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Factors influencing wood turtle (Glyptemys insculpta) home range size in Iowa: A comparison between suburban and rural populations

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FACTORS INFLUENCING WOOD TURTLE (*GLYPTEMYS INSCULPTA*) HOME RANGE SIZE IN IOWA:

A COMPARISON BETWEEN SUBURBAN AND RURAL POPULATIONS

An Abstract of a Thesis
Submitted
in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Joshua Gregory Otten
University of Northern Iowa

December 2017

ABSTRACT

Home range size, movement patterns, and site fidelity of wood turtles (*Glyptemys insculpta*) were compared between a suburban population in Black Hawk County (BH) and a rural population in Butler County (BC), Iowa. Approximately 89% of individuals captured for studies conducted in Iowa during 2014 and 2015 were >14 years old. 45 individuals (22 females, 18 males, and 5 juveniles) were used for radio telemetry surveys in 2014–2015, 24 of which were located in BC, and 21 at BH.

Home range size of male and female wood turtles was significantly different at the 100% Minimum Convex Polygon (MCP), 95% MCP, and 50% MCP levels, with male home range significantly larger than females in both populations. Male linear home range (LHR) and stream home range (SHR) was also significantly larger than those of females and juveniles. There was no significant difference in home range sizes between the two populations. Out of the seven criteria analyzed (body mass, carapace length, sex, injury class, total locations, age, and study site), sex had the greatest influence on the size of home range of wood turtles.

Wood turtles in Iowa had a high degree of site fidelity and displayed similar home range size between 2014 and 2015. Site fidelity was similar, and not significantly different between sexes, with females having a slightly higher degree of site fidelity. Site fidelity between the populations was nearly identical in 2014 and 2015. Overall, home range size remained fairly consistent at BH over the course of a 5-year period, and at BC over a 10-year time period. Year-to-year fidelity decreased over time in some instances (between 2011 and 2015), while remaining high in others (between 2004 and 2015).

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This Study by: Joshua Gregory Otten

Entitled: Factors Influencing Wood Turtle (*Glyptemys insculpta*) Home Range Size in Iowa: A Comparison Between Suburban and Rural Populations

Has been approved as meeting the thesis requirements for the

Degree of Master of Science

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INTRODUCTION

Our world is currently experiencing a global biodiversity loss of such magnitude that many scientists are calling this the “sixth mass extinction” event (Frankham et al. 2002; Barnosky et al. 2011). Biodiversity provides the world with goods and services valued between 4.3 and 20.2 trillion dollars annually (Costanza et al. 2014). Biodiversity loss can be attributed primarily to human activities resulting in habitat loss and degradation, environmental pollution, introduction of invasive species, diseases, global climate change, and overexploitation (Landweber and Dobson 1999; Gibbons et al. 2000; Böhm et al. 2013; Lindenmayer and Fisher 2013). Mankind’s growing influence on the environment is so vast that geologists are considering renaming the current geological epoch as the “Anthropocene” (Ellis 2015). Humans have transformed the ecology of the entire planet to a point that now it is no longer possible to understand, predict, or manage ecosystems without understanding how humans have reshaped ecological processes and patterns over the long term (Crutzen 2002; Ellis 2015).

Habitat loss, degradation, and fragmentation are considered the greatest threats to biodiversity (Gibbons et al. 2000). It is the primary factor for the decline of more than 85% of threatened and endangered species in the United States, as well as the decline of over 97% of herpetofaunal threatened and endangered species in the United States (Wilcove et al. 1998). Reptiles’ comparatively large home range sizes (the area over which an animal or groups of animals regularly travels in search of food, mates, or other resources), low population densities, and low fecundity rates make this group of animals particularly susceptible to habitat loss and fragmentation (Gibbons et al. 2000). Understanding and minimizing threats to Earth's biodiversity while exploring the ecological response of organisms to habitat loss is critical to preventing or slowing the extinction of species and extirpation of local populations. Determining how a species utilizes habitat is central in the conservation and ecology of any species. This identifies areas of essential habitat that promotes species survival and reproduction. Protecting and/or restoring habitat is oftentimes the most effective method to protect a declining species (Carriere and Blouin-Demers 2010).

Turtle populations are declining rapidly worldwide, and the percentage of chelonian species considered threatened with extinction is higher than birds, mammals, amphibians, and sharks (Turtle Taxonomy Working Group 2014). Currently, half of the world's 300 turtle species are threatened with extinction (Hoffman et al. 2010; www.iucnredlist.org; Turtle Taxonomy Working Group 2014). In the case of many freshwater turtle species, population declines and extinction can be attributed directly to humans. Overharvesting, poaching, invasive species introduction, pollution, disease, flooding, climate change, habitat destruction, and habitat degradation have decimated turtle populations worldwide (Gibbons et al. 2000; Ferronato et al. 2016). Turtles have been utilized for meat, eggs, and traditional medicine since at least the 16th century (Klemens 2000). In addition, they play a vital role in global ecosystems through the services they provide, such as cycling minerals and nutrients, serving as bioindicators of pollution, and dispersing seeds (Ernst and Lovich 2009; Turtle Conservation Coalition

2011). As a result, the loss of any turtle species or population could have negative, cascading impacts on the ecosystem it inhabited.

Turtles are long-lived, late maturing animals with high juvenile mortality rates that make recovery from decline difficult (Congdon et al. 1994). These same traits make them even more susceptible to population declines due to small changes in their environment. Small declines in already small populations can be detrimental, so management plans specific to species and populations are necessary to achieve sustainability of turtle populations (Gibbons et al. 2000). Before considering any management actions, there must be thorough and complete understanding of habitat use and behavior. Patterns in habitat use, behavior, and movement may vary between species and populations, because of both natural and anthropogenic factors (Bennet et al. 2009). Because habitat use and movement patterns may differ between populations of the same species, management recommendations for one population may not be suitable for another. In addition, long-term monitoring is necessary to gain thorough and adequate understanding of a species or population, as adverse situations can sometimes occur over long periods before the effects on a population become detectable (Russell 1999).

Despite federal laws such as the Endangered Species Act (ESA), the National Environmental Policy Act, the Clean Air Act, and the Clean Water Act that protect turtles and turtle habitat, turtles are still at risk in North America (Ernst and Lovich 2009). Of the 56 turtle species native to North America, 35 (63%) require some degree of conservation action or attention (Ernst and Lovich 2009). Turtle species at the greatest risk of population declines due to anthropogenic changes in the environment include terrestrial and semi-terrestrial species, or those having specific life cycles that require considerable movements overland. Species making overland movements are more susceptible to the negative effects of increased road density and human development. These overland movements occur as females seek nest sites, hatchlings migrate from the nest to water, individuals move from unfavorable habitat conditions, and males seek mates (Gibbons 1986). These factors may be particularly important for American box (*Terrapene* spp.), Blanding's (*Emydoidea blandingii*), bog (*Glyptemys muhlenbergii*), spotted (*Clemmys guttata*), and wood (*Glyptemys insculpta*) turtles. These species spend a large portion of their life on land foraging, thermoregulating, and seeking shelter (Carter et al. 1999; Joyal et al. 2001; Litzgus and Mousseau 2004; Ernst and Lovich 2009), and some have large home ranges, putting them at greater risk of encountering human development. Because of their extensive terrestrial movements, the decline of these species can be greatly attributed to increased development and the rapid expansion of road networks (National Research Council 1997; Steen and Gibbs 2004).

Currently, climate change is an issue of concern for many animal populations, including turtles (Refsneider et al. 2014). Species distribution, population dynamics, and timing of life history events have been, and are predicted to be, altered by climate change; therefore, conservation strategies must encompass not only existing but also possible future sites occupied by the species (McMahon and Hays 2006; Hawkes et al. 2007). Global climate change has the potential to eliminate the production of male turtles in species with temperature sex determination if the mean global temperature increases 4°

C, and increases of just 2° C may dramatically skew sex ratios (Janzen 1994; Mitchell and Janzen 2010).

The wood turtle is one species of particular interest that requires conservation action or attention. Population declines of the wood turtle have been observed across the species' range (Garber and Burger 1995; Daigle and Jutras 2005; Willoughby et al. 2013), with evidence indicating that these declines are caused by both direct (e.g., habitat loss, injury and death from road mortality and agricultural equipment) and indirect anthropogenic impacts (e.g., changes in river hydrology, flooding) (Saumure and Bider 1998; Saumure et al. 2007; Spradling et al. 2010; Lenhart et al. 2013; Parren 2013).

Movement Patterns

The way animals move and use space in their environment is an important life-history aspect, necessary for their survival. In turtle species, this is done through acquiring resources such as food, mates, and hibernacula, while avoiding interactions with predators, interspecies and intraspecies competitors, and roads/vehicles. Studying movement, behavior, and space-use can also be used in the selection and design of protected or important habitat areas (Parnell et al. 2006). Assessing patterns of movement may help determine the distribution and spatial dynamics of populations. These may include habitat use and selection, identification of critical habitat, dispersal of individuals, and home range size (Bowler and Benton, 2005). Habitat use and selection studies provide categorical information used to determine what types of habitat and when they are important to a species, while dispersal of individuals may determine locations of important travel corridors that are used for movement to and from areas. Home range studies provide the quantitative information used to determine the amount of habitat a particular species needs for survival, the factors that influence dispersal, and movement patterns. This aids in conservation management practices by helping define protected areas and habitat that may be in need of management (Borger et al. 2006; Laver and Kelly 2008).

Wildlife studies are typically short in duration (one to three years), which may make it difficult to adequately determine an individual’s life-long home range. Many wildlife studies focus on annual home range size and neglect differences in movement patterns and home range characteristics between years. Home range size and location within the landscape is influenced by several demographic and ecological factors; therefore, understanding annual changes in home range size and overlap can be important tools in management and conservation.

Wood Turtle Natural History

Life History

Description. The North American wood turtle (LeConte, 1830) is a semi-terrestrial riverine and riparian species that belongs to the family Emydidae. Adults are medium-sized (16–20 centimeter [cm]) turtles with a maximum carapace length (CL) of 251 millimeters (mm) (Conant and Collins 1998; Ernst and Lovich 2009). The carapace is lightly to strongly keeled, ranges in color from brown, reddish brown, tan, grey, or black, and often possesses yellow lines radiating on each scute. The carapace resembles sculptured wood, with its raised growth annuli, one reason for the species’ common and scientific name (Carr 1952). The yellow plastron is notched posteriorly, and is unhinged with distinctive, individually unique oblong black blotches. The skin is primarily dark brown except for areas of the throat, neck, tail and underside of the forelegs, which may be yellow, orange, or red (Harding 1997; Ernst and Lovich 2009). Color may vary in intensity based on geographic location, season, or by sex (Harding and Bloomer 1979; Lovich et al. 1990; Ernst and Lovich 2009).

Sexual maturity and dimorphism. Typical of other freshwater turtles, wood turtles exhibit late sexual maturity, usually initiating reproduction between 14 and 18 years (Harding and Bloomer 1979; Farrell and Graham 1991). Size may be a better determinant of sexual maturity than age; mean CL across most populations at maturity is >160 mm (Walde et al. 2003; Ernst and Lovich 2009). Maturity is achieved at a later age and at a larger body size at more northern latitudes compared to southern latitudes (Brooks et al. 1992; Walde et al. 2003). Because of their late sexual maturity, relatively low fecundity, and low recruitment, wood turtles rely heavily on adult survivorship. This ensures population stability similar to other species of freshwater turtles (Brooks et al. 1991; Congdon et al. 1994; Dodd et al. 2012).

Adult wood turtles exhibit sexual dimorphism (Figure 1). Adult males (190–251 mm CL; 900–1200 grams [g] mass) are typically 10% larger than females (170–200 mm CL; 700–1000 g mass) and are identifiable by secondary sexual characteristics, including, a concave plastron, a longer and thicker tail, and the cloaca extending beyond the edge of the carapace (Ernst and Lovich 2009). Juvenile wood turtles are defined by a CL ≤160 mm, while subadults are those that have a CL ≥160 mm and do not display pronounced secondary sexual characteristics (Harding and Bloomer 1979). After approximately 18 to

20 years of age, new growth annuli are no longer formed or are too small to discern. Exposure to the environment begins to abrade the shell to such a degree that exact age can only be determined via mark and recapture studies (Walde et al. 2003; Ernst and Lovich 2009); however, assessing the amount of annuli erosion and shell weathering allows age estimation in broad intervals (e.g., ≈ 21–25, 26–30, 31–35). Beyond 35 years of age, the shell may become so weathered, scarred, and pitted that the growth annuli no longer exist; so individuals can only be categorized as >35 years old (Berg 2014).

