**Project Title**: Fire Effects on a Special Concern Species, the Eastern Box Turtle

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**Principal Investigator**:

Dr. Gary J. Roloff, Associate Professor, College of Agriculture and Natural Resources Department of Fisheries and Wildlife, Michigan State University, Room 13 Natural Resources Building, 480 Wilson Road, East Lansing, MI 48824; Email: roloff@msu.edu

**Student Investigator**:

Ms. Tracy A. Swem, Graduate Research Assistant, College of Agriculture and Natural Resources Department of Fisheries and Wildlife, Michigan State University, Room 13 Natural Resources Building, 480 Wilson Road, East Lansing, MI 48824; Email: swemtrac@msu.edu

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## I. Abstract

Throughout North America, tension often exists between advocates of prescribed fire as an ecosystem restoration tool and herpetologists, primarily because fire effects on rare reptile and amphibian species are poorly understood. Research is needed that informs the implementation of prescribed fire programs in a manner that achieves the burn objectives (e.g., restoration, invasive species control, fuels management) while mitigating potentially negative fire effects on rare animals. The eastern box turtle, *Terrapene carolina carolina*, is experiencing population declines across much of its range; in Michigan, box turtles are listed as a species of special concern. We found that hatchling eastern box turtles emerged from nest cavities in both fall and the following spring, and tended to remain in the grassland habitats often associated with nest sites. We documented direct mortality on a single hatchling from a prescribed fire through grassland habitat. We monitored 32 adult eastern box turtles over the duration of the study; 12 of these were within the burn unit of the prescribed fire but only 6 were directly subjected to the flame front (the others were in aquatic refugia or areas that did not burn). Adult box turtles exhibited avoidance behavior (digging, fleeing) when the flame front was 10-20 m away. Of the 6 turtles directly subjected to the flame front, only 1 could not escape the fire and apparently died from burn injuries (2 weeks after the fire was extinguished). Turtles that were directly affected by the flame front were generally unavailable for sampling by visual surveys; they were either buried or vacated the burn area. Post fire detection surveys for adult turtles that were available for sampling within the burn unit boundary indicated that average detection probability was low (0.12 probability of detecting a turtle given that one is present). Hence, post fire visual encounter surveys, that typically involve a single walk-through, do not appear to be an effective technique for determining fire impacts on eastern box turtles. We also found that a growing season burn (15 cm flame height, 1.5 m/min spread) reduced the stem counts of invasive woody species that were $\leq$2 cm diameter, but was not effective at controlling larger stemmed species. We recommend that managers implement a prescribed fire regime that includes a variety of burn seasons and fire intensities. When box turtles are fully active, growing season fires in closed canopied, dry-mesic southern Michigan forests should be relatively slow moving with a single flame front. During growing season burns, we recommend that fire be excluded from large, rotted logs, wetlands or vernal pools, and seepage areas. We also recommend that grassland nesting habitats not be burned when female box turtles are beginning to nest (late May to mid-June) and not burned annually, as this may cause the loss of an entire age class when hatchlings are vulnerable to fire (late fall, early spring).

## II. Background and Purpose

Prescribed fire is increasingly being used to delay vegetation succession, restore historical disturbance processes, recycle nutrients, manage wildlife habitat, and control exotic invasive vegetation (Knapp et al. 2009). The severity, uniformity, and spatiotemporal extents of prescribed fire influence vegetation pattern, productivity, and corresponding behavioral responses of fauna located within treated areas (Smith 2000). Although prescribed fire can be an effective and inexpensive tool for vegetation management, direct effects (including injury and mortality) and indirect effects (including changes in body condition and animal movements or interactions) are not well understood for k-selected, and relatively immobile species like the eastern box turtle (*Terrapene carolina carolina*). *Terrapene* spp. are historically found in habitat types subjected to fire throughout eastern North America, including grasslands, oak dominated woodlands, and mesic habitats which has led some scientists to conclude that box turtles are behaviorally adapted to resist mortality by fire (Means and Campbell 1981). An understanding of prescribed fire effects on eastern box turtles is especially relevant because eastern box turtle populations are declining range-wide (Swarth and Hagood 2004) and, in Michigan, are listed as a species of special concern (Hyde 1999). Recent data indicate that box turtles currently occur in only 20 of the historically occupied 31 counties in Michigan.

Research suggests that losing even small numbers of breeding adults from k-selected, long-lived populations like box turtles can result in irreparable harm to population viability (Congdon et al. 1993). Although eastern box turtles evolved with fire, current turtle population sizes, fire regimes, and habitat configurations differ from historical conditions and frequently repeated prescribed fires may actually result in long-term population declines. This may also be true of early season fires, which typically coincide with box turtle emergence. Managers may inadvertently cause high mortality when conducting an early season prescribed fire before leaf out, with high fuel loads, as box turtles may be particularly slow and immobile when first emerging from winter refugia in the spring. Box turtles are particularly sensitive to environmental variables that affect ground cover (including vegetation, litter, and subsurface soils) because their entire life history depends on ground conditions (Dodd 2001). Box turtles are found in multiple vegetation types throughout their life cycle (Spencer and Thompson 2003) and some of these vegetation types are managed with prescribed fire. In Michigan, prescribed fire is used to restore open-understory vegetation communities, control invasive vegetation, and hinder woody encroachment in areas known to support box turtle populations.

