** | 0.25 | *** |
| | (0.11) | | (0.10) | | (0.09) | | (0.08) | | (0.08) | |
| **Reed canary** | 0.07 | | 0.07 | | 0.07 | | 0.07 | | | |
| | (0.07) | | (0.07) | | (0.07) | | (0.07) | | | |
| **Cattail** | -0.19 | . | -0.19 | . | -0.19 | * | -0.20 | * | -0.21 | * |
| | (0.10) | | (0.07) | | (0.10) | | (0.10) | | (0.09) | |
| **Saturated soil** | 0.21 | *** | 0.21 | *** | 0.21 | *** | 0.21 | *** | 0.22 | *** |
| | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | |
| **Total vegetation > 1m** | -0.01 | | -0.01 | | -0.02 | | | | | |
| | (0.07) | | (0.07) | | (0.07) | | | | | |
| **Canopy cover** | -0.04 | | | | | | | | | |
| | (0.06) | | | | | | | | | |
| **Grazing - ungrazed** | 0.26 | | 0.30 | | 0.30 | | 0.30 | | 0.30 | |
| | (0.22) | | (0.21) | | (0.21) | | (0.21) | | (0.21) | |
| **AIC** | 826.0 | | 824.5 | | 822.5 | | 820.6 | | 819.7 | |
| **df** | 13 | | 12 | | 11 | | 10 | | 9 | |
| **$R^2$** | 0.041 | | 0.040 | | 0.040 | | 0.040 | | 0.040 | |

Table A10. Results of mixed effects models predicting use/overall availability of bog turtles, where season includes all four seasons. Coefficient estimates and standard error are shown in parentheses for each fixed effect variable. All models were run as logistic regressions using glmer (lme4) in R (family = binomial). In all models, plot type was the response variable in which turtle plots were coded as 1 and random plots (both nearby and far) coded as 0. All models included nested random effects; Season/Site/TurtleID, ':' denotes an interaction. Significance codes: . = P < 0.1, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| Variable | 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -2.26 | *** | -2.20 | *** | -2.20 | *** | -2.22 | *** | -2.31 | *** |
| | (0.61) | | (0.60) | | (0.57) | | (0.55) | | (0.54) | |
| **Standing Water** | 0.24 | * | 0.24 | * | 0.24 | * | 0.24 | * | 0.23 | * |
| | (0.10) | | (0.10) | | (0.10) | | (0.10) | | (0.10) | |
| **Sedges/graminoids** | 0.09 | . | 0.09 | . | 0.09 | . | 0.09 | . | 0.09 | * |
| | (0.05) | | (0.05) | | (0.05) | | (0.04) | | (0.04) | |
| **Woody stem density (WSD)** | 0.08 | | 0.11 | | 0.11 | | 0.11 | | 0.08 | |
| | (0.14) | | (0.13) | | (0.13) | | (0.12) | | (0.12) | |
| **Reed canary** | 0.07 | | 0.07 | | 0.07 | | 0.07 | | 0.07 | |
| | (0.05) | | (0.05) | | (0.05) | | (0.05) | | (0.05) | |
| **Cattail** | -0.007 | | -0.000 | | | | | | | |
| | (0.08) | | (0.08) | | | | | | | |
| **Saturated soil** | 0.14 | ** | 0.14 | ** | 0.14 | ** | 0.14 | ** | 0.14 | *** |
| | (0.04) | | (0.04) | | (0.04) | | (0.04) | | (0.04) | |
| **Total vegetation > 1m** | 0.04 | | -0.008 | | -0.008 | | | | | |
| | (0.10) | | (0.05) | | (0.05) | | | | | |
| **Canopy cover** | -0.03 | | -0.03 | | -0.03 | | -0.03 | | | |
| | (0.04) | | (0.04) | | (0.04) | | (0.04) | | | |
| **Grazing - ungrazed** | 0.18 | | 0.17 | | 0.17 | | 0.16 | | 0.20 | |
| | (0.16) | | (0.16) | | (0.16) | | (0.15) | | (0.15) | |
| **Season - Summer 2017** | -0.30 | | -0.63 | | -0.63 | | -0.65 | | -0.68 | |
| | (0.63) | | (0.53) | | (0.52) | | (0.51) | | (0.51) | |
| **Season - Fall 2017** | -1.88 | ** | -1.81 | ** | -1.81 | ** | -1.82 | ** | -1.83 | ** |
| | (0.71) | | (0.59) | | (0.58) | | (0.58) | | (0.57) | |
| **Season - Spring 2018** | -1.93 | *** | -1.99 | *** | -1.99 | *** | -1.98 | *** | -1.97 | *** |
| | (0.51) | | (0.49) | | (0.49) | | (0.47) | | (0.49) | |
| **Standing water :** | 0.06 | | 0.07 | | 0.08 | | 0.08 | | 0.08 | |
| **Season - Summer 2017** | (0.15) | | (0.15) | | (0.15) | | (0.15) | | (0.15) | |
| **Standing water :** | 0.20 | | 0.21 | | 0.21 | | 0.20 | | 0.21 | |
| **Season - Fall 2017** | (0.16) | | (0.16) | | (0.16) | | (0.16) | | (0.16) | |
| **Standing water :** | 0.27 | * | 0.27 | * | 0.27 | * | 0.27 | * | 0.27 | * |
| **Season – Spring 2018** | (0.12) | | (0.12) | | (0.12) | | (0.12) | | (0.12) | |
| **WSD : Season - Summer 2017** | 0.13 | | 0.06 | | 0.06 | | 0.06 | | 0.06 | |
| | (0.18) | | (0.16) | | (0.16) | | (0.16) | | (0.16) | |
| **WSD : Season - Fall 2017** | 0.29 | | 0.27 | . | 0.27 | . | 0.27 | . | 0.27 | . |
| | (0.18) | | (0.15) | | (0.15) | | (0.15) | | (0.15) | |
| **WSD : Season - Spring 2018** | 0.18 | | 0.18 | | 0.18 | | 0.15 | | 0.16 | |
| | (0.18) | | (0.14) | | (0.14) | | (0.14) | | (0.14) | |
| **Total vegetation > 1m :** | -0.12 | | | | | | | | | |
| **Season – Summer 2017** | (0.14) | | | | | | | | | |
| **Total vegetation > 1m :** | -0.009 | | | | | | | | | |
| **Season – Fall 2017** | (0.15) | | | | | | | | | |
| **Total vegetation > 1m :** | -0.04 | | | | | | | | | |
| **Season - Spring 2018** | (0.13) | | | | | | | | | |
| **AIC** | 1491.2 | | 1486.2 | | 1484.2 | | 1482.2 | | 1480.8 | |
| **df** | 25 | | 22 | | 21 | | 20 | | 19 | |
| **$R^2$** | 0.164 | | 0.164 | | 0.164 | | 0.164 | | 0.164 | |

