The Risk and Response of Eastern Box Turtles (*Terrapene carolina carolina)* to Prescribed Fire in the North Carolina Sandhills

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Introduction

The longleaf pine/wire grass community is one of the most endangered terrestrial communities in the Southeastern United States. Historically, frequent low intensity fires have maintained this community, but only 3% of its historic distribution remains due in part to fire suppression and other improper management strategies (Frost 1993). Prescribed fire has become a common management technique to reduce fuel loads, eliminate invasive species, and to restore and maintain longleaf pine and other fire-adapted ecosystems. The purpose of these fires is to create and maintain habitat heterogeneity that benefits target biota, such as the endangered red-cockaded woodpecker (Van Lear et al. 2005), but effects on non-target species are not well understood. The eastern box turtle, *Terrapene carolina,* is commonly found in many habitats routinely subjected to prescribed burns, but its limited mobility and terrestrial tendencies may leave it vulnerable to the impacts of fire, including injury or mortality from burning (Babbitt and Babbitt 1951, Platt et al. 2010, Howey and Roosenburg 2013). However, fire maintains an open understory that could also attract turtles by providing additional basking opportunities or food during increased vegetative regrowth. Using radio-telemetry and temperature dataloggers, we examined the thermal biology, vital rates (growth, body condition, survivorship), and behavioral responses (e.g., habitat use, space use) of turtles to fire management at sites using prescribed burns compared to nearby unburned sites. These observations will allow biologists to better understand the ecology of terrestrial turtles in such systems, and help managers to better assess the risks of burning in longleaf and other forest or grassland systems.

Project Aims

- Assess seasonal habitat use and home range size in burned and unburned areas with the use of radiotelemetry
- Quantify the potential thermal quality and temperatures experienced by turtles in burned vs. unburned habitats
- Examine survival of turtles in response to controlled burns

- Provide data to natural resource practitioners that will then aid in decision making regarding non-target species

Methods

This study is a continuation of a long-term project initiated in 2011 at two North Carolina state parks - Weymouth Woods Sandhills Nature Preserve (WEWO) where prescribed burns have been used for the past 30 years to maintain a longleaf ecosystem, and the Lumber River State Park (LRSP), where burns have only been sporadically used and are not part of current management. These sites are within 25 km of one another, with WEWO in the sandhills physiographic region and LRSP in the upper coastal plain. We are using radiotelemetry to locate turtles once per week, where GPS coordinate are recorded along with information on status (alive, injured, dead), behavior, and macrohabitat use. Maps depicting habitat distribution and watercourses were developed in ArcGIS 10.1.

Mortality rates were compared between treatment groups (burned vs. unburned), over time (spring, summer, fall, winter), and with respect to individual covariates (sex) using the Program MARK.

Habitat use was examined by comparing macrohabitat associations at turtle locations relative to habitat availability in the study site using Euclidian distance analysis. Additionally, distance to water at each turtle location was compared to distances from randomly-selected points to water using chi-squared analysis.

Space use was assessed in ArcGIS from plotted GPS points as the 100% minimum convex polygon (MCP). MCPs were then be compared between burn treatments and sex groups using ANOVA.

Shell temperatures (*Ts*) were measured at 60 minute intervals on a subset (N = 8) of turtles at each site, and operative environmental temperatures (*Te*) were assessed in representative microhabitats in burned and unburned areas using ibuttons inserted into thermal models. Habitat thermal quality (*de*) was estimated as deviations of thermal models from preferred temperature range or set-point range (*Tset*), representing the central 50% of body temperature distribution for turtles on a laboratory thermal gradient (Hertz et al. 1993). *Tset* was determined for 14 turtles following procedures of Sousa do Amarai et al. (2002). Turtles were introduced individually to a wooden box (2m long x 0.5m wide x 0.2m high) with metal floor covered in sand to a depth of 2 cm. The room was maintained on a 12hr L:D cycle and room temperature at 15 C. A heat source (heat pads regulated by a rheostat and/or ceramic heat "light") were placed at one end of the enclosure and maintained at 45 C to generate a thermal gradient over which the turtle could choose their location and position. A hermetically-sealed thermocouple was inserted 3 cm into the cloaca of each turtle and dataloggers were attached to and trailed behind the shell to record body temperature.