Land managers using prescribed fire across a range of habitat types where eastern box turtles potentially occur should understand where and when this species is most vulnerable, and adjust management techniques as appropriate. This project evaluated whether growing season fires (i.e., fires during early to mid-summer) were effective in achieving vegetation management goals yet slow enough to allow box turtles to evade the fire front. Specific questions of this study included:

1. Did the fire accomplish the vegetation restoration management goals?
2. Do box turtles actively seek refuge during a fire?
3. What is the injury and mortality of box turtles associated with growing season fire exposure?
4. What are the longer-term effects and differences in box turtle behavior after a fire?
5. Are hatchling box turtles susceptible to annual spring fires common to the habitat types (grasslands) where their nests are usually located?
6. Do hatchling box turtles move out of these areas in the fall or spring?
7. How effective are post-burn survey techniques for box turtles in detecting this cryptic species?

## III. Study Description and Location

### Location:

This study was conducted within the boundaries of Fort Custer State Recreation Area (FCSRA), located in the southern lower peninsula of Michigan, specifically the Kalamazoo Interlobate region (Kalamazoo and Calhoun Counties, 1225.79 ha), USA. The Kalamazoo Interlobate landscape is characterized by heterogeneous vegetation patterns resulting from topography, climate, and human influence including high levels of agricultural and urban development (Eagle et al. 2005, Albert 1995). Most of the soils of the region are calcareous and loamy, derived from underlying limestone, shale, and sandstone bedrock. Glacial till deposits are primarily loams, silt loams and clay loams (Eagle et al. 2005). Soils are classified by Albert (1995) as Alfisols (typical well-drained forest soils of temperate climates) and Histosols (mucky wetland soils), with Mollisols (prairie soils) in the southwestern portion of the subsection. The climate in this ecoregion is considered humid continental, although FCSRA is strongly influence by the Maritime Tropical air mass and proximity to Lake Michigan, resulting in a warmer climate (Köppen climate classification Dfa), moderated inland temperature fluctuations, and induced lake-effect snow (Eichenlaub 1979, Denton 1985, Albert et al. 1986, Eichenlaub et al. 1990). The average length of the growing season is 154 days (Albert et al. 1986).

The Kalamazoo Interlobate subsection was historically dominated by fire-dependent oak savanna and prairie (Albert 1995), and contained the only extensive areas of mesic prairie found in Michigan (Kost 2004). Intensive agriculture in Michigan was concentrated in this region because of its comparatively mild climate (Eagle et al. 2005). Natural vegetation in this region was broadly classified as black oak-white oak (*Quercus velutina-Q. alba*) savannas and forests, as well as beech-sugar maple (*Fagus grandifolia-Acer saccharum*) forests (Palmgren 2004).

Early-1800's plant communities to FCSRA included dry and dry-mesic southern forest (oak-hickory), oak barrens (mixed oak savanna), emergent marsh, and southern (mixed hardwood) swamp (Palmgren 2004). Oak barrens existed in a large area throughout the center of the park, while dry and dry-mesic southern forests dominated the uplands east and west of the oak barrens. Emergent marsh and hardwood swamp existed along the Kalamazoo River, around Jackson, Whitford, Lawler, and Eagle Lakes, and in low depressions throughout the area (Palmgren 2004). FCSRA is presently composed of degraded patches of oak barrens and prairie openings, scattered oak-hickory forests, and large patches of non-native black locust (*Robinia pseuodacacia*; Palmgren 2004). Lee et al. (2002) found that "aggregate mining and military land use (i.e., land shaping, impact craters, and tank barriers) have also caused significant changes to the topography of portions of the recreation area."

FCSRA was chosen for this project because it has been the focus of vegetation restoration activities since 1997 that likely effects local box turtle populations and, in turn, elucidates the efficacy of habitat management strategies aimed at minimizing box turtle mortality. Some of these activities involved spring or fall prescribed fires, mowing, invasive plant removal, or herbicide application. A large area of mature black locust was subjected to wind throw during a storm in October 2001 with approximately 53 ha of forest between the park headquarters and Whitford-Lawler Lakes effected (Palmgren 2004, Figure 1). This area was in active restoration to open barrens and prairie. FCSRA is located within the most northerly range of the eastern box turtle (Figure 2). Eastern box turtles were indeed found within the boundaries of the park, and after restoration activities had taken place (A. Ihnken, Michigan Department of Natural Resources, personal communication).

The research burn for this project was conducted in a 7.2 ha management unit of FCSRA consisting of mixed upland and lowland vegetation types. These included dense stands of invasive black locust, emergent marsh, dry-mesic southern (oak-hickory) forest, open grassland, red pine plantation, and mixed lowland hardwoods. The research burn was conducted in late May, 2015.