Table A11. Number of tracks and home range size for each turtle tracked 2017-2018. Home range estimation was only conducted for turtles with 10 or more tracks during 2017 ($n$ = 19). MCP = minimum convex polygon, KDE = kernel density estimation.

| | | | | | | 2017 - 2018 | | |
|---|---|---|---|---|---|---|---|---|
| **Turtle ID** | Site | Sex | 2017 tracks | 2018 tracks | Total # Tracks | MCP (ha) | 95% KDE (ha) | 50% KDE (ha) |
| 885 | UGR2 | M | 5 | 6 | 11 | | | |
| 765 | UGR2 | M | 12 | 9 | 21 | 0.3319 | 0.8282 | 0.2164 |
| 315 | UGR2 | F | 13 | 9 | 22 | 0.1724 | 0.3607 | 0.0876 |
| 685 | UGR1 | M | 6 | 5 | 11 | | | |
| 176 | UGR1 | M | 11 | 8 | 19 | 0.0524 | 0.1296 | 0.0352 |
| 055 | UGR1 | F | 12 | 8 | 20 | 5.1932 | 4.9050 | 0.8342 |
| 226 | UGR1 | F | 12 | 8 | 20 | 0.9300 | 2.1477 | 0.4878 |
| 118 | UGR1 | M | 13 | 8 | 21 | 0.8322 | 1.0689 | 0.2212 |
| 398 | UGR1 | F | 14 | 8 | 22 | 0.2539 | 0.5282 | 0.0988 |
| 246 | GRZ2 | F | 7 | 0 | 7 | | | |
| 615 | GRZ2 | M | 8 | 0 | 8 | | | |
| 135 | GRZ2 | F | 10 | 5 | 15 | 3.5702 | 5.2571 | 1.0394 |
| 733 | GRZ2 | F | 0 | 5 | 5 | | | |
| 536 | UGR3 | M | 8 | 6 | 14 | | | |
| 447 | UGR3 | F | 10 | 9 | 19 | 0.0647 | 0.1004 | 0.0172 |
| 097 | UGR3 | M | 10 | 9 | 19 | 0.3320 | 0.4889 | 0.1011 |
| 665 | UGR3 | F | 11 | 9 | 20 | 0.4195 | 0.7028 | 0.1238 |
| 215 | UGR3 | M | 0 | 9 | 9 | | | |
| 814 | UGR3 | F | 0 | 8 | 8 | | | |
| 992 | UGR3 | F | 0 | 4 | 4 | | | |
| 005 | UGR3 | M | 0 | 4 | 4 | | | |
| 585 | GRZ1 | F | 10 | 9 | 19 | 0.1084 | 0.2162 | 0.0514 |
| 825 | GRZ1 | M | 10 | 9 | 19 | 0.1881 | 0.2929 | 0.0601 |
| 337 | GRZ1 | F | 12 | 9 | 21 | 0.2616 | 0.3859 | 0.0645 |
| 466 | GRZ1 | M | 12 | 7 | 19 | 0.2090 | 0.3890 | 0.0793 |
| 016 | GRZ1 | F | 13 | 9 | 22 | 0.2702 | 0.5771 | 0.1293 |
| 155 | GRZ1 | F | 13 | 9 | 22 | 0.8230 | 1.3960 | 0.3069 |
| 268 | GRZ1 | M | 14 | 9 | 23 | 0.2391 | 0.3868 | 0.0875 |
| 705 | GRZ1 | F | 16 | 9 | 25 | 0.1063 | 0.1758 | 0.0366 |