Results

Radiotracking

Thus far we have been able to radiotrack 34 individuals (17 male and 17 female) at WEWO and 27 (13 male, 14 female) from LRSP. Individual turtles have been tracked for durations ranging from 1 - 39 months.

Habitat Use

Turtles at WEWO exhibited strong selection of hardwood and mixed hardwood / pine forests and avoided longleaf (Wilks $\lambda = 0.582$, $F_{2,41} = 14.7$, $P < 0.001$, Fig. 1a). Turtles at LRSP selected mixed hardwood / pine forests and field while avoiding all habitats containing longleaf forests, though such associations were statistically marginal (Wilks $\lambda = 0.849$, $F_{2,33} = 3.0$, $P = 0.067$, Fig. 1a). WEWO turtles also strongly selected bottomland areas and avoided uplands ($F_{1,42} > 17.5$, $P < 0.001$), while LRSP turtles selected upland ($F_{1,34} = 5.8$, $P = 0.021$) and avoided bottomland ($F_{1,34} = 4.0$, $P = 0.051$, Fig. 1b).

a)

b)

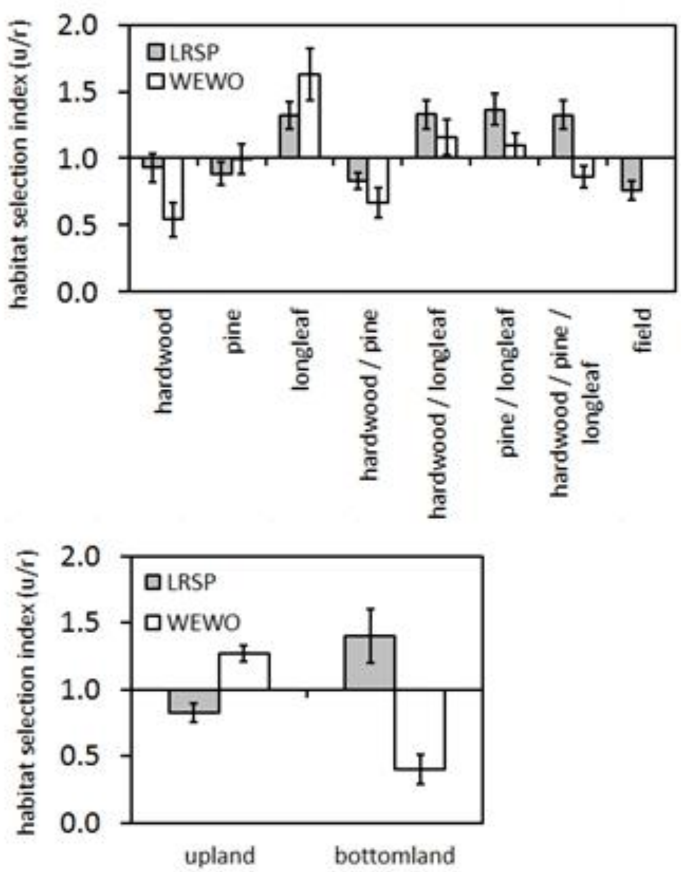

Figure 1. Habitat selection indices (u/r) for eastern box turtles at two sites differing in burn use and history for a) forest composition and b) hydric conditions. An index < 1 indicates selection, > 1 avoidance, and = 1 random use.

During winter, turtles increased use of hardwood forests (season: P = 0.032, season x site: P = 0.069) and decreased use of mixed hardwood / pine forests at both sites (season: P = 0.031, season x site: P = 0.367, Fig. 2). Proportional use of all other forest habitat types did not vary among seasons (Fig. 2). Use of habitats containing longleaf ranged from 22 - 30% during April - October (active period) and 13% from December - March (overwintering period).