Figure 1. Sexual dimorphism in the wood turtle; adult females (left) have a flat plastron, smaller average body size, shorter tail, a proximal cloaca, and smaller head. Adult males (right) have a concave plastron, larger average body size, longer tail with a distal cloaca, and a larger head. Specimens from Butler County, Iowa. (Photo by Jeffrey W. Tamplin).

Distribution

The wood turtle is endemic to the Midwestern and the northeastern United States and southeastern Canada. In the U.S., they occur as far east and north as Maine, south to Virginia, and west to northeast Iowa and eastern Minnesota. In Canada, they range through southern Quebec, Ontario, Nova Scotia, and New Brunswick (Ernst and Lovich 2009). Wood turtle fossils have been found as far south as Georgia, where this species existed until the end of the Wisconsin glaciation period, approximately 11,700 years ago. As glaciers receded, the wood turtle retreated into its current distribution (Ernst and Lovich 2009).

Iowa distribution. All known populations in Iowa exist in the northeastern part of the state, within the Cedar River drainage basin. This includes parts of the upper Cedar River, West Fork of the Cedar River, Shell Rock River, and Winnebago River, from the Iowa-Minnesota border south through northwestern Black Hawk County. Tributary streams and riparian areas within this watershed may also contain wood turtle populations (Christiansen and Bailey 1997; Spradling et al. 2010; LeClere 2013; Williams 2013; Berg 2014). Because the Cedar River drainage basin headwaters originate in the southern Minnesota counties of Dodge, Freeborn, and Mower, it is likely that the Iowa population of wood turtles extends into southern Minnesota (Carol Hall, personal communication). These populations are likely isolated from other populations in Minnesota (Spradling et al. 2010). According to the Iowa Department of Natural Resources (DNR), wood turtles occur in Benton, Black Hawk, Bremer, Butler, Cerro Gordo, Delaware, Floyd, Franklin, Iowa, Mitchell, and Washington counties (IDNR NAI 2016). They may occur in the Shell

Rock and Winnebago Rivers in Hancock, Winnebago, and Worth counties, but no confirmed records exist from these counties. Records from Benton, Delaware, Iowa, and Washington counties are considered incorrect, as they are single records with no vouchers, all from a single year (1989), and are presumably misidentified Blanding's turtles. There are no other specimens known from these drainages, and the habitat at the location of each report is not suitable for wood turtles because there is no lotic water source. Documented populations in Iowa are small, scattered, and comprised mostly of adults and few juveniles, decreasing potential for recruitment in those populations (Williams, 2013; Berg, 2014; Iowa NAI, 2016).

Habitat

Wood turtles utilize habitat that is centered on lotic waters, utilizing perennially clear, moderate to fast moving streams, creeks, and rivers with high dissolved oxygen levels (Ernst and Lovich 2009). Rivers and streams provide necessary hibernacula sites. Wood turtles typically overwinter near in-stream cover such as the undercut banks, roots of trees, flood debris, snags, North American beaver (*Castor canadensis*) dams, and muskrat (*Ondatra zibethicus*) burrows (Ernst and Lovich 2009). There are records of wood turtles overwintering exposed on the bottom of the stream channel (Greaves and Litzgus 2007; Otten, this study). Wood turtles also utilize terrestrial habitats around lotic habitat, including riparian areas of associated woodlands, coniferous forest, early successional forest, meadows, and agricultural fields. Turtles select open canopy areas of habitat that allow access to solar radiation for thermoregulation during active seasons (Dubois et al. 2009).

Habitat use varies seasonally, geographically, and in some populations, between sexes (Harding and Bloomer 1979; Ernst 1986; Tuttle and Carroll 1997; Saumure and Bider 1998; Ernst and Lovich 2009). Wood turtles are considered an “edge species” as they are often located near the border between different habitat types (Kaufman 1992; Compton et al. 2002). Edge habitat often provides a mosaic of forest and open-canopy habitat adjacent to lotic areas that allows wood turtles to maintain dietary needs, facilitates effective thermoregulation, and provides shelter from potential predators (Compton et al. 2002; Dubois et al. 2009; Ernst and Lovich 2009).

Wood turtle habitat use varies across the species’ range; populations in the eastern United States are less aquatic than some Midwestern populations (Harding and Bloomer 1979; Ernst and Lovich 2009) perhaps due to regional climate differences. In some populations, males may spend more time in aquatic habitats than females, particularly during the warm summer periods when females typically aestivate terrestrially, and males use rivers and creeks as corridors to access various females (Kaufmann 1992a). In New Hampshire, females spent 80% of the active season on land compared to 64% for males (Tuttle and Carroll 1997).

Seasonal Activity Periods

The wood turtle’s annual activity cycle can be roughly divided into four or five periods. Ernst and Lovich (2009), Ernst (1986), and Niederberger and Seidel (1999) classified the wood turtle as having four activity periods: winter brumation (hibernation-like state that cold-blooded animals utilize during cold weather), spring aquatic, summer terrestrial, and fall aquatic. Arvisais et al. (2002), Williams (2013), and Berg (2014) identified five wood turtle activity periods: hibernation (brumation), prenesting, nesting, postnesting, and prehibernation. The five activity period classification divides the spring aquatic phase into two activity periods: prenesting and nesting; otherwise the other activity patterns (winter brumation or hibernation, summer terrestrial or postnesting, fall aquatic or postnesting) are similar in activity, habitat, and timing.

Wood turtles brumate in lotic habitat with high levels of dissolved oxygen that typically don’t completely freeze during the winter (Greaves and Litzgus 2007). During this activity period, turtles are primarily in hibernacula and/or completely submerged within the stream channel. Activity during this period is typically limited, although movement has been observed (Greaves and Litzgus 2007; Tamplin, personal observation).

The spring aquatic period or prenesting period is initiated when a rise in water and air temperatures trigger the turtles to become active. During the prenesting period, turtles in Iowa utilize terrestrial habitats nearly 75% of the time (Williams 2013). Females tend to bask more frequently, which most likely benefits the development of eggs (Harding and Bloomer 1979). During this period, night temperatures can fluctuate drastically; thus, both sexes typically return to aquatic habitats each evening because the water temperature remains more constant than air. The prenesting period ends in late May or June, when gravid females begin to move to nesting areas to lay their eggs (Walde et al. 2007).

Nesting typically occurs from late May to early July depending on latitude and seasonal environmental conditions (Ernst and Lovich 2009). During this time, both sexes are tied closer to lotic habitats, as night temperatures can fluctuate and aquatic habitats remains more constant. Females will be found more often on sandy riverbanks in areas or suitable nesting habitat (Berg 2014).

During the summer terrestrial, or postnesting period, turtles tend to forage for food further inland and farther away from lotic habitats than during any other activity period (Kaufmann 1992a; Tuttle 1996; Breisch 2006). Turtles may spend several days on land without returning to aquatic habitats. When ambient temperatures exceed 30° C, wood turtles may estivate on land (Dubois et al. 2009; Flanagan et al. 2013). During this time, they may be concealed under protective cover such as sticks and grass, or partially buried in the soil. Estivating turtles may not move from this location for days or weeks until lower ambient temperatures return.

Activity during the fall aquatic period is divided equally between terrestrial and aquatic habitats (Williams 2013). Turtles begin preparing for brumation by sometimes moving long distances to congregate around hibernacula. During this period, turtle location and habitat preference (terrestrial or aquatic) may be dictated by air temperature, water temperature, and sunlight availability (Arvaisis et al. 2012; Flannagan et al. 2013; Brown et al. 2016).

Feeding

Wood turtles are “opportunistic omnivores” and consume a wide variety of plant and animal matter (Harding and Bloomer 1979). Their diet includes berries, green leaves, grasses, mushrooms, algae, mollusks, insects, earthworms, tadpoles, and dead fish (Harding 1991; Strang 1983; Kaufmann 1995; Walde 1998; Neiderberger and Seidel 1999). Harding (1991) suggested that hatchlings and juveniles are more carnivorous than adults. Wood turtles in Iowa consumed (in order of frequency of observations) grasses, slugs, violet (*Viola* spp.) leaves, prairie ragwort (*Senecio plattensis*) leaves, black raspberries (*Rubus* spp.), earthworms, snails, and dandelion (*Taraxacum officinale*) leaves (Tamplin 2006).

Wood turtles use a “worm stomping” behavior to force earthworms to exit their burrows; a turtle will stomp its feet and slam its plastron on the ground, mimicking the vibrations of rain or mole tunneling (Kaufmann 1986; Ernst and Lovich 2009). This behavior has been documented in some captive and wild turtles, but not observed in most reported populations (Kaufmann 1986; Kirkpatrick and Kirkpatrick 1996).

Reproduction

Mating has been recorded at all times during the active season (spring, summer, and fall) (Ernst and Lovich 2009); however, most courting and mating occur in the spring and fall (Brooks et al. 1992; Walde et al. 2003). Wood turtles typically mate in aquatic environments, although terrestrial mating has been observed (Harding and Bloomer 1979; Ernst 1986; Walde 1998; Ernst and Lovich 2009; Tamplin, personal observation). Multiple males may court and mate with the same female in a single season, in some instances resulting in multiple paternities within clutches (Kaufmann 1992b).

Females are known to nest on open sand bars along lotic water sources and in sandy riparian woodland edges. Nesting typically occurs between May and June, but may extend into July in northern populations and/or during cooler than average years (Harding and Bloomer 1979; Quinn and Tate 1991; Tuttle 1996; Walde et al. 2007; Ernst and Lovich 2009). Most often, nesting sites are located in areas that have ample exposure to direct sunlight and sandy, well-drained soils that retain some moisture. Prime nesting sites have substrate free of rocks and thick vegetation and are not prone to flooding (Harding and Bloomer 1979; Harding 1997).

Females typically lay one clutch of eggs per year, but may not nest every year (Harding and Bloomer 1979; Ernst and Lovich 2009). Total clutch size varies geographically and by individual turtle, but can range from 3–20 eggs (Harding and Bloomer 1979; Brooks et al. 1992; Tuttle and Carroll 1997; Walde 1998). Wood turtles have genetic sex determination with X and Y sex chromosomes, and the sexes are often equally distributed in a clutch of eggs (Bull et al. 1985; Ewert and Nelson 1991; Montiel et al. 2016). Hatchlings emerge from August to October (Harding and Bloomer 1979; Lovich et al. 1990), although in a Vermont population hatchlings overwintered within the nest (Parren and Rice 2004).

Social Structure

Wood turtles are not territorial; however, a social hierarchy occurs within populations. A linear rank hierarchy of dominance is maintained by repeated social interactions, and a variety of aggressive, submissive, and neutral acts have been observed both between and within sexes. Typically the oldest, largest, and heaviest male turtle is most dominant (Kaufmann 1992b). Galbraith (1991) determined that the dominant males in a population fathered a significantly greater number of offspring than lower ranked males. Selection pressures likely drive the establishment of a social hierarchy, because higher ranked males demonstrate greater reproductive success (Kaufmann 1992b; Pearse and Avise 2001).

Species Status

The wood turtle is a candidate species for federal listing under the Endangered Species Act in the United States, due to perceived broad-scale declines, (USFWS 2015). Candidate species are plants and animals for which the USFWS has sufficient information on their biological status and threats to propose them as threatened or endangered, but the development of a proposed listing regulation is precluded by other high priority listing activities (USFWS 2017). The wood turtle is listed as endangered, threatened, or special concern in every state and Canadian province that they are known to occur (Green, 1996; Bowen and Gillingham, 2004). Among the Midwestern states, wood turtles are listed as endangered in Iowa, threatened in Minnesota and Wisconsin, and a species of special concern in Michigan. (571-Chapter 77, Iowa Administrative Code; Christiansen and Bailey, 1997; IA Natural Resource Commission, 2009).

Threats

Predation

Predators may impact every life stage of wood turtles, but egg and hatchling predation are at the greatest risk. Mesopredators such as the raccoon (*Procyon lotor*) and striped skunk (*Mephitis mephitis*) frequently attack and kill adult turtles (Harding, 1985), sometimes consuming only the head or legs. Other confirmed predators of adults include fishers (*Martes pennant*) (Parren, 2013) and the North American river otter (*Lontra canadensis*) (Carroll and Ultsch, 2006). Raccoons and striped skunks are the most common predators of nests and young turtles. Other confirmed nest and hatchling predators are: common snapping turtles (*Chelydra serpentina*), American crows (*Corvus* *brachyrhynchos*), various large fish, Virginia opossum (*Didelphis virginiana*), eastern coyote (*Canis latrans*), feral cats (*Felis catus*), and feral dogs (*Canis lupus familiaris*) (Harding and Bloomer, 1979). In studies conducted on a population in Michigan during the 1970's, some year's mammalian predators caused nearly a 100% loss of eggs (Harding and Bloomer, 1979). Between 2003 and 2006, approximately 36% of wood turtle nests at Iowa study sites were destroyed prior to hatching by predators (Spradling et al., 2010). Human-impacted environments may increase predation risk due to elevated mesopredators densities (Harding and Bloomer, 1979; Riley et al., 1998).