**Study Description**

Radio-telemetry and Fire Observation of Adult Eastern Box Turtles:

Meandering transect visual encounter and wildlife detector dogs were used to find adult eastern box turtles during daylight hours in May of 2012 and June of 2013. Captured adult box turtles were radio-tagged with a Holohil R1-2B 14.5g Transmitters (Holohil Systems Ltd., Carp, Ontario, Canada) attached to the right or left anterior pleural carapacial scutes using multi-purpose 5-minute set epoxy putty (Loctite®, Henkel 289 Corporation, Cary, NC, USA). Straight carapace length from the right first and last marginal scute, straight carapace width at the articulation of the second and third vertebral scutes, and carapace height at the third of fourth vertebral scute was measured using digital calipers or rulers as in Boucher (1999). Age was estimated by counting annual rings on the carapace (Legler 1960). Turtles were also marked by notching the shell (Cagle 1939). Radio-tagged adult box turtles were monitored during the active seasons (April through October) from May 2012 to August 2015 using portable receivers (Advanced Telemetry Systems, Isanti, MN, USA) and radio-tracked 1-3 times per week and visually located. Behavior, locational, and environmental data were recorded during each encounter, including cloud cover, air and surface temperature and humidity, leaf litter depth, adult behavior, and vegetation type.

During active nesting periods (late May through June), females were located nightly between the hours of 1800 and 2200 to determine nesting status. If a female was found to be alert after 1900, she was repeatedly checked for digging behavior until 2200. Once a female was found to be digging, her location was marked using natural materials found in the area, such as dried plant stems or rocks, a GPS point was recorded along with date, hour, location, sky condition, ambient air temperature and humidity, and vegetation type. The site was left alone until morning. Sites were checked for egg deposition the following day by gently digging into the soil until the surface of at least one egg was observed. Nests with eggs were protected and monitored (see below).

Telemetered adults were located 24 hours before a research burn at which point transmitters were spray-painted with RUST-OLEUM™ High-Heat Spray to prevent fire damage. The carapace was covered with a spray guard to prevent heat resistant paint from adhering to the turtle itself. Upon fire ignition, research animals were relocated from behind the flame front using radio-telemetry to observe direct, fire related behavior. Researchers stayed at 10-20 meter distances to minimize influence on behavior. Research animals were checked 12, 24 and 48 hours after the burn for direct injury and mortality, and thereafter checked 1-3 times per week.

Nest Protection and Monitoring:

Within 24-72 hours of observed female nesting activity, box turtle nests were covered with 0.610m x 0.610m x 0.305m bottomless wooden-framed cubes wrapped in 0.635 cm wire mesh. These predator exclosures were preserved and camouflaged with an acrylic-based solid stain in olive drab green and featured a removable lid attached with (4) 3.175 cm deck screws. Exclosures were dug 5 cm into the soil surface around the nest. Nests were checked daily starting August 1st at which point 152mm x 91mm x 22mm sponges were placed within the corner farthest from the nest cavity and wetted daily to prevent desiccation of the hatchlings upon emergence. Emergence was determined by the positive identification of an emergence hole near the nest cavity. After emergence in 2013 and 2014, nests were excavated to count eggs through reconstruction of egg shell evidence, calculate hatching and emergence success and determine causes of hatching and emergence failure. If nests did not emerge in the fall, they were left caged and excavated in June of the following year; emergence monitoring was paused from November – April in these cases.

Hatchling Movements:

Upon emergence, hatchlings were weighed using a Micro-Line 10g x 0.1g spring scale (Pesola®, Baar, Switzerland). Straight carapace length from the right first and last marginal scute, straight carapace width at the articulation of the second and third vertebral scutes, and carapace height at the third or fourth vertebral scute was measured using digital calipers (Boucher 1999). Hatchling turtles were individually marked using nail clippers to notch small triangles in the marginal scutes (Cagle 1939). Each hatchling was fitted with a 13 cm long trailing thread of orange fly line backing (RIO® Products, Idaho Falls, ID) by threading it through the left or right 11th marginal scute with a sterilized hand needle and tying with an improved clinch knot. A subset (n = 7) of hatchlings found in 2014 were also fitted with 0.62 g BD-2 transmitters (Holohil Systems Ltd., Carp, Ontario, Canada) attached to the carapace with silicone aquarium sealant (Marineland®, Spectrum Brands, Blacksburg, VA). We released hatchlings within 0.5 meters of each nest cavity after they were weighed and measured. Hatchlings were relocated after dusk using black lights (trailing thread) and telemetry every 24-48 hours. Hatchling locations were recorded using a handheld GPS. Behavior was recorded, along with vegetation type, percent concealment, type of concealment used and temperature and humidity. Some hatchlings were located before a spring fire in a grassland management unit known to be an annual nesting area before and after a prescribed burn on May 19, 2014, to assess direct mortality from a typical grassland fire.