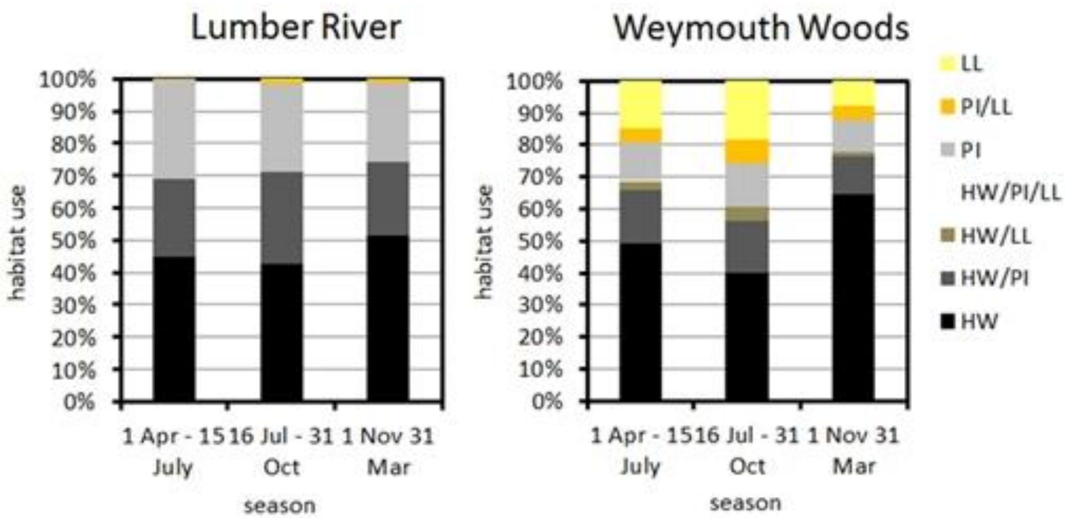

Figure 2. Seasonal habitat use for eastern box turtles at two sites differing in burn use and history.

Turtles at WEWO used locations significantly closer to watercourses than random, with an average location of 37 m from water. Turtles at LRSP used locations randomly with respect to watercourses at an average of 121 m from water (Fig. 3).

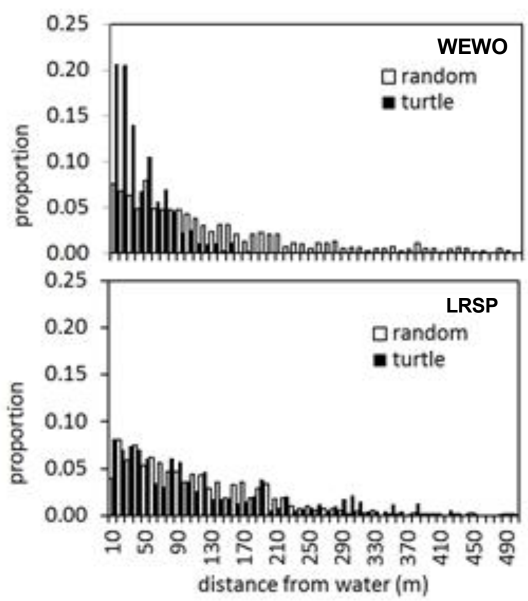

Figure 3. Frequency distribution of eastern box turtle locations relative to water compared to random points

Space Use

Home range size (100% minimum convex polygon) differed between sexes but not site, as females used areas 3.5 × larger than males at both sites (site: $F_{1,18} = 0.427$, $P = 0.522$; sex: $F_{1,18} = 6.57$, $P = 0.020$, site × sex: $F_{1,18} = 0.408$, $P = 0.531$; Fig. 4).