Flooding

Flooding, excessive rainfall, and increased storm events are known to negatively affect the success of eggs hatching and recruitment of a wide range of turtle species (Ernst and Lovich 2009; Lenhart 2013). In areas near where wood turtles occur in Iowa, flooding occurred in 13 of 20 years (1989–2008), with 6 involving major or moderate flooding (USGS gage 05458900 above 12 ft) during peak nesting times (June and July). These increases in summer flood events during incubation have likely increased nest failure rates in populations of wood turtles in Iowa (Spradling *et al.* 2010), in which these events may be exacerbated through wetland draining and conversion to agriculture. Flooding appears to be the primary cause of nest failure in Iowa, with nearly 64% of wood turtle nests destroyed by flooding during a 2003–2006 study (Spradling et al. 2010). All known wood turtle nesting sites in Iowa experience flood events throughout the incubation period, inundating nests for extended periods of time, while water levels still remain 0.5–1.0 meter (m) below flood stage (Spradling et al. 2010).

Habitat Destruction, Fragmentation, and Degradation

Like many other herpetofaunal species, the wood turtle is primarily threatened by the fragmentation, destruction, and alteration of its riverine, riparian, and upland habitats (Garber and Burger 1995; Gibbons et al. 2000). Wood turtle population declines are exacerbated by direct and indirect human induced causes such as, road mortalities, agricultural machinery mortalities, excessive pressure from natural and exotic predators, increased and more severe flood events, and collection for the pet industry (Harding and Bloomer 1979; Garber and Burger 1995; Saumure and Bider 1998; Levell 2000; Saumure et al. 2007; Jones and Sievert 2009).

Human-dominated systems, especially those found in growing urban and suburban environments, clearly have negative impacts on wood turtle populations. Because of this, numerous conservation programs have been used to minimize or eliminate potential harmful human interactions (Brown et al. 2016). The ability to create effective conservation strategies requires knowledge and understanding of a population's habitat requirements, habitat use patterns, movements, and home range requirements, and how human encroachment may impact these. It is important to consider habitat availability, population demographics, and the amount of human impact occurring on turtle populations when considering turtle movement and home range characteristics.

While it is important to base conservation planning and management on species' primary ecological requirements, including the spatial relationship they may have with their environment, many individual populations may have unique spatial and temporal patterns of movement. These can depend on a variety of environmental factors, including but not limited to, climate, landscape characteristics, and availability of suitable habitat. For instance, if limited suitable habitat existed in constricted linear habitats, individuals in these areas may have larger and more linear home ranges than those in a population where the habitat is more square. Studies on movement patterns of individuals can be extrapolated to include any unique spatial requirements and habitat preferences of populations. An individual's movement patterns are dependent on the requirements of survival and reproduction for that species. This includes how the animal moves to acquire resources, how they avoid mortality sources and minimize competition, and participate in social interaction and mating opportunities (Fahrig 2003). These differences among populations make implementation of effective conservation strategies across a species' range a considerable challenge.

Understanding where and when a particular species occupies its home range throughout the year is one factor that is important to conservation efforts of the species. One should also consider how, and the frequency with which a species moves throughout its home range. While calculating home range size provides a snapshot of the area that a species may occupy at any given time during its lifetime, establishing and understanding patterns of movement related to a species' ecology, life history, and behavior is necessary for their effective conservation (Rubenstein and Hobson 2004). This often requires that individuals of populations be tracked on a seasonal or annual basis.

Anthropogenic habitat changes may negatively impact animal populations in several ways. One such way is by reducing habitat availability, and thereby increasing or decreasing home range sizes, depending on the extent of changes. Second, anthropogenic changes can impede or create additional mortality hazards in both daily and dispersal-related movements, thereby reducing interactions amongst individuals (mating, maintaining social hierarchy, etc.), and reducing adult survivorship (e.g., vehicular mortality). One key factor of interest when studying animal movements is to determine how organisms' respond to their environment and to changes in occupied habitat. Given that urbanization is considered to be a major threat for most species, and urban expansion is accelerating globally, research and conservation efforts should target these species that may be impacted to these changes (Makelainen et al. 2016).

Many wildlife populations maintain connectivity through narrow linear corridors of habitat between core populations (Cushman et al. 2013). Although these small, narrow linear habitat corridors may be important in certain landscapes, it is increasingly recognized that connectivity planning must be applied to broader landscapes to conserve animal populations (Cushman et al. 2013). This is especially important in the conservation of wood turtle populations, a species known to make long distance terrestrial movements away from a narrow linear corridor (e.g., lotic habitat). In addition, two revealing measures of an animal's use of space are the distance that it moves within a 24-hour period (mean daily movement [MDM]), and distance that one moves during an active season (total distance [TD]). These metrics provide transferable and applicable measurements to a variety of populations and may even correlate with other terrestrial species. Comparative investigations of MDM and TD across populations and species can provide habitat managers with the necessary data to promote conservation through informed management recommendations, especially on vulnerable wood turtle populations in Iowa.

Rural (non-suburban) population. A rural (non-suburban) population is defined as a population of a particular species that exists away from excessive human interaction and is found on larger tracts of relatively undisturbed natural land. These tracts of land are associated with increased species diversity and individual species success (Fahrig 2003). Undisturbed natural land is generally associated with "habitat specialists" or those species that require an undisturbed, unfragmented, heterogeneous landscape. For example, species such as the Northern spotted owl (*Strix occidentalis*) need large tracts of unfragmented land, as well as require greater areas of interior habitat to prosper (Lamberson et al. 2002).

Semi-aquatic turtle species (e.g., the wood turtle) that utilize multiple habitats throughout their annual life cycle are species that are particularly sensitive to anthropogenic changes and increased habitat fragmentation. These species may not thrive in disturbed suburban habitats (McKinney 2002; Randa and Yunger 2006; Krausman et al. 2008; Pittman and Dorcas 2009). As human population growth and urbanization increases suburban sprawl, large tracts of undisturbed land is fragmented forcing rural animal populations to exist as suburban populations. Species sensitive to landscape changes, require specific habitats, and are slow to grow and reproduce are significantly affected by even moderate suburban development, and may become locally extirpated (Gibbs 1998; McKinney 2002; Destefano and Degraff 2003; Baldwin et al. 2004).

Suburban population. A suburban population is defined as a population of species that occurs within or along the outskirts of cities, before the onset of open non-developed, non-suburban land (DeStefano and DeGraff 2003; McKinney 2006; Krausman et al. 2008). These are populations with individual home ranges that may encompass residential yards, public parks, golf courses, or fragments of natural land amongst a suburban landscape. Suburban sprawl can be one of the greatest threats to species diversity, and is especially harmful to those species requiring large tracts of undisturbed land (Germaine and Wakeling 2001; Kjoss and Litvaitis 2001; Marchand and Litvaitis 2004). Species that are considered “habitat generalists” (e.g., white-tailed deer [*Odocoileus virginianus*], fox squirrels [*Sciurus niger*], raccoons) have been found to function well and thrive in human disturbed areas compared to rural control populations (Bowers and Breland 1996; DeStefano and DeGraff 2003; Prange and Gehrt 2004; McKinney 2006). Suburban areas may offer new habitats or food sources that allow certain species, also known as “urban adapters”, to flourish (Bowers and Breland 1996; Prange et al. 2003; Prange and Gehrt 2004).

Turtle species that move large distances for nesting, mating, and/or feeding often encounter disturbed areas of landscape, such as the presence of roads. There is a correlation between increased disturbances and increased risk of mortality (Gibbs and Shriver 2002; Steen and Gibbs 2004; Aresco 2005). Furthermore, suburban landscapes contain a greater density of egg predators such as raccoons, which put turtle nest sites at increased risk of predation and cause turtle populations to experience decreased annual recruitment (Marchand and Litvaitis 2004; Aresco 2005).

The wood turtle is a vulnerable species that is sensitive to human disturbance. Pressures from human disturbance warrant increased monitoring, especially given that the wood turtle is in danger of extirpation when their habitat is no longer isolated from human contact (Garber and Burger 1995).

PREVIOUS RESEARCH

Home Range

To date, approximately 40 published studies across the wood turtle's geographic range have provided quantitative information on home range, habitat association, and movement metrics. The majority of these studies have only evaluated one type of movement metric (i.e., homing ability), habitat association (i.e., nesting preference), or home range criteria (i.e., kernels, minimum convex polygons), making comparative results across populations difficult on a wide scale. The majority of studies were conducted in the eastern region of the United States, and focused on the temperate broadleaf and mixed forests biome. Only 10 studies have focused on Midwestern populations, and even fewer exist from the temperate grassland biome (Hoekstra et al. 2010; Spradling et al. 2010; Williams 2013; Berg 2014; Brown et al. 2016).

Widely distributed species have natural geographic ranges extending over multiple ecoregions and even larger biomes. Research is often conducted in a limited portion of a species' range; thus, conservation strategies derived from this research and then uniformly applied over multiple ecoregions risk being ineffective for those species that occupy different habitat types and climatic zones across their range (Davies et al. 2013). Despite this being of particular importance for species' conservation, there remains limited understanding of regional variation in species-habitat relationships within broad geographic ranges (Davies et al. 2013). This problem is particularly important when knowledge about the movement patterns and home range sizes of individuals at the edge of the species' range is limited (Kanda et al. 2009). Habitat selectivity may be higher in landscapes located at or near the edge of a species' geographic range because high-quality habitat resources may be scarcer (Avila-Flores et al. 2010), or because the animals may be experiencing climate variables that approach their physiological limits (Walther et al. 2002). Food may not always be the limiting resource, especially in species known to eat a variety of foods, such as the wood turtle. Low population densities, hibernacula availability, scarcity of open canopy sites, and the quality of habitat may contribute to the necessity of larger home range sizes in order to meet wood turtle's physiological or breeding requirements (Arvisais et al. 2004; Matthews and Green 2012). Investigating movement patterns and resource selection at the edge of a widely distributed species' boundary and determining how these patterns vary across a landscape gradient will improve our understanding and management of animal-habitat relationships.

A limited number of studies on wood turtles movements and home range have been published from Wisconsin (Brewster and Brewster 1986; Ross et al. 1991), Minnesota (Brown et al. 2016), and Iowa populations (Spradling et al. 2010; Williams 2013; Berg 2014) have been published. Little information exists regarding movement patterns, habitat preference, or home range sizes of wood turtles in the Midwest, and there have been even fewer studies on the western edge of their distribution. Movement patterns, habitat use, and population dynamics of other semi-aquatic turtle species can vary across habitat types and climates (Hecnar 1999; Baldwin et al. 2004; Merchand and Litvaitis 2004). This makes understanding wood turtle movement patterns and home range size in a unique biome at the western edge of its geographic distribution imperative to ensure that conservation and recovery efforts are implemented properly.

Site Fidelity

Studies have demonstrated that turtles have high site fidelity throughout the year, and that annual home range size is similar across years (Arvisais et al. 2002; Freedberg et al. 2005; Bernstein et al. 2007). In sea turtles, there is evidence of long-term fidelity to foraging and breeding sites, and the ability to migrate between these sites at regular intervals (Miller 1997; Nordmore et al. 2004). In many freshwater turtle species there is evidence of high site fidelity to breeding/nesting sites (Standing et al. 1999; Tucker 2001; Freedberg et al. 2005; Rowe et al. 2005); some individuals even laid eggs within one meter of previous nest locations (Walde 1998). Several multi-year studies have documented home range fidelity in box turtles (Metcalf and Metcalf 1978; Holy 1995; Bernstein et al. 2007), and tortoises (Heise and Epperson 2005; Harless et al. 2009). In addition, several studies evaluating the success of translocating various tortoise and box turtle species have evaluated site fidelity, but this occurred on individuals moved outside of their known home range to new locations (Tuberville et al. 2005; Field et al. 2007).

Wood turtles may exhibit high degrees of site fidelity, sometimes being found in the exact location on nearly the same day from one year to the next (Harding and Bloomer 1979; Tamplin, personal observation). Other individuals, after being released to areas outside of their known home range (<2 kilometers [km]) have shown the ability to find their way “home” (Carroll and Ehrenfeld 1978; Barzilay 1980). Few wood turtle studies have looked specifically at site fidelity between subsequent years of survey. Of these, one investigated nest site fidelity (Walde 1998), and another determined home range fidelity of individuals tracked between 1996 and 1997 in the northern portion of their range (Arvisais et al. 2002). No studies to date have evaluated the change in size or degree of site fidelity in home ranges of wood turtles over more than two years.