Vegetation and Fire Data Collection:

Pre- and post-fire vegetation information was collected using a grid of semi-permanent 2-meter radius circular plots spaced 40 meters apart (n = 80). The center of each plot was marked using a wooden stake; location was recorded with a handheld GPS. Woody stem count was recorded per species and growth class using 1 cm increments. Growth classes included 0 to <1 cm, 1 to <2 cm, 2 to <3 cm, 3 to <4 cm, 4 to <5 cm, and ≥5 cm. Litter depth, percentage of exposed ground, and total dead and down woody debris by size/piece class were recorded within each circular plot. Size/piece classes corresponded to the 1-hour, 10-hour, 100-hour, or 1,000-hour fuel classes, which translated to <0.6 cm, 0.6 to <2.5 cm, 2.5 to <7.6 cm, and 7.6 to <20.3 cm. We recorded nearest invasive woody plant species using the point center quarter method, and recorded the distance in meters, stem diameter, height, and canopy diameter in centimeters. Near the center of each vegetation plot, we placed a set of 3 Omega TL-10 adhesive, non-reversible temperature labels (OMEGA Engineering, INC., Stamford, Connecticut) with a total temperature range from 87 – 260 degrees Celsius (190 – 500 degrees Fahrenheit). Labels were affixed to a rectangle (11 cm x 20 cm) of aluminum roof flashing. The rectangle was bent to a 90-degree angle and fixed into the soil so that the side with the temperature labels ran parallel to and 4 centimeters above the soil surface. Fire rate of spread was recorded by direct observation and by observing the time at which the flame front reached each wooden stake. Average char height for each wooden stake was recorded in centimeters. Air temperature, humidity, smoke behavior, and wind speed and direction were recorded throughout the duration of the fire. Flame height was recorded using direct observation. Completeness of burn was recorded as percentage and depth of char at each vegetation plot 48 hours after the burn. Temperature at each plot was recorded to the nearest 6 degrees Celsius, as observed from the temperature labels. Post fire vegetation sampling was completed using the same methods from pre-fire sampling, and conducted in September, 2015. Pre-fire vegetation sampling was completed in June of 2014, and plots were re-checked for major vegetation differences in May of 2015 prior to the burn.

Post Fire Detection of Box Turtles:

We measured detection probability of adult eastern box turtles at this site using the marked subsample method described by Lancia et al. (2005). We conducted visual encounter surveys (2, 1-ha survey areas within the management unit, 6 observers conducting the same survey independently) between the hours of 1:30 p.m. and 7:00 p.m. on May 22, 2015; 48 hours after the research prescribed fire had occurred. Seven adult box turtles were located using radio-telemetry and determined to be available for detection during the survey period. During each survey, 6 observers independently walked a predetermined path, following parallel transects that amounted to 100 square meters, while scanning the ground for eastern box turtles. Each observer made one pass through each survey area during each survey period and was blind to the number of available research animals. Surveys were aggregated into a capture history matrix 6 columns across (survey occasion) by 7 rows down (individual turtle within a survey area, available for detection). We calculated box turtle detection probability, $\beta i$, for each of the 6 survey periods using equation 12 in Lancia et al. (2005):

$$\beta i = m / n_1$$

Where $m$ is the number of transmittered box turtles observed during each visual-encounter survey and $n_1$ is the number of transmittered box turtles present in the survey area at the time of each visual-encounter survey as confirmed by concurrent radio-telemetry. We used the average detection probability over the 6 survey periods as the overall detection probability, $\hat{\beta}$.

## IV. Key Findings

Adult and Hatchling Direct Fire Effects

We tracked 58 hatchling eastern box turtles using fluorescent string trailing and/or transmitters. Of the 58 hatchlings, 3 were successfully tracked until they began overwintering in late October, where they remained until their spring emergence in May of 2014.Only 1 of these hatchlings was located in a management unit where prescribed fire was utilized during this study. This hatchling was not located immediately prior to the burn, but last located 1 week before ignition. The individual was subsequently found dead 24 hours after the burn, and from body condition, it was likely to have died as a direct result of fire. Hatchlings emerged from nests from early September to late October in 2013 and 2014 with 6 of 58 hatchlings (approximately 10 percent) overwintering successfully in the nest cavity, and emerging the following spring. Hatchling box turtles were observed above the soil surface until commencing overwintering in late October. Hatchlings (9 observed) remained within 2 cm of the soil surface throughout overwintering, until the following May. The majority of hatchlings with thread trailers remained in grassland areas for 1-2 weeks after fall emergence from the nest, after which most were not relocated. Hatchlings with transmitters remained within grassland areas throughout the winter and into the spring.