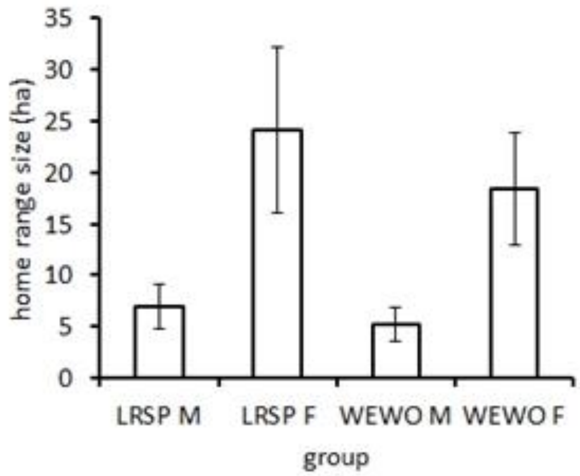

Figure 4. Home range size for male and female eastern box turtles at sites that differ in use and history of fire.

Survival

The survival model with most support (46.5% weight) was for variation between sexes, but similar survival probability between sites and over time (Table 1). Males had higher annual survival (95 - 96%) than females (81 - 92%) at both sites (Table 2).

Table 1. Model comparisons for eastern box turtle survival analyzed using known fate models in the program MARK. Sites differed in use of prescribed fire, and time intervals were annual quarters.

Model	AICc	ΔAICc	Weight	N	deviance
S (sex)	86.5	0.00	0.465	2	34.5
S (.)	87.6	1.04	0.277	1	37.6
S (site)	89.0	2.46	0.136	2	37.0
S (site x sex)	89.2	2.68	0.122	4	33.1
S (site x sex x time)	179.2	92.7	0.000	56	0.0

Table 2. Estimates of annual survival for eastern box turtles at two sites that differ in burn use and history.

Group	Annual survival (%)	95% CI
WEWO Male	96.4	78.1 - 99.6
WEWO Female	81.1	60.5 - 91.5
LRSP Male	95.3	71.3 - 99.2
LRSP Female	91.9	71.6 - 98.0

Thermal preference

We obtained 3,182 measurements of T_b from 14 turtles in the thermal gradient, with T_b ranging from 17.5 - 34.5 ^{o}C (Fig. 5). Mean T_b was 28.8 ± 0.6 ^{o}C, and the 25% and 75% quartiles (T_{set}) averaged across individuals was 27.0 - 31.0 ^{o}C (Fig. 5).

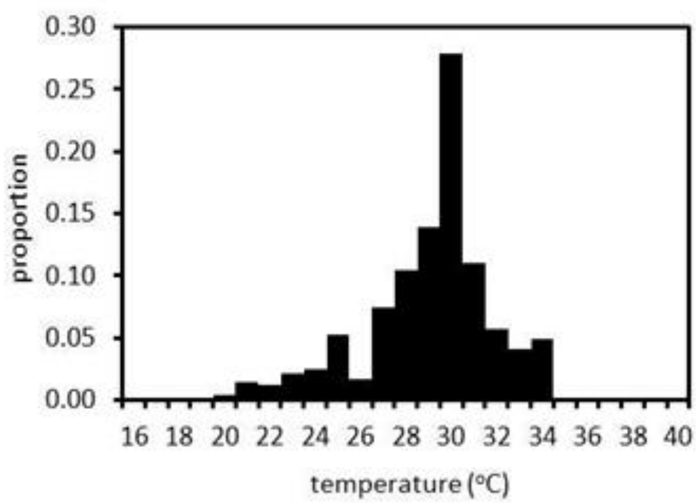

Figure 5. Frequency histogram of temperatures for eastern box turtles along a laboratory thermal gradient.

Operative environmental temperatures

Temperature of physical models was correlated with T_b of turtle carcasses ($r^2 = 0.963$, $F_{1,158} = 4115.2$, $P < 0.001$). Because models slightly underestimated T_b by 0.41 ± 0.11 ^{o}C (paired t = 3.85, $P < 0.001$), we adjusted temperatures of models using the equation:

We recorded 19,600, 18,270, and 2,012 T_e in the spring, summer, and fall seasons respectively. For both surface and refuge models, temperature indices (T_e, d_e, and time in T_{set}) varied by habitat, season, and the interaction (surface: habitat $F_{3,22} = 37.80$, $P < 0.001$; season: $F_{6,44} = 252.90$, $P < 0.001$; habitat × season: $F_{6,44} = 21.03$, $P < 0.001$; refuge: habitat $F_{3,19} = 18.81$, $P < 0.001$; season: $F_{6,38} = 102.20$, $P < 0.001$; habitat × season: $F_{6,38} = 4.65$, $P = 0.001$; Fig. 6).