Iowa Wood Turtle Studies

To date, ecological research has been conducted on only two Iowa wood turtle populations: a 2003–2006 study (Tamplin 2006; Spradling et al. 2010) surveying wood turtles in Butler County (BC), and a 2009–2012 study (Williams 2013; Berg 2014), analyzing home ranges, temperature, and habitat preferences of wood turtles in Black Hawk County (BH). Williams (2013) and Berg (2014) defined the BC study site as a non-suburban or rural site. The human population of Butler County in 2015 was 14,867, and the nearest city was approximately 6.2 miles north of the study site, with a population of 1,025. Williams (2013) and Berg (2014) defined the BH study site as a suburban site. The study site falls within the northwest corner of the city limits of Cedar Falls, Iowa, which when combined with the confluent city of Waterloo, Iowa, has a total population of 108,932. In Black Hawk County, the human population increased 4.2% from the 2000 to 2015 censuses (U.S. Census Bureau 2016); it is the fourth most populated county within the state, which may increase human pressures in areas wood turtles occur.

Spradling et al. (2010) found that wood turtles from the BC population in Iowa are genetically distinct from wood turtle populations in the northeastern United States and

Minnesota. Iowa turtles represent a peripheral isolate that may be an important reservoir for distinct alleles absent in populations outside the state. The BC population is described as a rural population that has exposure to agriculture and limited exposure to human development (Spradling et al. 2010; Williams 2013; Berg 2014).

Williams (2013) and Berg (2014) surveyed the BH population from 2009–2012, studying habitat preferences, thermal ecology, and home range characteristics. The majority of the study occurred on public protected land, but the site was bisected by an elevated rail line and a heavily used public roadway. In addition, the adjacent private property was heavily impacted by anthropogenic development; and subsequently, they described this wood turtle population as a suburban population consistently in the presence of human disturbance and development.

OBJECTIVES OF STUDY

Home Range and Movement Patterns

The primary objective of this study is to investigate the differences in mortality rates, movement patterns, and home range size of two distinct wood turtle populations in Iowa: a population from a suburban location and a population from a rural location. Wood turtle populations in Iowa are unique in that they are one of the few populations that are found within a historical prairie-forest ecotone of the Great Plains ecoregion (Ornernik 1987). Determining home range size and movement patterns based on habitat availability, sex, and age class of Iowa wood turtles can provide conservation recommendations for specific populations in the form of habitat restoration and maintenance.

Hypotheses tested are as follows: 1) because males search for mates and patrol their home range for rivals more than females, males will have larger home ranges (minimum convex polygons, linear home range, and stream home range), and move throughout their home range farther, and more often than females; 2) because suburban habitats are more fragmented and degraded due to human disturbance, turtles from a suburban population will have larger home ranges (minimum convex polygon, linear home range, and stream home range), and move more often and farther throughout their home range compared to those from a rural population, and 3) within each sex, because larger/older turtles are more resilient to fluctuating environmental variables than small/younger turtles and because males are known to search for mates and patrol their home range for rivals more than females, sex and body size of turtles (mass and straight carapace length [SCL]) will have a greater correlation with home range size and movement patterns compared to other variables.

Site Fidelity

As an ectotherm, the energy required for a turtle to move through their environment is dictated by body temperature, which is ultimately driven by the temperature of their environment. If an individual turtle can minimize the effort required to move to various basking locations within its home range, this may increase energy stores that can be used for finding food or mates (Huey 1982), so utilizing known basking locations for temperature regulation can be beneficial for turtles and other ectotherms. In addition, utilizing and returning to areas that have ample food resources or mates could lead to high site fidelity, where an individual turtle may use the same areas from one year to the next for food, safety, or energy consumption (i.e., the same bush for berries, the same hibernacula, and the same clearing for basking). The benefit of high site fidelity may increase survival of turtles, while exploratory forays into “new” areas may increase mortality risk (Beaudry et al. 2010).

The secondary objective of this study is to investigate the changes in yearly home range size, site fidelity, and population demographics of wood turtles in Iowa. Wood turtle populations in Iowa are unique as they are one of the only populations that are found within a historic prairie-forest ecotone, so determining changes in populations over time and movement patterns between years, can shape conservation recommendations for populations as they relate to habitat conservation, restoration, and maintenance. I predict that wood turtles will have a high degree of site fidelity from one year to the next, or over the course of several years, and that little change in home range size and area would occur over many years.

Hypotheses tested are as follows: 1) because turtles will utilize the same areas each year for feeding, mating, hibernating, and thermoregulation, adult wood turtles will have a high degree of site fidelity between subsequent years (overlap in home ranges between years); 2) because adult turtles will utilize the same areas that were successful in their survival between many years, adult wood turtles will have a high degree of site fidelity between several years; 3) turtles maximize survival through the minimization of movement by utilizing and occupying the same areas year after year for feeding, mating, and thermoregulation, therefore, adult wood turtle home range size is predicted to change little over time.

CHAPTER 2

MATERIALS AND METHODS

Study Sites

My research was conducted at two distinct study sites in Black Hawk (BH) and Butler (BC) counties in northeastern Iowa (Figure 2). Each study site was established along second-order tributaries (Beaver Creek in Black Hawk County and the West Fork of the Cedar River in Butler County) of the upper Cedar River (Figures 2), and encompassed areas of private and public land. The study sites were approximately 23.0 km straight-line distance from one another, and were separated by numerous county highways, gravel roads, and agricultural fields. A continuous waterway connects both sites, approximately 45.0 river channel km between sites. Study site boundaries were determined by creating a 300 m buffer (the maximum distance from water recorded for any turtle at these sites) around the main lotic water sources in the study area, and the furthest upstream and downstream locations. Land cover types were determined from the National Land Cover Database, field verified, and mapped with aerial images and a handheld Global Positioning Systems (GPS) unit (Trimble Geo Geoexplorer 7x; NAD 83), when possible. Land cover was broken into 12 categories. Agriculture, pasture, residential, and roads and railroads were considered human development. Ephemeral water, lentic water, and lotic water were considered aquatic habitats. Coniferous woodland, deciduous woodland, restoration, grassland, and open sand and willows were considered terrestrial habitats. Agriculture land is dominated by row crops such as cultivated corn or soybeans, pasture are areas of disturbed upland used for either cattle

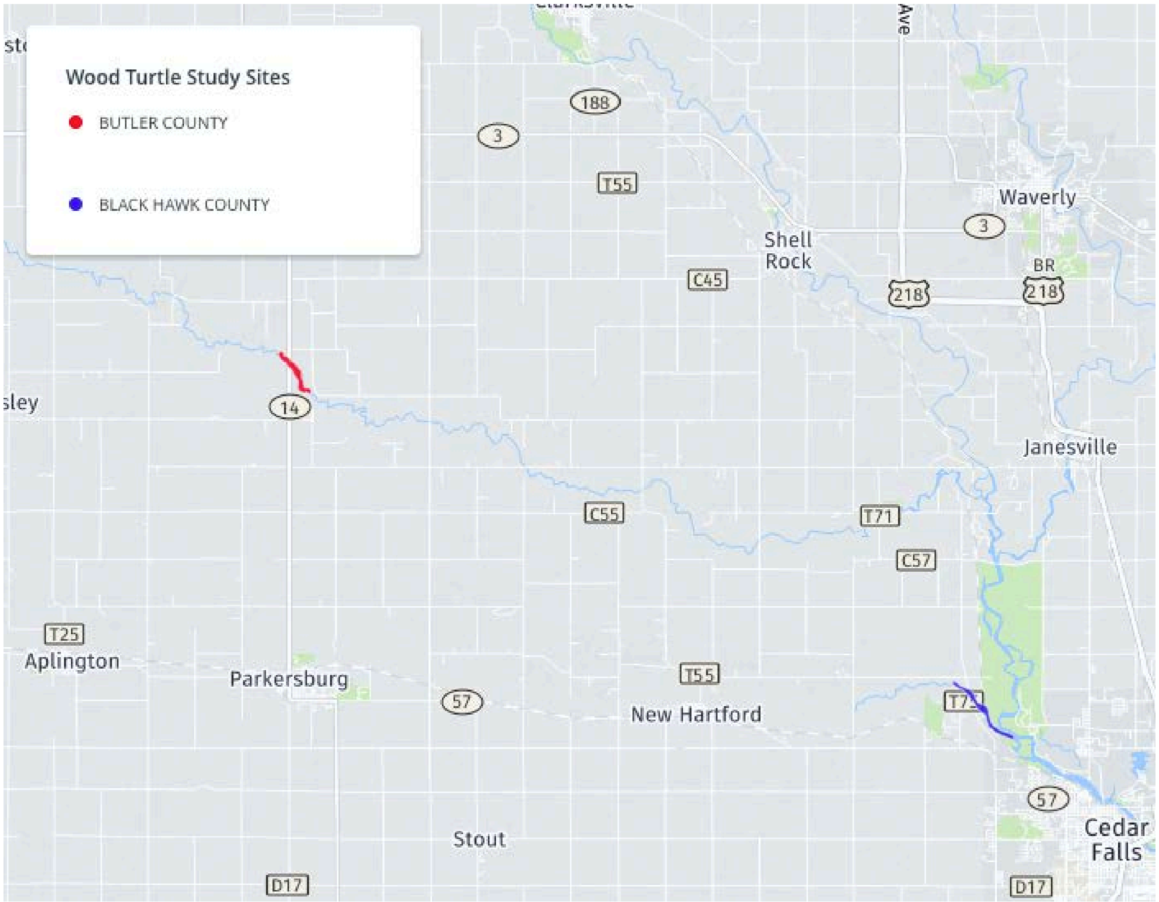

Figure 2. Locations of the Black Hawk (BH) and Butler County (BC) wood turtle study sites assessed during 2014–2015. The BH population occurs along Beaver Creek while the BC population occurs along the West Fork of the Cedar River.

grazing or horse pastures which are typically dominated by grasses less than 10 cm, residential includes houses, garages, barns, residential yards, and driveways, while roads and railways contain paved or gravel roads and rail lines including gravel road banks. Ephemeral water areas are those that dry up during some portion of the year, lentic water contains standing water such as farm ponds, and lotic water contains flowing water such as Beaver Creek, the West Fork of the Cedar River, and the Cedar River. Coniferous woodlands are areas dominated by trees that do not lose their leaves during the year, deciduous woodlands are dominated by trees that lose their leaves during a portion of the year, restoration includes areas that had been managed during the 2014/2015 study either via canopy clearing or edge feathering, grassland are those areas dominated by grasses greater than 10 cm in height, usually contain reed canary grass (*Phalaris arundinacea*) or native prairie species, and open sand and willows are those areas dominated by open sandy soils or willow trees, typically associated with bends in rivers or creeks.

A field study of home range size, movement patterns, habitat preferences, and thermal ecology of wood turtles was conducted at the two sites from 2003–2006, and 2011–2015, using radio-telemetry techniques. Additional sporadic telemetry and visual encounter surveys were conducted from 2006–2010. The present analysis utilizes data generated in conjunction with these prior studies.

Black Hawk County Site

The BH study site, located in northwest Black Hawk County, was approximately 298.9 hectares (ha), and centered along a 3.5 km stretch of Beaver Creek, which originates approximately 55 km (straight line distance) to the west of the study site (Figure 3). Beaver Creek runs west to east, draining into the Cedar River at the eastern boundary of the study site. The substrate of Beaver Creek varies, but primarily consists of sand. Mixed mud and gravel substrates are also present in limited quantities scattered throughout the creek. Small areas of broken rock and riprap are found along railroad lines, roads, and bridges located within the study site. Approximately 128.6 ha (43.0%) of the study site is located on county-owned public land open to outdoor recreation activities such as hunting, fishing, and hiking. Primitive camping sites were discovered within the study site; however, camping is not allowed on site.

The BH study site is bisected by Union Road, a high traffic, paved, two-lane road that crosses Beaver Creek via a 90 m concrete bridge that extends approximately 20 m beyond either bank of the creek (Figure 3 and 4). The road runs 675 m through the study site, paralleling the southern boundary of the eastern half before curving north-south where it crosses the creek. An additional paved road runs 1450 m east-west along the northern boundary of the western half of the study site. A railroad line extends 2375 m through the eastern half of the study site. The railroad line has a 5–6 m tall rock embankment extending 3–4 m on either side of the tracks. A 75 m railroad bridge crosses Beaver Creek, extending approximately 5 m beyond either bank. The railroad line runs parallel with the eastern half of Beaver Creek, approximately 40–100 m south of the southern bank, before curving and traveling north out of the study site (Figures 3 and 4).