Although we monitored 32 adult eastern box turtles during this study, the single research burn only affected portions of 12 home-ranges; 7 female, 5 male. Of these, 10 were within the burn unit the day of the fire; 6 were soaking in a wetland within the unit and unaffected by the flame front, and 1 was within a dense black locust stand and unaffected by the flame front. The remaining 3, plus one unmarked female found the day of the fire, were directly subjected to the flame front. Within the affected group, all but one adult reacted to the advancing flame front when it was 10-20 meters away. Three of the adults actively negotiated the flame front, becoming alert, moving away from the front quickly, and/or beginning to dig into the mineral soil. This resulted in one adult female outrunning the flame front to an area of low fuels and digging partially into mineral soil in an area of oak and sumac, one adult male completely burying into the mineral soil in a grassland area and a third actively negotiating the flames but being overtaken by the advancement of two flame fronts from fires that were lit separately on both sides of her in a grassland area. A firefighter picked up this female and placed her in the black to prevent her from being completely overtaken by flames. Once in the black she immediately sought refugia under an unburned decaying log and completely buried. The fourth adult female remained “in form”, or within its shell until the flame front was within 5 meters and was overtaken by the flame front in a grassland area.

Adult Indirect Effects

Adults that were completely buried remained buried for 12 hours following fire extinguishment and then began migrating to wetland areas. All adults remained soaking in wetland areas, or within 3-5 meters of wetland areas for 1-2 weeks following extinguishment of the fire and were not seen in burned areas until well after green-up. One adult female that remained outside the burn unit for the duration of the fire migrated directly through charred leaf litter of a dry-mesic oak forest to the wetland area and remained there. The only adult that had direct contact with the flame front migrated to an unburned black locust stand within 12 hours of extinguishment and to a wetland area to soak where she remained until succumbing to her injuries two weeks later. Adults that were migrating to wetlands or emerging from wetlands seemed to remain within 1-2 meters of unburned refugia such as decaying logs, unburned patches of leaf litter, or in areas unaffected by fire until other sources of vegetation growth provided cover. Female turtles in the burn unit were not observed nesting the season directly following the fire.

Vegetation Effects

The growing season fire implemented in this study produced average flame lengths of approximately 15 centimeters (6 inches), an average rate of spread of approximately 1.5 meters/minute, and average temperatures reaching 82.2 degrees Celsius (180 degrees Fahrenheit). The fire was effective at reducing leaf litter, and reducing woody vegetation under 2 cm diameter. Invasive woody plant species that failed to produce new buds, leaves, or pliable green pith within terminal branches after the fire (but within the same growing season) included multiflora rose (*Rosa multiflora*), autumn olive (*Elaeagnus umbellate*), honeysuckle (*Lonicera* spp.), buckthorn species (*Frangula alnus* , *Rhamnus cathartica*), black locust (*Robinia pseudoacacia* ) and the invasive vine oriental bittersweet (*Celastrus orbiculatus*). Native species that declined after the fire included dogwood species (*Cornus sericea*, *Cornus florida*), maple species (*Acer saccharum, Acer rubrum*), black cherry (*Prunus serotina*), hornbeam species (*Carpinus caroliniana*, *Ostrya* spp.), *Viburnum* spp. and *Sassafras* spp. Of the vegetation sampled in the research vegetation plots affected by fire, 90 percent of all woody vegetation, <2 cm in diameter failed to produce new growth by the September following the May prescribed research burn. Fire failed to carry into dense locust stands and mixed lowland hardwoods where little fuel was available and bare, mossy ground or mineral soil dominated the forest floor. Further vegetation monitoring is needed to determine whether the fire effects on woody vegetation persist into subsequent growing seasons.

Post Fire Detection Probability of Adult Box Turtles:

During each of the 6 visual-encounter surveys, 7 adult eastern box turtles were confirmed via telemetry to be within the survey areas and thus, available to be detected. We detected 2 individuals during the surveys. The detection probability ranged from 0.0 to 0.29 within sampling occasions. Overall detection probability, $\hat{\beta}$, calculated from the average of all 6 sampling occasion probabilities was found to be 0.12.

## V. Management Implications

Adult and Hatchling Direct and Indirect Behavioral Effects

Hatchling eastern box turtles are most likely susceptible to direct mortality from spring fires in grassland areas. In some management regimes, areas suitable for nesting are burned annually to maintain open grassland or restore native prairie. Land managers using prescribed fire should carefully consider the frequency of burns in grassland areas as this study found that the majority of tracked hatchlings remained within grassland areas 1-2 weeks after fall emergence from the nest cavity (but we caution that the majority of hatchlings were only tracked for 2 weeks). The maximum observed distance a hatchling box turtle moved from the nest cavity was 123.7 meters in two weeks. Hatchlings were never observed more than 2 centimeters below the soil surface, and burying into the soil surface was only observed in late October, when hatchlings began to overwinter. Hatchlings may therefore be unable to avoid direct mortality through evasive burying behavior. Our limited data on hatchling eastern box turtles suggests that grassland nesting habitats should not be burned every year when hatchlings are vulnerable to fire (late fall, early spring).