Surface T_e was highest in summer, intermediate in spring, and lowest in fall (Fig. 6, Table 3). Surface T_e was approximately 3 °C higher in longleaf forests than in adjacent mixed hardwood / pine forests in both spring and summer, but did not differ between habitats in fall. The elevated surface T_e in longleaf forests during spring and summer was due to a higher proportion of T_e recordings above T_{set} between 31-50 °C, while surface T_e distributions were less variable between habitats in the fall (Fig. 6).

Table 3. Thermal metrics (T_e, d_e, and maximum) for longleaf and mixed hardwood / pine forests in spring (top), summer (middle), and fall (bottom).

Habitat	T_e		d_e		Max
Longleaf	24.7	0.2	5.3	0.1	62
HW / Pine	21.8	0.1	5.4	0.1	37

Habitat	T_e		d_e		Max
Longleaf	27.4	0.2	4.0	0.1	55
HW / Pine	24.5	0.1	3.0	0.1	47

Habitat	T_e		d_e		Max
Longleaf	13.0	0.1	14.0	0	32
HW / Pine	13.4	0.3	13.5	0.3	31

Surface d_e was lowest (i.e., of higher thermal quality) in summer, intermediate in spring, and highest in fall (Table 3).

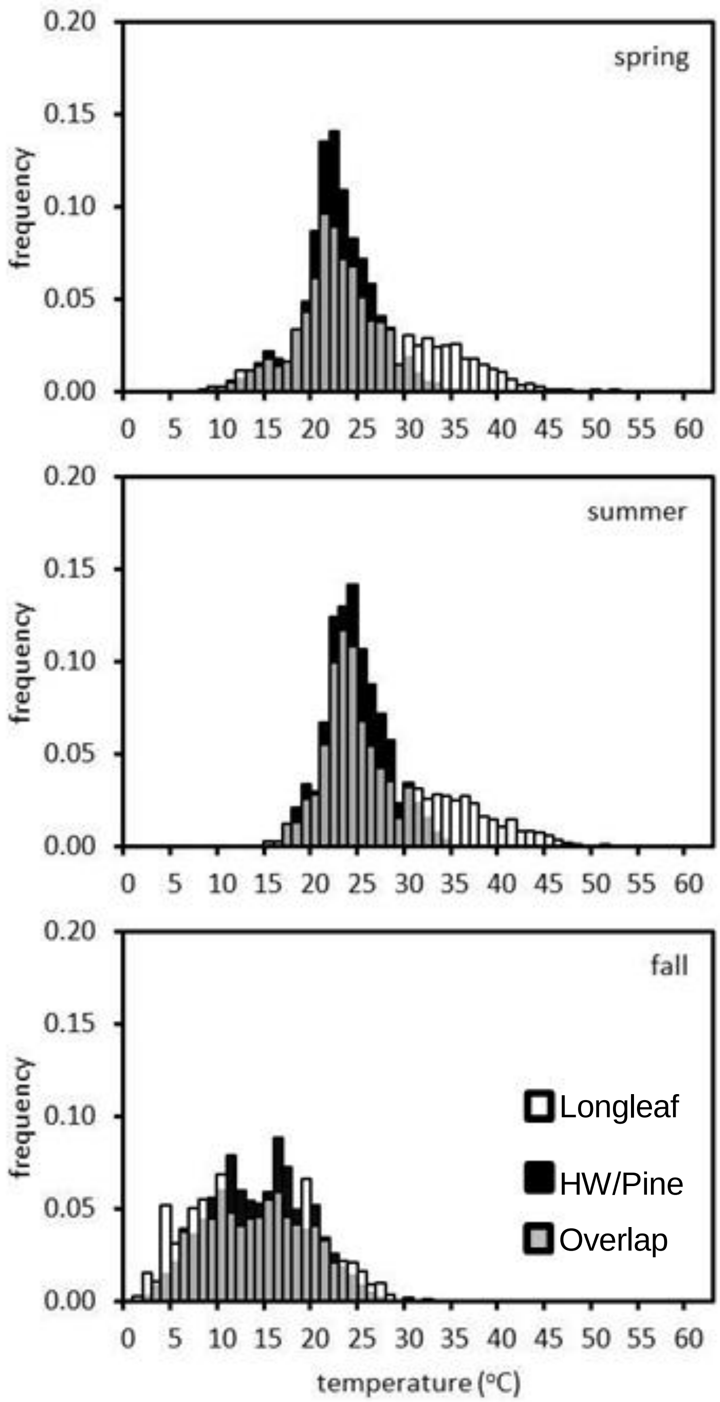

Figure 6. Histogram of temperatures for surface models in two habitat types in three seasons coinciding with turtle surface activity.

Surface d_e was lower (i.e., thermal quality higher) in mixed hardwood / pine forests than adjacent longleaf forests in the summer, but did not differ between habitats in spring or fall (Table 3).

We recorded 28,896 and 29,640 hourly shell temperature recordings for turtles at WEWO and LRSP, respectively. Turtles at burned and unburned sites differed in shell temperature in August and October, with turtles at WEWO experiencing temperatures nearly 1 - 2 °C above those at LRSP ($P < 0.05$; Fig. 7).

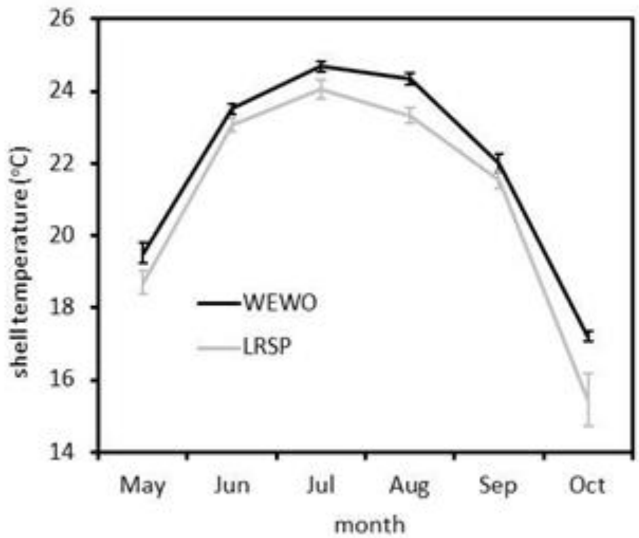