Human development and infrastructure including pastures, maintained yards, houses, driveways, railroads, garages, and barns make up approximately 28.0 ha (9.5%) (Table 1) of the study site and mostly occur along the southern boundary of the study site. East of Union Road, human development in the form of six houses or farmsteads range from 150–320 m south of Beaver Creek. In the western portion of the study site (west of Union Road), four houses range from 75–350 m from the creek, the majority north of the creek.

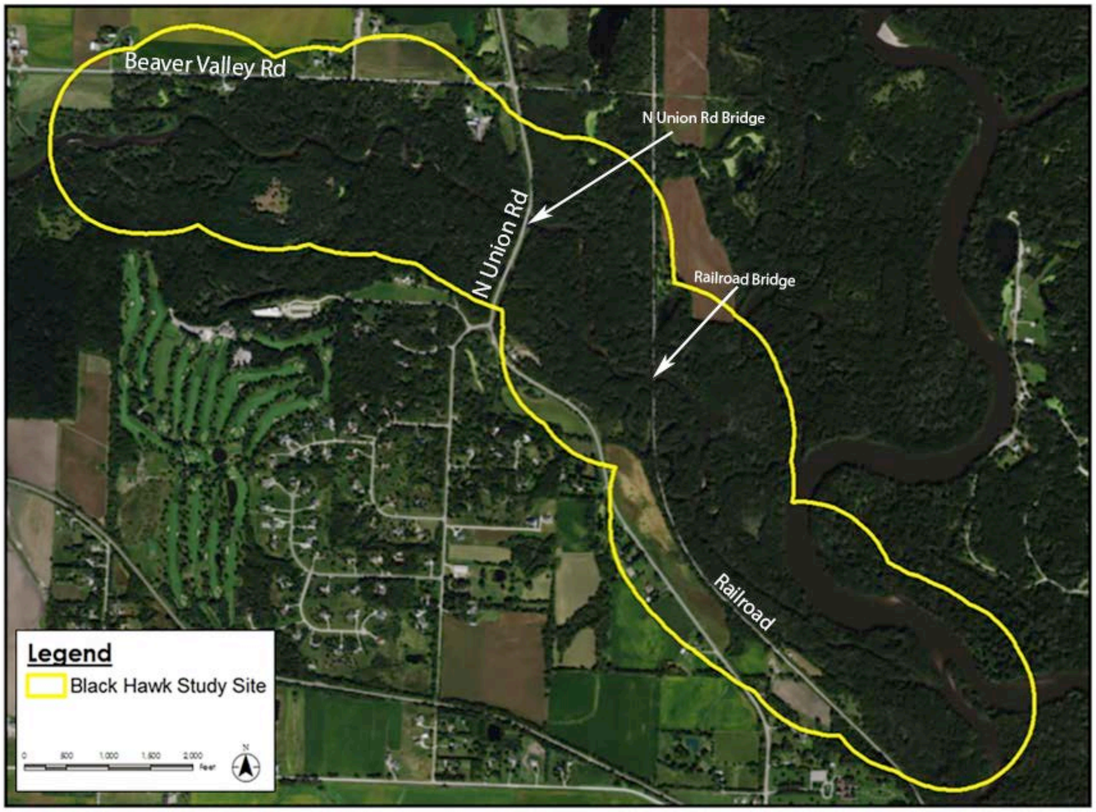

Figure 3. Aerial image of the Black Hawk (BH) study site located in northwest Black Hawk County. The study site is centered along Beaver Creek, defined by a 300 m buffer around the lotic habitat.

A limited amount of agricultural development in the form of cultivated corn and soybeans, 25.5 ha (8.5%), is located within the study site (Table 1). The majority of agricultural development is found north of the paved road, west of Union Road, with additional areas found along the southeastern boundary, and an isolated area north of Beaver Creek, and east of the railroad line (Figures 3 and 4).

The study site is comprised of moderately mature to mature riparian floodplain woodland, 192.5 ha (64.4%) of the study site (Table 1; Figures 3 and 4), which are dominated by trees such as silver maple (*Acer saccharinum*), eastern cottonwood

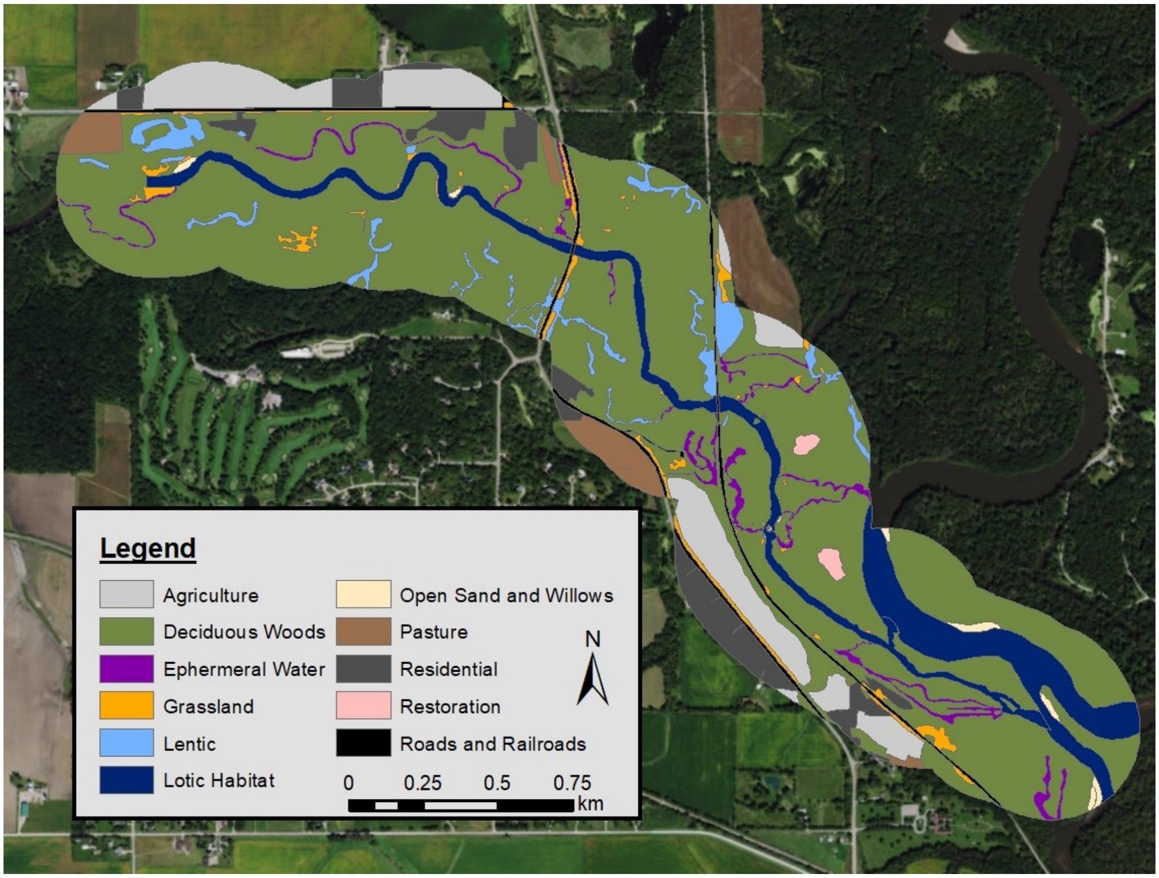

Figure 4. Map of the land cover types located within the Black Hawk County (BH) study area. Land cover was ground-truthed then digitized using ArcGIS 10.3.

(*Populus deltoides*), American elm (*Ulmus americana*), and mulberry (*Morus* spp.). In recent years, the Cedar River drainage basin, including Beaver Creek, has experienced a substantial increase in the frequency, strength, and depth of flooding events, potentially due to the effects of climate change and altered agricultural practices in the surrounding landscape (Spradling et al. 2010). As a result, herbaceous species along Beaver Creek can be limited and vary from year to year. Numerous piles of flood-deposited woody debris of various sizes are found throughout the site, both in stream and in adjacent uplands.

Table 1. Total hectares and percentage of land cover at the Black Hawk and Butler County study sites. Habitat was ground-truthed and digitized using ArcGIS 10.3. Total human development includes pasture, residential, and roads and railroads. Total aquatic habitat includes ephemeral, lentic and lotic water. Total terrestrial habitat includes coniferous and deciduous woodland, restoration, grassland, and open sand and willows.

Habitat Type	**Black Hawk County**		**Butler County**	
	Hectares	**Percentage**	**Hectares**	**Percentage**
Agriculture	25.5	8.5	70.7	16.3
Pasture	7.0	2.4	0.0	0.0
Residential	15.2	5.1	0.9	0.2
Roads and Railroads	5.8	2.0	3.9	0.9
Ephemeral Water	7.5	2.5	5.1	1.1
Lentic Water	9.0	3.0	8.8	2.0
Lotic Water	28.0	9.3	26.4	6.1
Coniferous Woodland	0	0.0	1.2	0.3
Deciduous Woodland	192.5	64.4	253.1	58.3
Restoration	1.1	0.4	0.9	0.2
Grassland	6.0	2.0	57.5	13.3
Open Sand and Willows	1.3	0.4	5.7	1.3
Total	**298.9**	**100.0**	**434.2**	**100.0**
Total Human Development	28.0	9.5	4.8	1.1
Total Aquatic Habitat	44.5	14.8	40.3	9.3
Total Terrestrial Habitat	200.9	67.2	318.4	73.3

Butler County Site

The BC study site, located in central Butler County, is approximately 434.2 ha and is centered along a 3.5 km stretch of the West Fork of the Cedar River (West Fork) that originates approximately 70.0 km (straight-line distance) to the northwest of the study site. The West Fork runs northwest to southeast, eventually draining into the Cedar River. The substrate of the West Fork varies, but primarily consists of sand. Mud and gravel substrates are present in limited amounts in scattered locations throughout the study site. Small areas of broken rock and riprap are found along the roads and bridges that pass through the study site. Approximately 54.8% of the study site is located on public state property and is used for a variety of recreational activities such as hunting, fishing, kayaking, and hiking. Camping sites were discovered within the study site; however, camping is not allowed on the site.

The site is bisected by State Highway 14, a high traffic, two-lane, paved road that runs north-south for 1436 m through the central portion of the study site. This highway crosses the West Fork via a 100 m concrete bridge that extends approximately 25 m beyond either bank. An additional gravel road runs 1979 m east-west along the northern boundary of the central portion of the study site, before turning into a low-use dirt (B-level access) road running north-south and east-west in the eastern portion of the study site. Also, a gravel road runs 408 m along the south central portion of the study site (Figures 5 and 6).

Anthropogenic disturbance in the form of pastures, agricultural operations, driveways, garages, and barns make up a limited amount of the study site, approximately 4.8 ha (1.1%; Table 1). These areas are limited to small farmsteads and one residence found in the north central portion and southeast corner of the study site. Human development in the form of houses or farmsteads range from 250 m north of the West Fork in the central portion of the study site, to 275 m south in the southeast corner of the study site. Approximately 70.7 ha (16.3%) of the site is agricultural corn and soybean crops (Table 1). The majority is found north of the West Fork, just north of the tree line along the dirt road. A smaller portion is found in the western half of the study site, just south of the tree line along the West Fork (Figures 5 and 6).