Although variable by site, we observed that slow moving growing season burns conducted during full leaf out may allow adult eastern box turtles to evade potential injury. Burning at this time coincides with some individuals occupying wetlands and, for those individuals in the burn area, allowing time for responsive behaviors such as burying and seeking refugia in decayed logs and wet areas. We observed successful evasive behavior of adult eastern box turtles during a fire with flame lengths averaging approximately 15 centimeters (6 inches) and an average rate of spread of approximately 1.5 meters/minute. Because this was a relatively small burn in a heterogeneous landscape with a small sample size, further work that determines the indirect and direct effects of fire in different vegetation types is crucial. Managers should avoid burning grasslands when adult female box turtles are seeking nesting sites, which, we observed was between mid-May and mid-June for southwestern Michigan. We also recommend that managers avoid firing types that resulting in converging flame fronts or fast-moving fronts when the presence of eastern box turtles is suspected. Managers should also be aware that the seasonality of fire likely plays a large role in minimizing box turtle mortality. Early spring fires may prove to be more detrimental than growing season fires in dry-mesic forests because "good fire weather", i.e. a prolonged warm, dry period before leaf out, will most likely coincide with "good turtle weather", when adults begin making their way out of winter hibernacula (winter burrows). At this time, adult box turtles may be lethargic, unable to react to fast moving fires that are often associated with early spring burns. When planning for growing season fires, managers should consider plant phenological characteristics, such as the emergence and growth stages of leaves on certain deciduous tree species, and the appearance and flowering of specific forest floor species such as mayapple (*Podophyllum peltatum*), rather than specific weeks or days of the month, as the timing of these events changes from year to year. For example, box turtles were most likely be emerging when mayapples first appeared at FCSRA, but this date changes year to year and may not coincide with burn plans for a site. We also recommend patchy fires that leave refugia such as decaying logs and unburned patches around seeps or wetland areas to accommodate the fact that box turtles will seek refuge from a flame front.

### Vegetation Effects

Our preliminary data on vegetation effects of growing season fires suggests that control of invasive woody vegetation with stem diameters below 2 centimeters is possible. Our fire would be considered a creeping fire with short flame lengths and we found it was effective at reducing leaf litter and woody vegetation below a 2 centimeter diameter regardless of species 4 months after the burn occurred (September 2015). Our fire was not effective at reducing large, well established invasive shrubs such as honeysuckle (genus *Lonicera*) or glossy buckthorn (*Frangula alnus*).

### Detection Probability Post Fire

Due to the observed behavioral changes in eastern box turtles during and immediately following a fire, including burying, concealment in remaining refugia, and migration to wetland areas, managers may underestimate mortality when conducting a post fire survey for eastern box turtles. We found that one individual withstood the initial extensive injury from a fire, and to the untrained eye seemed unaffected, only to seek refuge in concealed areas most likely never to be seen by managers, and succumb to injuries weeks later.

## VI. Relationship to Other Work

Data regarding herpetofauna mortality resulting from prescribe fire are lacking (Russell et al. 1999; Keyser et al. 2004). Studies to date have generally focused on herpetofaunal populations in forest ecosystems, and have also focused on short-term pre- and post-abundance and species richness surveys (Cole et al. 1997, Moseley et al. 2003). Some researchers have explored fire effects on short-term abundance for r-selected species (Griffiths and Christian 1996), and pre- and post-abundance effects of seasonal fires (Keyser et al. 2004, Greenburg and Waldrop 2008). Others have focused on long-term behavioral changes and survival, but assessed associations with processes other than prescribed fire (Currylow 2012a,b). Some studies suggest that fire induced herpetofauna mortality is relatively low, or that certain species have adapted to frequent fire (Driscoll and Henderson 2008; Erwin and Stasiak 1979; Means and Campbell 1981; Smith et al. 2001).

Research on eastern box turtles suggests that the species is in decline throughout its range (Stickel 1978, Williams and Parker 1987, Schwartz and Schwartz 1991, Hall et al. 1999, and van Dijk 2013). Hypothesized causes for this apparent decline include collecting for the pet trade, ranavirus or other disease spread, agricultural development, road or mowing mortality, and habitat loss (Belzer and Steisslinger 1999, De Voe et al. 2004, Nazdrowicz et al. 2008, Dodd 2001, van Dijk 2013). Studies on box turtle population dynamics suggest that high levels of reproductive activity, high adult population densities and low adult mortality are needed to ensure viability (Congdon et al. 1993, Lieberman 1994, Doroff and Keith 1990, Hall et al. 1999 and Dodd 2001). Reed et al. (2002) suggested that 2% declines annually in breeding individuals resulted in gradual extirpations. For example, adult box turtle density on Patuxent Wildlife Refuge in Maryland steadily declined for 50 years following a catastrophic flooding event (Hall et al.1999). Because this species is so long-lived, late to mature, has low reproductive success, is difficult to study during the hatchling and juvenile stages, and gradual yet irreparable population declines are easily masked by repeated adult detections, studies that examine effective management practices as a correlate to body condition and reproductive success are needed (Klemens 1989).