Figure 7. Shell temperatures (mean ± se) of eastern box turtles at sites differing in burn use and history.

Discussion

By studying the behavior and select vital rates of eastern box turtles in two nearby systems that differ in the use of prescribed fire, we gained valuable insight into the potential responses of turtles to this commonly used management tool. Turtles at the burn site (WEWO) exhibited stronger selection of mesic forest types containing hardwood trees, closer associations with watercourses and bottomland areas, while avoiding forests dominated by longleaf. In contrast, turtles at the unburned site (LRSP) exhibited weaker overall associations with mesic forests containing hardwood, selected upland areas over bottomlands, and did not associate with watercourses. However, avoidance of forests containing longleaf pine was strong. It is possible that such differences are attributable to turtle responses to burn regimes, as mesic forests in close proximity to streams would be less prone to burn, or may ameliorate fire intensity. Turtles associating with these habitats and locations would more likely survive fire, resulting in selection of such behaviors. It is also possible that the strong natural contrast between xeric and mesic habitats that occur in the sandhills region have also shaped such behavior on local scales in box turtles, and such associations with wetter habitats confer the same protections from fire. Regardless of the mechanism driving differences in habitat associations between sites, the outcomes for burn management are unequivocal. Risk of exposure to fire is minimized at WEWO due to turtles largely avoiding areas targeted for prescribed burning. In fact, less than 5% of turtles in our sample were burned, and only one died as a direct result of fire.