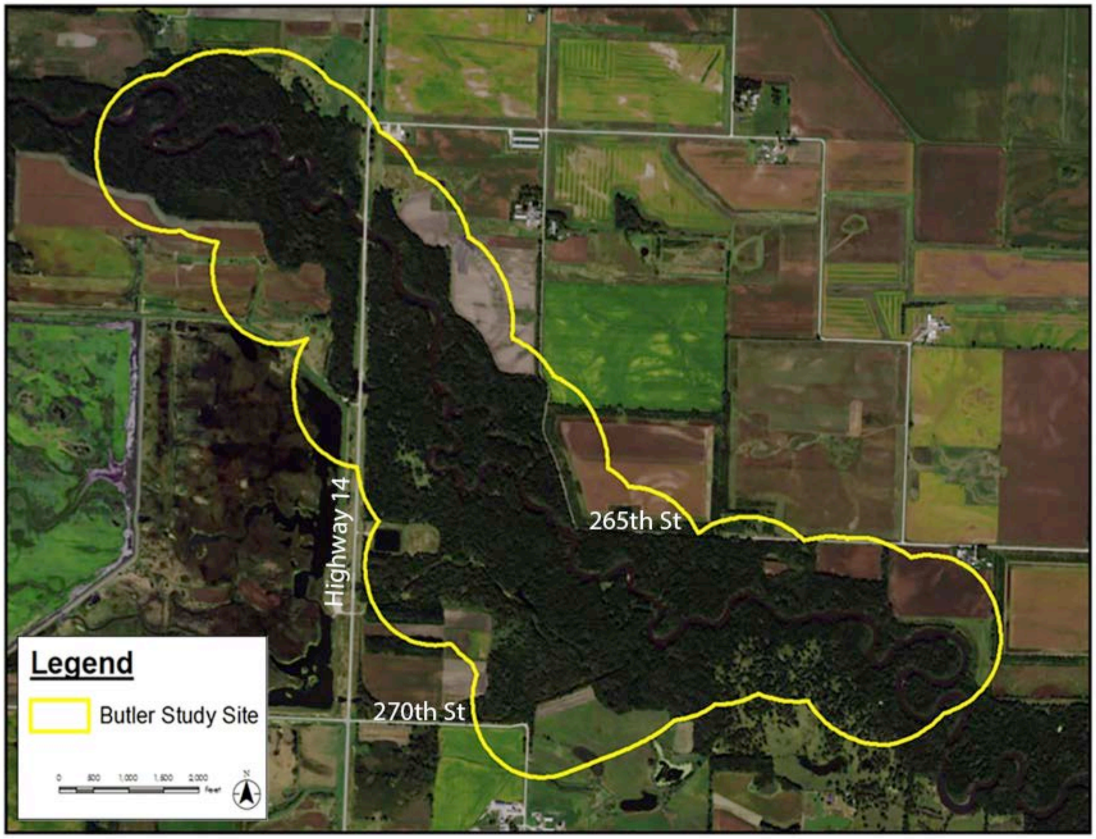

Figure 5. Aerial image of the Butler County (BC) study site located in central Butler County. The study site is centered along the West Fork Cedar River, defined by a 300 m buffer around the lotic habitat.

The study site is primarily comprised of moderately mature to mature riparian woodlands (253.1 ha [58.3%]; Table 1), with shrubby young woodlands found along the edges. The dominant tree species found include but are not limited to: silver maple, eastern cottonwood, American elm, box elder (*Acer negundo*) and oak trees (*Quercus* spp.). A moderate amount of open grassland areas of varying sizes are found throughout the site in scattered locations along the river, road ditches, and uplands. The majority of these have less than one ha of open canopy within the riparian woodlands. A small

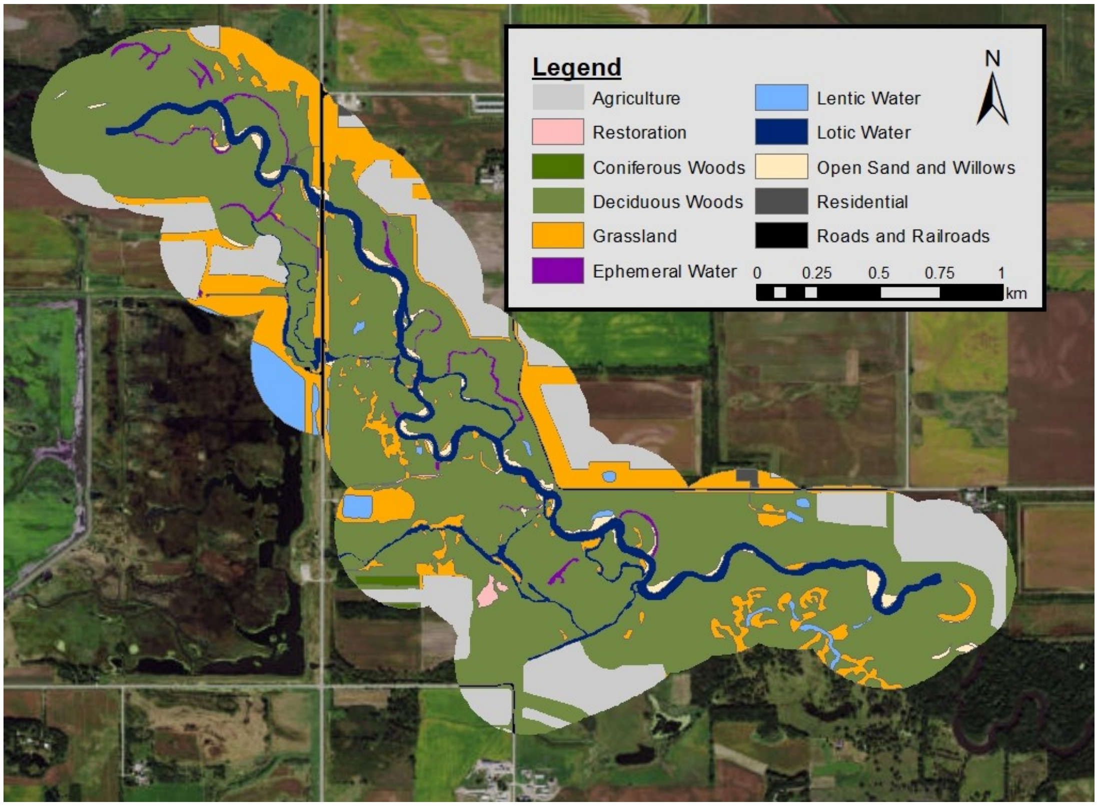

Figure 6. Map of the land cover types located within the Butler County (BC) study area. Land cover was ground-truthed then digitized using ArcGIS 10.3.

number (<10) of grassland areas are larger (>5 ha), and are dominated by reed canary grass (*Phalaris arundinacea*), crown vetch (*Coronilla varia*), orchard grass (*Dactylis glomerata*), and other thick growing forbs and grasses.

Because suitable habitats of both sites are similar in size and structure, and the length of time in which similar studies have occurred here, these areas make ideal locations to examine how annual home range size of wood turtles may change over time. Although no measurements were taken to determine the quality of habitat, a similar amount paved roads fragment the eastern and western portion of both sites. Based on the quantitative comparison of overall ha total of human development and number of houses located at either site, BH was considered a suburban site because it contained nearly 7% more human development and 10 times the amount of houses compared to BC, which was considered a rural site.

Turtle Captures

Both BC and BH had various wood turtle surveys conducted prior to the commencement of the current study. Results of those surveys were combined with the current study to provide an overall population demographic of wood turtles in Iowa, how demographics have changed over time, and evaluated mortality rates between studies. Periodic visual encounter surveys and radio telemetry surveys were conducted from 2003–2009 at the BC site. During this time, 48 (31 females, 16 males, and 1 juvenile) turtles were captured, aged, marked, and assessed based on methods described below. Eight of these individuals (6 females and 2 males) were tracked utilizing radio telemetry periodically from 2003–2006 (Tamplin, personal observation; Williams 2013; Berg 2014).

Similar studies were conducted at BH from 2010–2013. During this time, 36 (16 females, 16 males, and 4 juveniles) turtles were captured, aged, marked, and assessed based on methods described below. One additional hatchling was found, but was too small to be marked. Based on the unique plastron pattern, this turtle was thought to be recaptured as a 3-year old two years after its initial capture. Twenty-two individuals (11 females and 11 males) were tracked utilizing radio telemetry from 2009–2013. Tracking of these individuals was only terminated due to death of the turtle, loss of signal due to an individual presumably leaving the study site, or the transmitter failing (Williams 2013; Berg 2014).

At the beginning of the current study, 15 turtles (7 females and 8 males) at BH were still being located weekly via radio telemetry. Additional wood turtles were captured opportunistically by hand during visual encounter surveys in April and May of 2014 and 2015. Opportunistic captures were also made during biweekly radio telemetry surveys from September 2013 to July 2015. Wood turtles were initially located by searching streams, rivers, riverbanks, and adjacent vegetation. All turtles captured were sexed, approximately aged by counting growth annuli on scutes, weighed to the nearest 0.1 g, and digitally photographed (carapace, plastron, and lateral views). Sex was determined through secondary sexual characteristics (Harding and Bloomer 1979). The SCL of each turtle was measured to the nearest 0.1 mm using digital calipers.

Age Structure

Age and sex of all individuals captured was determined at first capture. Sex was determined by secondary sexual characteristics. Turtles were classified as “juveniles” and labeled as unknown sex if they had new growth visible to the annuli, and/or were approximately aged to <14 years, based on the approximate age of maturity (Ernst and Lovich 2009). As age may is difficult to determine for turtles older than 20 years, age was estimated in five-year increments (e.g., 21–25) based on shell appearance (Harding and Bloomer 1979). Turtles were assigned one of six age-classes based on growth annuli, plastron and carapacial wear, pigment loss and shell pitting. These categories were ≤5 years, 6–14, 15–20, 21–25, 26–30, 31–35, and >35. The age structure of the entire population at both study sites was calculated for all individuals captured from 2003–2015. In addition, mortality rates at each site were determined from all mortalities observed during all years of study (2003–2015).

For initial captures, the point of capture (latitude/longitude) was recorded with a handheld GPS unit (Garmin GPSMap 60CSX; NAD 83). Additional habitat characteristics, behavior, environmental conditions, temperatures and sunlight availability (lux) were recorded for each location. Each individual turtle was given a unique numerical code and marked by drilling holes along the posterior marginal carapace scutes (modified from Cagle 1939). All capture and handling methods were approved by UNI's Animal Care and Use Committee and were conducted under Iowa DNR scientific collector's permit SC-647.

Assessing Level of Injury

To assess the effects of injuries on wood turtle home range size, I used an index similar to Jones (2009) to quantify the level of physical damage to individual turtles. Each turtle's limbs, tail, and head (eyes and mouth) was rated based on the degree of injury: none (0), little (1), moderate (2), or high (3). I calculated an "injury index" was ranging from 0 to 9 summing the scores from each category.

Radio Telemetry

A radio transmitter (Advanced Telemetry Systems [ATS] model R2220 and R2222; 35 g and 25 g, respectively) was attached with PC-7 (Protective Coatings, Inc.) marine epoxy to the carapace on the right third and fourth coastal scutes, and each turtle was released at the point of capture once the epoxy cured. Transmitters, including epoxy, weighed less than 5.0% of each turtle’s body mass. The battery life of R2220 is approximately nine years, and R2222 is approximately five years. Radio transmitters attached in previous studies (2003–2005) at these sites were designed to have a battery life of about 24 months, so these individuals had up to two years of telemetry data recorded during that time.

From the initial capture date through December 2015, each transmitter-equipped turtle was located via radio telemetry (Advanced Telemetry Systems R410 receiver, and 3-element, collapsible Yagi antenna) at least once a week, when possible. The study period included all elements of the activity cycle of a wood turtle as defined by Arvisais et al. (2004), including: hibernation, prenesting, nesting, postnesting, and prehibernation. The exact dates for each activity period varied between years based on seasonal climate patterns and yearly temperature variation.

When possible, turtles were visually located and their behavior (feeding, mating, basking (>20% exposed), hiding (≤20% exposed), nesting, or moving) was recorded. Behavior was noted as either aquatic or terrestrial, and when necessary, more subjective behavioral assessments were noted, such as basking on a log or nest-searching. When unable to visually locate a turtle (e.g., hiding in water, in swift current, etc.), triangulation methods were employed to determine a turtle’s location to the nearest m, when possible. Each turtle location was recorded using a handheld GPS unit with an accuracy of <3.66 m. For each site visit, turtles were located in a random order, but sometimes not every turtle was found.

I recorded information on multiple habitat variables within 5 m of each turtle location (approximately 20 m^2), centered on the turtle's location. Habitat was categorized based on the dominant cover of the 20 m^2 plot and categories included; lotic aquatic (river/creek), lentic aquatic (oxbow/pond/lake/marsh), deciduous woodland, emergent grasses and forbs (prairie/grass ditches/open canopy), riparian grasses and willows, river bank (with vegetative cover), open bank (no vegetative cover), non-cultivated field, agricultural field, and other (e.g. railroad embankment, road, etc.). The presence of a pronounced ecotone between habitat types was noted when observed. At all terrestrial locations, the straight-line distance (m) to the nearest permanent water source was recorded.

For the analyses described below, the dataset was restricted to telemetry locations recorded between hibernation events (defined as the time a turtle was found exclusively in aquatic habitat, did not move, and water temperature dropped below 12° C). This included the last hibernation location before an animal became active (first moved >10 m) and the first confirmed hibernation location after an active season. An active season was defined as all locations of a wood turtle found during non-hibernation events, generally ranging from 15 April to 15 November. Turtles with fewer than 20 observations during this period were excluded from annual home range analyses.