Box turtle nesting ecology and behavior has been studied in several regions of the United States, although not as thoroughly as general population ecology (reviewed by Dodd 2001; Ernst and Lovich 2009). Kipp (2003) determined that nest sites in open areas were significantly more successful than those in interior, forested areas, suggesting box turtles will tend to nest on forest edges. Kipp also (2003) suggested that landscapes fragmented by roadside crossings and agricultural lands may reduce recruitment from road and equipment mortality. Incubation temperature affects sex of offspring, development rate, and possibly some general fitness characteristics of hatchlings such as growth rate and size (St. Clair 1998).

Despite an understanding of individual- and population-level movement and habitat use (Stickel 1950, Dodd 2001, Claussen et al. 1991), knowledge on long-term individual responses to habitats altered with prescribed fire is lacking. Early studies suggested that fires had little direct effect on local herpetofauna populations and that animals associated with fire dependent vegetation types are themselves adapted to fire (Means and Campbell 1981). For box turtles, thermoregulation is hypothesized as the process that determines individual response to habitat perturbations, however these observations were based on box turtle response to timber harvest and not prescribed fire (Currylow et al. 2012a). Currylow et al. (2012a,b) evaluated box turtle movement and thermal ecology for two years following timber harvest and found that movements were shorter and more frequent. These movements generally corresponded to box turtles traversing into and out of clearcuts and group selection openings (Currylow et al. 2012a). The Currylow et al. (2012a) study was the first to combine telemetry and visual observation of eastern box turtle behaviors with anthropogenic habitat alteration. Saumure et al. (2007) completed a similar study on direct mortality of wood turtles (*Glyptemys insculpta*) in fragmented agriculture-forest landscapes.

## VII. Future Work Needed

Longer term studies on the relationships between eastern box turtles and fire seasonality, ignition type, ignition time of day (box turtles are mainly active during morning and evening hours in hot summer months), and intensity are crucial to conservation in areas subjected to fire. This includes changes in disease prevalence, diminishing health, changes in winter refugia site selection, nesting habits and home range. One of the main issues with prescribed fire and box turtle conservation is how long-term mortality relates to fire frequency. Gibson (2009) examined the effects of spring prescribed fires on eastern box turtles in southwest Michigan, but focused on developing temperature, moisture, and number of growing season day thresholds and triggers of spring emergence. Given that the home range of an animal should, at least partially, be an expression of fitness (Roloff and Haufler 1997, 2002), it follows that changes in home range space use can be used to measure an animal's response to environmental perturbations. The habitat quality for box turtles appears to directly link to the abundance of leaf litter and hence, fire removal of leaf litter should be linked to lower quality box turtle habitat, at least in the short term. If frequent burns maintain low leaf litter throughout a box turtle home range, it seems reasonable to assume a negative fitness consequence. Lack of significant changes in home ranges before and after prescribed fire events might indicate that turtles essentially remain in unburned patches surrounded by temporarily unsuitable burned habitat. Gibson (2009) noted that turtles not directly injured by fire maintained the extent of their home ranges following fire, but these turtles changed their space use within the home range to restricted patches of unburned leaf litter, which we also observed. This behavior could result in lower body index values throughout the growing season after a fire and behavior changes in selecting winter refugia sites, movements the following year, susceptibility to disease and indirect mortality.

Studies that try to understand specific triggers of box turtle behavioral changes to an approaching flame front can provide crucial information to fire managers. Specifically, if heading or backing fires trigger evasive behaviors, if heat, smoke or sound triggers behavior in different vegetation types, and if behavior changes based on the seasonality of the fire can provide fire managers with applicable tools to create a fire that is safe for active adult box turtles.

Lastly, very little data exist that describe the effects of prescribed fire on terrestrial turtle nests or hatchlings; a research topic that is hindered by lack of a cost effective methodology for detecting terrestrial hatchlings in heavily managed areas. One of the biggest challenges facing box turtle conservation is documenting and understanding the factors that affect hatchling survival. Thread trailing devices were pioneered by Breder (1927) and Stickel (1950) and continue to be used for tracking short-term movements of small mammals, reptiles and amphibians. With the advent of small, lightweight transmitters, information regarding the susceptibility of hatchling turtles to seasonal fire, based on seasonal movements should be studied further. Because hatchling box turtles are cryptic, secretive, and small, little data exists on seasonal movements, detection rates, or prescribed fire mortality. One study stated that hatchlings appear to hide under litter, which exposes them to fire, rather than burrowing or creating forms (Ernst et al. 1995), which we also observed. Because box turtles typically nest in open, grassy areas that can be subjected to frequent fire; the further understanding of seasonal movement and fire mortality is crucial in the overall conservation of this species.