Survivorship did not vary between sites differing in use and history of prescribed fire, but instead differed demographically. Male survival rates were consistently higher than females. Fire accounted for mortality of one male, while the other died of unknown causes. Surprisingly, several females died at both sites from causes ranging from vehicular collisions to disease and overwintering, but none were even exposed to fire. The overall high annual survival of turtles at the burn site is undoubtedly a consequence of their using mesic habitats offering refuge from fire. It should be noted that managers did not reach their burn targets during our study. Managers at WEWO seek to burn on a rotation of 2 - 5 years, meaning that fire must be applied to a minimum of 20% of areas in burn management each year. Such targets were only reached in one of the four years of our study. Continuing the study during periods representative of target burn regimes is critical to fully assess turtle responses to fire and implications for turtle populations.

Home range sizes were considerably larger than those described for other populations of eastern box turtles, and especially so for females (Dodd 2001, Greenspan et al. 2014). Given the closer associations with mesic forest types and watercourses at the burn site, we expected animals to be more heavily restricted in availability of suitable habitats and thus to have smaller home range size, but turtles continued to traverse large areas at both burned and unburned sites. Apparently, resource needs are spread over large areas at both sites, requiring animals to move long distances among foraging, reproductive, and overwintering locations. Turtles at the burn site regularly made short-duration long distance forays into or across xeric uplands as they travel among mesic areas offering refuge from fire, with much of this travel closely following narrow streambeds and drainage courses that offer only ephemeral surface water.

Even though our analysis indicated strong avoidance of forests dominated by longleaf, turtles occasionally used such habitats. In fact, during active months (April - October), turtles spent on average 22 - 30% of their time in habitats containing longleaf. Fire-maintained longleaf forests cover broad areas at WEWO, and most turtles that maintained associations with longleaf used areas along the edge such that they were rarely very far from mesic forests and watercourses. One potential benefit to using fire-maintained forests is the open understory created, as ectotherms using such areas could potentially maintain temperatures in the optimal (preferred) range more easily. Thermal models placed in habitats differing in fire management did suggest variation in the temperatures and thermal "quality" offered to turtles, with fire-maintained longleaf forests being hotter than unburned mixed hardwood / pine forests throughout most of the active season. However, the thermal quality, quantified as deviations outside of the thermal preference range (27 - 31^{o}C in our population) was actually higher (lower d_e) in unburned forests during summer and equivalent during spring and fall, owing largely to the wide fluctuations in temperature exceeding thermal optima and even exceeding lethal limits (above 40^{o}C) in fire-maintained open understory environments. Perhaps as a consequence of thermal properties, turtles had additional incentive to use mesic environments owing to their thermal stability in or near the thermal preference range. Nonetheless, we did not see strong seasonality in habitat use, and it does not appear that turtles in our system are following thermal gradients over broad spatial scales (macrohabitat selection). Further examination of microhabitat use and timing of activity (daily and seasonal) may reveal how individuals behave in response to local small-scale variation in habitat thermal properties.

Conclusions

Our results offer insight into the ecology of a widespread species in an ecosystem in which they have received little study (Greenspan et al. 2014). Box turtle behavior can vary widely among study systems over small spatial scales. Ours is also one of only a few studies that have examined turtle responses to natural or prescribed fires (Babbitt and Babbitt 1951, Platt et al. 2010, Howey and Roosenburg 2013). Whether our findings translate to improved burn management at WEWO is still an open question, as burn regimes that mimic natural disturbances and management targets need to be restored to WEWO. Whether our findings translate to other systems is also in question, as fire is a tool employed in a range of forested and grassland systems for multiple management purposes (fuel reduction, invasive species control, maintenance of fire-adapted species, silviculture practices). More research is needed to base comparisons among such systems and advise best management practices to maximize benefits for target species, and minimize conflicts with non-target species. Given their life history traits associated with long lifespans (Congdon et al. 1993, 1994), it is also important to study turtle responses over longterm periods spanning several years or decades that cover natural environmental variation and changes in management (Roe and Georges 2008).

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