DATA ANALYSIS

Home Range Estimation

The overall home range was estimated for each turtle with >20 location points, excluding hibernation in each year (2014–2015) using five home range types: linear home range (LHR), stream home range (SHR), 100% minimum convex polygon (MCP), 95% MCP, and 50% MCP. For those turtles that had >20 locations during each year, 95% MCP home range for each year of activity was also calculated. The MCP technique is sensitive to auto-correlated data (Swihart and Slade, 2004). To ensure the independence, data points were separated by at least a 72-hour period.

Linear Home Range (LHR)

LHR is defined as the straight-line distance between the two most distant point locations where a turtle was found (Plummer, 1977; Morales-Veredeja and Vogt, 1997). The combination of LHR with other home range estimates, particularly in lotic systems, can increase the understanding of how a species utilizes both terrestrial and aquatic habitats within their home range (Vokoun, 2003). LHR was calculated in ArcGIS 10.3 by measuring the straight-line distance between the two most distant turtle locations from 2014–2015, which could include aquatic or terrestrial locations or a combination of both.

Stream Home Range (SHR)

SHR is defined as the shortest linear distance between the furthest upstream and downstream turtle locations along a lotic corridor, which is well suited for evaluating aquatic turtle movements (Ouellette and Cardille, 2011). SHR was calculated in ArcGIS 10.3 using only locations within a lotic water source or on the immediate riverbank during 2014–2015 by measuring the shortest continuous distance between the furthest upstream and downstream locations found within and along the lotic water source. This measurement also includes observations in tributaries that were connected to overwintering streams/rivers, as turtles were assumed to have traveled via the channel between these locations.

Home Range Analysis (100%, 95%, and 50% MCP)

Three MCP home ranges (100%, 95%, and 50%) were estimated using the GME extension in ArcGIS 10.3 to determine overall home range size of each individual turtle during 2014–2015: The 100% MCP is the smallest polygon in which no internal angle exceeds 180 degrees and which contains all of the locations for each individual (Burgman and Fox, 2003). The 100% MCP, also known as the integral range (Saumure, 2004), encompasses all locations found for each individual, including any outliers. The 100% MCP may include areas not known to be used by an individual, but was analyzed to compare with previous studies of wood turtle home range (Quinn and Tate, 1991; Ross et al., 1991) and because some outliers occurred during nesting forays, an important and vulnerable time period in a wood turtle's life history. The 100% MCP home range analysis included all active points found during both active seasons (2014 and 2015), including the first and last hibernation location from each year. This determines the total area an individual may occupy over multiple years, and potentially is not confined to just a brief snapshot of its life that may be calculated with other metrics. Some species have been found to occupy certain portions of their total home range over multiple years, and do not just have annual migration/movement patterns in which all portions of their home range is occupied during some portion of the year (Block et al., 2011; Hays and Scott, 2013).

In addition, 95% (statistical range) and 50% (core range) MCP's were determined for each individual with ≥20 locations. The 95% and 50% MCP's were calculated for each individual by omitting 5% or 50% of individual turtle location points. The 95% MCP controls for outliers and is commonly used for constructing utilization distributions (Mohr, 1947; Getz et al., 2007). Because this method emphasizes the "unstable boundary properties of a home range," several alternative methods are considered preferable (e.g., kernel density analysis [Powell, 2000]); however, recent studies demonstrate that kernels are not an accurate method for analyzing herpetological data (Row and Blouin-Demers, 2006; Boyle et al., 2009) as they inherently inflate home range data by buffering actual data points (Millspaugh et al., 2006). As a result, more traditional MCP calculations for herpetological home ranges are considered most accurate. The 50% MCP is the smallest area in which an individual has a 0.50 relocation probability, or the core area that an animal spends approximately 50% of its time.

Site Fidelity Analysis

To evaluate site fidelity and home range overlap of wood turtles, only turtles that had at least two years of 95% MCP home ranges were calculated. Annual 95% MCP home ranges were calculated using the methods described above. Site fidelity was calculated for each individual with 95% MCP's in 2014 and 2015, as well as between any additional years found over the entire study period (2003–2015).

To study the fidelity of 95% MCP home range between two years, the overlapping area between fixed intervals (e.g., from one year to the next) was calculated. Area of overlap of an individual's home ranges for each year calculated was completed in

ArcGIS 10.3. As the overlapping measure we used the percentage of the Minta index (Minta 1992):

$$\text{Percent overlap} = \frac{((\text{area A}) \cap (\text{area B}))}{\sqrt{(\text{area A} * \text{area B})}} * 100$$

where ((area A) ∩ (area B)) is the intersection (overlap) area between home ranges from two different years (A and B). A percentage of 100 on the Minta index indicates there is complete overlap between the two areas, where a 0 signifies that no part of either home range area overlaps. Categories presented by Kernohan et al. (2001) were used to define the extent of overlap: low (0–33.9%), moderate (34–66.9%), and high (67%–100%). The degree of overlap of the 95% MCP home ranges was compared between each annual home range calculated.

Williams (2013) conducted home range analysis on wood turtles at BC and BH prior to 2013, but these methods were inconsistent with the current study, so the raw data were used and analyzed utilizing methods described in this study.

Movements

Active Season Movement Behaviors

Four animal movement variables were calculated for individual wood turtles in Iowa from the two study sites: TD moved in an active season, MDM, maximum distance between subsequent relocations (MDR), and Maximum Distance from Lotic Habitat (MDLH). TD provides an overall assessment of how much individuals are moving through their home range during the active season. Oftentimes, location points are found during times of inactivity (hot weather, hiding in water, hiding in vegetation, etc.), which gives the appearance that wood turtles may be more sedentary than they are. TD may also provide an insight to habitat quality, and how often and far an animal needs to move throughout their habitat to meet their basic needs (e.g., food, shelter, mates). Finally, TD provides a benchmark that is easily compared between populations and other species. MDM provides a measurement of the distance that turtles are moving through their habitat each day, and how often they potentially could come in contact with human interference (e.g., roads, agriculture). MDR provides a temporal determination of important time periods and events (e.g., nesting forays, long distance movement to hibernation), and the distance these events involve. Finally, MDLH can determine how much habitat centered on lotic habitats is necessary in order to protect terrestrial movements of turtles and increase the connectivity of habitat corridors.

Animal movement criteria were generated via radio telemetry surveys, and calculated for the previously described individual turtles during the 2014–2015 active seasons. Animal movement criteria were calculated for those turtles with ≥20 location points, excluding hibernation locations, within a single calendar year.

Maximum Distance From Lotic Habitat (MDLH)

The MDLH is defined as the maximum distance (m) from the nearest utilized lotic habitat that each individual turtle was found during the active season. The combination of MDLH with other animal movement measurements, particularly in species that occupy and move through a mosaic of habitats annually, can increase the information content of the home range estimation (Vokoun 2003). Understanding how wood turtles move through their home range during the active season can shape habitat management recommendations and conservation efforts.

MDLH was calculated by measuring the straight-line distance from all upland (terrestrial) turtle locations found during the 2014–2015 active seasons and the nearest utilized lotic habitat. Utilized lotic habitat is defined as flowing water that was never observed dry during the study period, with at least one telemetry location within 10 m of its banks. This included Beaver Creek, the Cedar River, the West Fork of the Cedar River, and a few 3rd order streams associated with each of the above listed water bodies. MDLH was calculated with the Nearest Feature Extension in ArcGIS 10.3 for each individual turtle; means were calculated based on sex, study site, and a combination of sex and study site.

Total Distance Moved (TD)

Each turtles' TD was calculated to determine how far it moved during each active period of 2014 and 2015. In addition, both years were averaged to get a combined active season TD moved. To determine TD, the Euclidean distance between two successive telemetry relocations were calculated in Microsoft Excel using the Pythagorean theorem. TD moved was determined as the sum of all locations found during the active season, including the first and the last hibernation location.

Mean Daily Movement (MDM)

The MDM is well suited for comparing aquatic turtle movements (Ouellette et al., 2011). MDM was calculated by dividing TD by the total number of days the animal was radio-tracked, not including hibernation days during 2014–2015. This measurement includes all active season observations, including aquatic and terrestrial relocations. In addition, 2014 MDM and 2015 MDM were determined for each individual with at least 20 locations within that years' active season.

Maximum Distance Between Relocations (MDR)

MDR was calculated for each individual turtle by finding the Euclidean distance between two successive telemetry relocations. This was done in Microsoft Excel using the Pythagorean theorem, and then dividing by the number of days between successive relocations. The maximum mean was reported in m per day (d), and total days between relocations. This calculation compares important temporal periods (those periods of time in which turtles move great distances in a short period of time). The higher the MDR, the more susceptible turtles may be to mortality events as they may have a higher likelihood of coming in contact with automobiles or agricultural equipment (Samure and Bider 1998).

Statistical Analysis

All data were analyzed with RStudio (Version 0.98.501; RStudio, Inc.). A two-way ANOVA test was used to compare the mean home ranges (LHR, SHR, 100% MCP, 95% MCP and 50% MCP) and movement variables (MDLH, MDM, MDR, and TD) between males, females, and juveniles, and between sites, with significance level for all statistical analysis set at alpha = 0.05. In addition, Tukey's HSD was used to compare which sexes differed significantly from one another amongst the five home range types, and four movement variables.

A paired two-tailed t-test was used to compare individual annual 95% MCP home ranges between 2014 and 2015, with the significance level for all statistical analysis set at alpha =0.05. A two-way ANOVA test for significance was completed for percentage of home range overlap between sites (BH and BC), and between sexes.

I analyzed my data using multivariate linear regression to evaluate the influence of seven variables (body mass, SCL, sex, injuries, total locations, age, and study site) on the sizes of five home range types in Iowa. My initial hypothesis was that home range size and movement in wood turtles would be correlated to the size of turtles (SCL, mass) and to the extent of their injuries. To evaluate this, multiple linear regression was used for each home range and movement type using predictors with significant P-values from the tests described above to determine what factors impact the home range size and movements of Iowa wood turtles.

CHAPTER 3

RESULTS

Age Structure

The 93.8% of the 128 wood turtles (84 BC, 44 BH) captured from 2003–2015 were adults >14 years old (Figure 7). Only 8 juveniles or hatchlings were captured at either location over 13 years of surveys. Overall, more females (68) were captured than males (52). While sex ratios were similar in Black Hawk County, 21 females to 22 males, they skewed towards females in Butler County, 47 females to 30 males. The age structure of the 47 radio-tracked turtles in this study (42 adults, 5 juveniles) was similar to what has been observed overall in both populations. (Tables 3 and 4).

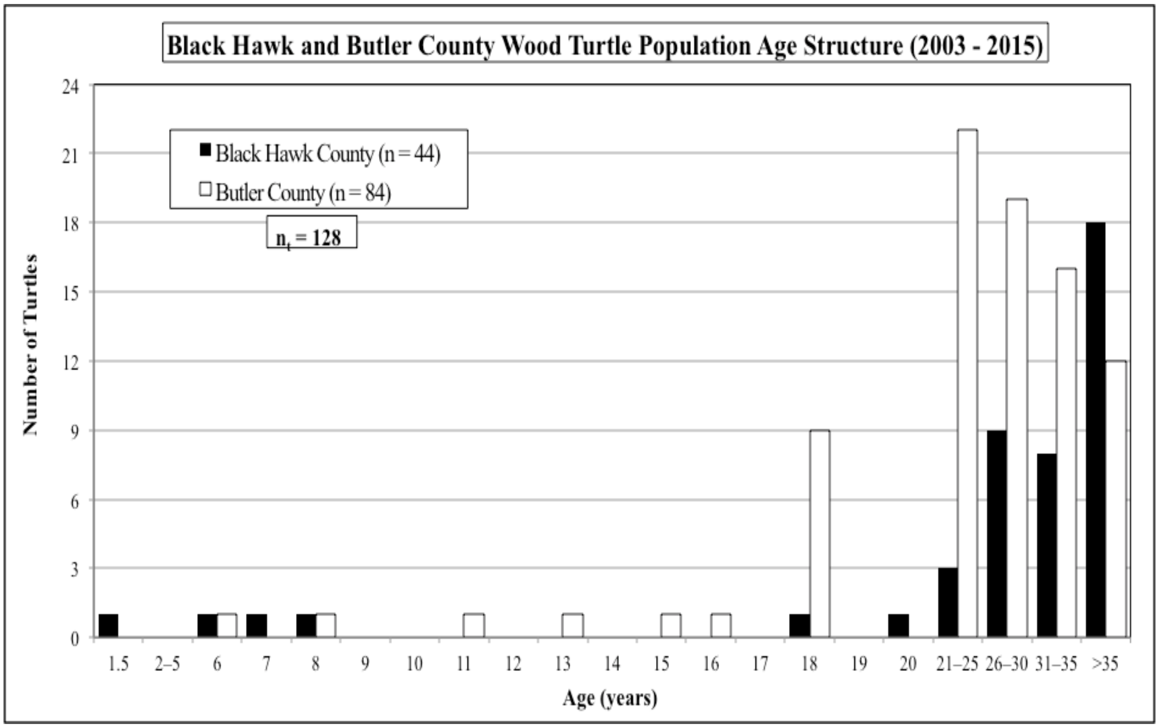

Figure 7. Age at first capture of all individual wood turtles captured from BC and BH, Iowa during studies conducted from 2003–2015.