Table A12. Results of linear models used to determine effects of season, sex, and site on distance per day. Coefficient estimates and standard error are shown in parentheses for each fixed effect variable. All models were run using lme (nlme) in R. In all models, log transformed distance per day was the response variable and included nested random effects; Site/TurtleID, ':' denotes an interaction. Significance codes: . = P < 0.1, * = P < 0.05, ** = P < 0.01, *** = P < 0.001.

| **Variable** | **1** | | **2** | | **3** | |
|---|---|---|---|---|---|---|
| **(Intercept)** | 0.68 | ** | 0.65 | *** | 0.72 | *** |
| | (0.26) | | (0.16) | | (0.14) | |
| **Season - Summer 2017** | 0.02 | | -0.02 | | -0.03 | |
| | (0.18) | | (0.18) | | (0.18) | |
| **Season - Fall 2017** | -1.07 | *** | -1.13 | *** | -1.13 | *** |
| | (0.20) | | (0.20) | | (0.20) | |
| **Season - Spring 2018** | 0.00 | | -0.08 | | -0.08 | |
| | (0.16) | | (0.16) | | (0.16) | |
| **Sex - Male** | 0.18 | | 0.14 | | | |
| | (0.15) | | (0.15) | | | |
| **Site – UGR1** | -0.06 | | | | | |
| | (0.26) | | | | | |
| **Site - GRZ2** | 0.38 | | | | | |
| | (0.32) | | | | | |
| **Site - UGR3** | -0.39 | | | | | |
| | (0.26) | | | | | |
| **Site - GRZ1** | -0.09 | | | | | |
| | (0.25) | | | | | |
| **AIC** | 1315.1 | | 1309.7 | | 1306.6 | |
| **df** | 11 | | 7 | | 6 | |
| **$R^2$** | 0.166 | | 0.163 | | 0.164 | |

Appendix B

Turtle ID ____________________ Transmitter freq ______________________________

Site ID ______________________ Date ________________________ Time __________

Weather conditions _______________________________________________________

Turtle plot/Paired plot (circle) Paired Distance/Direction______________ Size _2m_

GPS N ____________________ W _____________________________

Turtle location and notes (disturbance, cow density, turtle health, etc.) ____________

__________________________________________________________________________

__________________________________________________________________________

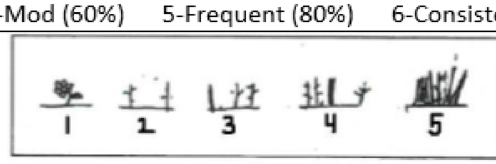
| | |
|---|---|
| 1. Percent cover reed canary grass (*Phalaris arundinacea*) | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 2. Percent cover purple loosestrife (*Lythrum salicaria*) | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 3. Percent cover cattail (*Typha spp.*) | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 4. Percent cover common reed (*Phragmites australis*) | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 5. Percent cover moss | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 6. Percent cover sedges (*Carex spp.*) and other graminoids | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 7. Percent cover woody vegetation, forbs, ferns | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 8. Percent cover saturated soil (within plot) | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 9. Percent cover standing water (within plot) | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 10. Percent total vegetation > 1m | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 11. Percent woody vegetation > 1m | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 12. Percent forbs/ferns > 1m | < 1   1 ≤ 5   6 ≤ 10   11 ≤ 25   26 ≤ 50   51 ≤ 75   76 ≤ 100 |
| 13. Distance (rank) from plot center to standing water/saturated soil (m) | 1-0.00   2- 0.01 ≤ 0.50   3- 0.51 ≤ 1.00   4- 1.01 ≤ 2.00   5- 2.01 ≤ 5.00   6- 5.01 ≤ 10.00   7- > 10.00 |
| 14. Index of refugia availability | 1-None   2-Very little (20%)   3-Little (40%)   4-Mod (60%)   5-Frequent (80%)   6-Consistent (~100%) |
| 15. Woody stem density |  1 – none   2-very few   3-few   4-moderate   5-dense |
| 16. Max height of combined woody vegetation, forbs, ferns (m) | 1- No veg   2- 0.01 ≤ 0.50   3- 0.60 ≤ 1.00   4- 1.01 ≤ 2.00   5- > 2.00 |
| 17. Canopy cover (%) | # dots =   #dots (96 possible) x 1.04 =   % |

Figure B1. Vegetation survey form. Numerical estimates converted to ranks outlined in Table 2.