## VIII. Crosswalk Table

| Deliverable Type | Description | Delivery Dates |
|---|---|---|
| Master's Thesis | Three chapters (adult turtle response to fire, hatchling response to fire, and adult post-fire detection). | In progress, tentative defense date early 2016 |
| Refereed Publications | Three publications (adult turtle response to fire, hatchling response to fire, and adult post-fire detection). | In progress, to be submitted in 2016 |
| Presentations | Midwest Fish and Wildlife Conference, Annual Meeting of The Wildlife Society, Michigan Chapter of Partners for Amphibian Research and Conservation, MSU Graduate Student Organization Symposium, Michigan Box Turtle Working Group, Stewardship Network Meeting | Jan 2013/2014, Feb/Mar 2014, Oct 2014. January 2015 |
| Webinar | Lake States Fire Science Consortium – Assessment: Fire Characteristics and Eastern Box Turtle Behavior | In progress, tentative dates for mid-2016 |
| Poster | Ongoing research: Prescribed Fire Effects on Eastern Box Turtles, Michigan Chapter of Partners for Amphibian Research and Conservation Annual Meeting | Jan 2013 |
| Training Session | Telemetry and field techniques training sessions, undergraduate MDNR volunteer groups | Mar 2013, Sep 2013, Mar 2014 |

| | | |
|---|---|---|
| Spatial Dataset | 3 year dataset of hatchling and adult eastern box turtle movements before and after fire events | In progress, tentative delivery date of March 2016 |
| Final Report | JSFP Final Report, Electronic Version | December 2015 |

## IX. Literature Cited


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## X. Figures

Figure 1. Management unit boundaries of Fort Custer State Recreation Area, Augusta, Michigan. Property and management boundaries are presented as solid black lines.

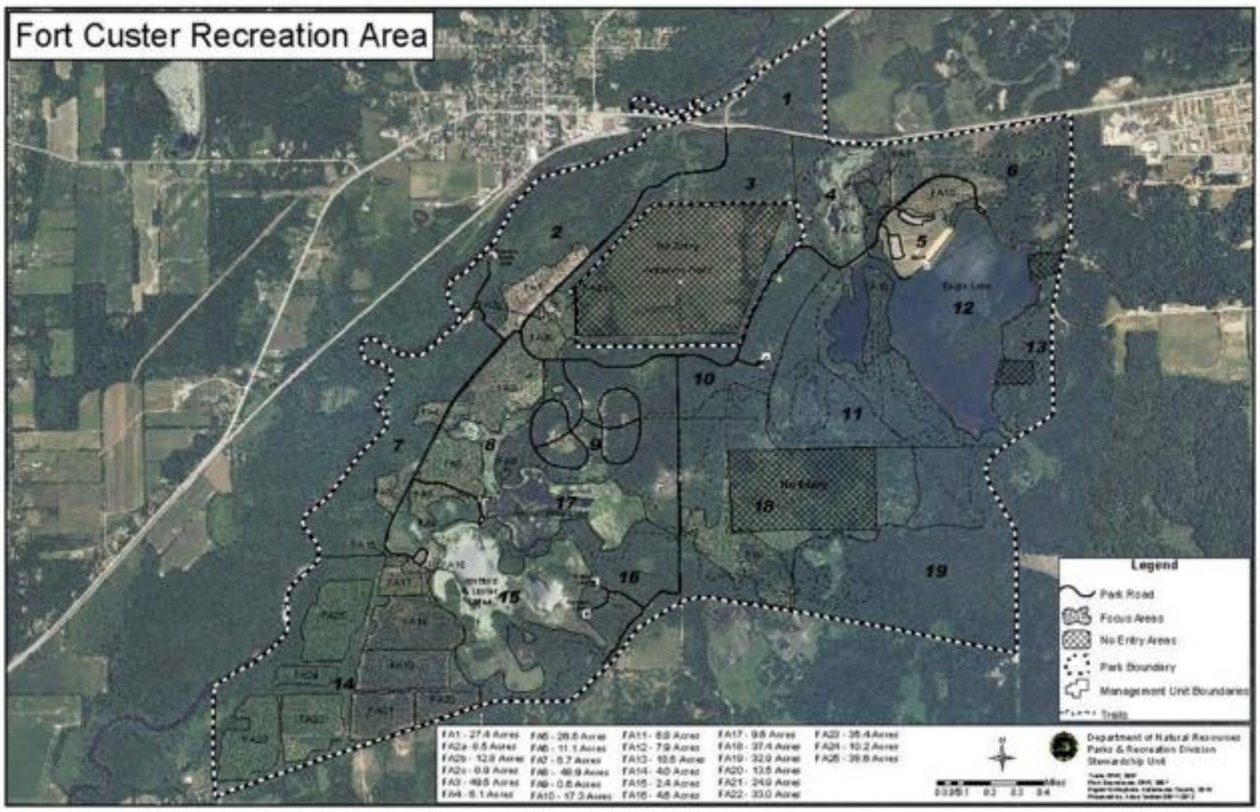


Figure 2. Range of the Eastern box turtle (*Terrapene c. carolina*) in orange.
Image credit: Davidson College Herpetology Lab