For the current study, five wood turtles (2 females, 3 males) were captured at BH during visual encounter surveys. Of these, four (2 females, 2 males) were used for radio telemetry surveys. At BC, 23 wood turtles (12 females, 8 males, 3 juveniles) were captured during visual encounter surveys, and 17 (8 females, 6 males, 3 juveniles) were used for radio telemetry surveys. The other 26 turtles that were used in radio telemetry surveys for this study had either been captured during a previous study, or were turtles that were continuously tracked from the BH study site.

Mortality

During studies conducted at BH from 2009–2015, 12 individuals were found deceased, either through predation, drowning or other unknown causes. During this time, one mortality was observed from 2009–2012, while eleven mortality events were observed during 2013–2015. All mortalities observed at BH were from turtles that were previously marked or had been being used for radio telemetry surveys, signifying that they had perished at some point during studies. The majority of mortality events at BH were caused from predation.

During studies conducted at BC from 2003–2015, a total of 13 individuals were found deceased, the majority to predation or other unknown causes. Mortality was observed in seven individuals at BC from 2003–2013, five of which were found to have perished before first observation, making it difficult to determine what had killed the turtle. Two individuals used for radio telemetry surveys at BC during this time were found deceased, presumably from a predator due to injuries observed. During surveys conducted in 2014 and 2015, six mortality events were observed, four of which occurred before first observation, making it difficult to determine the cause of death. In addition, two individuals that were used for radio telemetry surveys were thought to have been killed by predators, because of injuries suffered between radio telemetry events.

Level of Injury

Only the 45 wood turtles (22 females, 18 males, and 5 juveniles) used for home range analysis were given a numerical injury index. Thirty-two turtles (71%) from both sites had either no injuries or slight superficial injuries (stub tail). Compared to BC (18 individuals; 75%), turtles at BH had a lower percentage of the population with no or superficial injuries (14 individuals; 66.7%) and more cases (5) of severe injuries (e.g., missing feet, eyes, limbs) (Table 2). Only one turtle, IA045, had a severe injury (missing limb) at BC (Table 3).

Home Range

Between February 2014 and November 2015, 47 wood turtles (23 females, 19 males, and 5 juveniles) were used for radio telemetry surveys at BC and BH. One female from BC (IA003) and one male from BH (IA077) were not included in the home range and movement analysis due to insufficient number of relocations (n=19 and n=15, respectively). IA003 was last located on 2 September 2014, after which it had been apparently struck by farming equipment in a grass field used for hay. Only a transmitter could be located in the freshly mowed field near the locations it had previously been located. IA077 was not relocated through a large portion of the 2014–2015 active seasons, potentially due to issues with the transmitter signal.

Table 2. Variables included in multiple linear regression analysis of BH turtle home range size. Number of locations is the number of times a turtle was located outside of hibernation during radio telemetry surveys in 2014–2015. Mass, SCL, age, and injury notes were determined at first capture.

Turtle No.	Sex	No. of locations	Mass	SCL	Age	Injuries - Injury Score
IA061	Female	59	1042	192.9	21–25	None - 0
IA064	Female	59	778	183.8	8–10	None - 0
IA067	Female	45	1062	196.7	26–30	Stub tail - 1
IA073	Female	57	1072	187.4	35+	Missing left eye, stub tail - 3
IA081	Female	60	1026	178.8	35+	None - 0
IA084	Female	58	1134	189.6	26–30	Stub tail - 1
IA094	Female	34	1061.7	182.5	26–30	Stub tail - 1
IA119*	Female	39	967.4	186.8	21–25	None - 0
IA122*	Female	27	1090.3	203.2	20	None - 0
IA085	Juvenile	27	882.7	187.6	10	Stub tail - 1
IA087	Juvenile	59	625.3	169.4	8	None - 0
IA066	Male	51	1040	196.8	26–30	Stub tail -1
IA069	Male	20	1004	190.2	35+	Lower jaw split - 2
IA076	Male	53	1142	202.4	31–35	None - 0
IA082	Male	42	986	192.2	35+	One claw missing - 1
IA086	Male	32	1144	203.4	35+	Stub tail - 1
IA092	Male	44	976	188.2	35+	Missing front and back right foot, stub tail - 4
IA095	Male	31	998.3	203.4	35+	Missing right front leg, stub tail - 4
IA098*	Male	65	1030.9	203.7	18–20	None - 0
IA111*	Male	53	957.6	187.8	35+	Missing right front foot - 2
IA116*	Male	40	896.5	191.2	35+	Missing right arm at elbow, missing claws on left hand- 4

*** Turtles first captured during the current study (2014 or 2015)**

Excluding hibernation locations, 24 turtles (13 females, 8 males, and 3 juveniles) at BC were located on average 55.08 times (±19.45 SD; range =21–76 locations; Table 4) for periods of 147–588 days ($\bar{x}$=457.52 ±160.37 SD). At BH, 21 turtles (9 females, 10 males, and 2 juveniles) were located on average, 45.48 times (±13.92 SD; range =20–65 locations; Table 4) for periods of 222–686 days ($\bar{x}$=525.95 ±183.59 SD; Figure 8 and 9). Turtles were located weekly during hibernation to determine the exact date when the active season began and ended for each year. Only the first and last location during hibernation for each year were used in home range calculations so as to not skew results.

Table 3. Variables determined at first capture included in multiple linear regression analysis of BC turtle home range size. Number of locations is the number of times a turtle was located outside of hibernation during radio telemetry surveys in 2014–2015.

Turtle No.	Sex	No. of locations	Mass (g)	SCL (mm)	Age	Injuries – Injury Score
IA005	Female	29	791.5	175.0	31–35	Predator scratch/teeth mark, stub tail - 1
IA040	Female	64	1101.3	190.3	35+	Stub tail - 1
IA059	Female	76	884.7	182.4	31–35	Stub tail - 1
IA060	Female	73	1200.2	195.1	35+	Stub tail, chunk out of marginal scute -2
IA083	Female	72	1000	188.8	31–35	Stub tail - 1
IA103*	Female	67	972.1	180.9	26–30	Stub tail -1
IA104*	Female	69	987.6	189.0	31–35	Chunk out of marginal scute -1
IA106*	Female	68	937.7	188.1	14–15	Stub tail -1
IA108*	Female	56	959.6	186.9	35+	None - 0
IA110*	Female	62	1018.6	185.0	21–25	Stub tail, missing claw on hind foot - 2
IA112*	Female	64	1175.1	195.5	31–35	Stub tail, bone sutures visible - 2
IA120*	Female	35	940	180.0	26–30	Stub tail - 1
IA121*	Female	23	1154	196.4	30+	Stub tail - 1
IA114*	Juvenile	60	803.7	176.7	11	Stub tail - 1
IA118*	Juvenile	40	871.1	189.0	12–14	None - 0
IA129*	Juvenile	21	571.41	166.1	8–10	None - 0
IA029	Male	73	1090	190.5	31–35	None - 0
IA045	Male	66	979.2	189.5	35+	Missing right front foot, stub tail, carapace and bridge heavily damaged - 5
IA102*	Male	70	1008	193.1	35+	Stub tail - 1
IA105*	Male	66	1140.1	206.9	15–20	Stub tail - 1
IA107*	Male	40	1070.4	194.1	35+	Stub tail - 1
IA115*	Male	59	1067	199.1	35+	Missing 3 claws on right front foot - 1
IA117*	Male	41	1056.7	190.5	30+	Small amount of bone exposed - 1
IA123*	Male	28	953	195.8	18	None - 0

*** Turtles first captured during the current study (2014 or 2015)**

Linear Home Range

The only significant difference in sizes of LHR of wood turtles in this study was between sexes ($F_{39,2}$=10.44, p-value <0.001); while study site ($F_{39,1}$=0.48, p=0.49) and sexes between study sites ($F_{39,2}$=0.64, p-value=0.53) had no significant difference. Male LHR ($\bar{x}$=1.17 km ±0.48 SD, n=18) was significantly larger than females (p-value <0.001, $\bar{x}$=0.61 km ±0.40 SD, n=22) and juveniles (p-value=0.007, $\bar{x}$=0.49 km ±0.11 SD, n=5). Male LHR was nearly twice the length of both females and juveniles (Table 4 and 5; Figure 8).

Table 4. Total number of individual turtle locations found during the 2014–2015 study. For each turtle 100% minimum convex polygon (MCP; in ha), 95% MCP (in ha), 50% (in ha), linear home range (LHR; in km), and stream home ranger (SHR; in km) were calculated.

Turtle No.	Sex	Study Site	No. of locations	100% MCP	95% MCP	50% MCP	LHR	SHR
IA061	Female	BH	59	9.31	5.95	0.59	0.80	0.90
IA064	Female	BH	59	23.24	16.93	6.78	1.80	2.28
IA067	Female	BH	45	6.62	5.60	0.95	1.40	1.62
IA073	Female	BH	57	10.67	6.08	0.53	0.94	1.09
IA081	Female	BH	60	15.57	3.20	0.89	0.52	0.53
IA084	Female	BH	58	5.79	4.76	1.01	0.50	0.50
IA094	Female	BH	34	2.69	1.84	0.51	0.43	0.48
IA119	Female	BH	39	1.66	1.52	0.12	0.20	0.20
IA122	Female	BH	27	1.92	1.63	0.44	0.20	0.19
IA085	Juvenile	BH	27	4.60	4.06	0.35	0.54	0.50
IA087	Juvenile	BH	59	5.25	3.71	0.49	0.37	0.35
IA066	Male	BH	51	26.64	22.98	7.40	1.46	1.69
IA069	Male	BH	20	12.14	10.34	4.78	1.26	1.51
IA076	Male	BH	53	32.42	27.55	3.93	1.40	1.65
IA082	Male	BH	42	11.77	8.71	4.17	1.09	1.48
IA086	Male	BH	32	12.66	9.91	1.02	0.84	1.08
IA092	Male	BH	44	93.69	80.56	7.47	2.45	3.25
IA095	Male	BH	31	3.39	2.99	0.32	0.55	0.59
IA098	Male	BH	65	8.66	3.71	0.74	0.73	0.77
IA111	Male	BH	53	25.65	25.47	1.56	1.21	1.65
IA116	Male	BH	40	8.41	7.89	1.73	0.52	0.52
IA005	Female	BC	29	16.15	14.58	3.42	0.65	0.79
IA040	Female	BC	64	16.89	14.93	0.58	1.24	1.43
IA059	Female	BC	76	2.86	2.51	0.53	0.44	0.26
IA060	Female	BC	73	8.80	4.03	1.16	0.33	0.35
IA083	Female	BC	72	3.08	2.19	1.03	0.33	0.19
IA103	Female	BC	67	9.44	8.56	2.31	0.45	0.77
IA104	Female	BC	69	4.45	3.98	0.82	0.36	0.49
IA106	Female	BC	68	7.03	4.93	2.43	0.49	0.67
IA108	Female	BC	56	6.78	6.71	0.49	0.41	0.25
IA110	Female	BC	62	7.27	1.77	0.46	0.34	0.50
IA112	Female	BC	64	10.47	9.09	1.94	0.49	0.52
IA120	Female	BC	35	11.85	9.84	0.49	0.56	0.78
IA121	Female	BC	23	8.46	7.06	3.11	0.61	0.73
IA114	Juvenile	BC	60	11.03	10.89	3.09	0.52	0.79
IA118	Juvenile	BC	40	6.16	5.35	1.55	0.63	0.72
IA129	Juvenile	BC	21	2.65	1.50	0.06	0.38	0.47
IA029	Male	BC	73	24.53	15.80	2.86	1.51	2.22
IA045	Male	BC	66	20.07	17.38	4.17	1.06	1.45
IA102	Male	BC	70	40.42	31.74	8.18	1.32	2.05
IA105	Male	BC	66	37.44	37.14	32.57	1.21	1.94
IA107	Male	BC	40	38.99	25.13	9.16	1.63	2.33
IA115	Male	BC	59	11.35	9.86	1.25	0.98	1.29
IA117	Male	BC	41	4.83	3.40	1.13	0.45	0.61
IA123	Male	BC	28	31.32	31.24	5.26	1.47	2.10
Total Mean			**50.6**	**14.78**	**11.89**	**2.97**	**0.83**	**1.03**

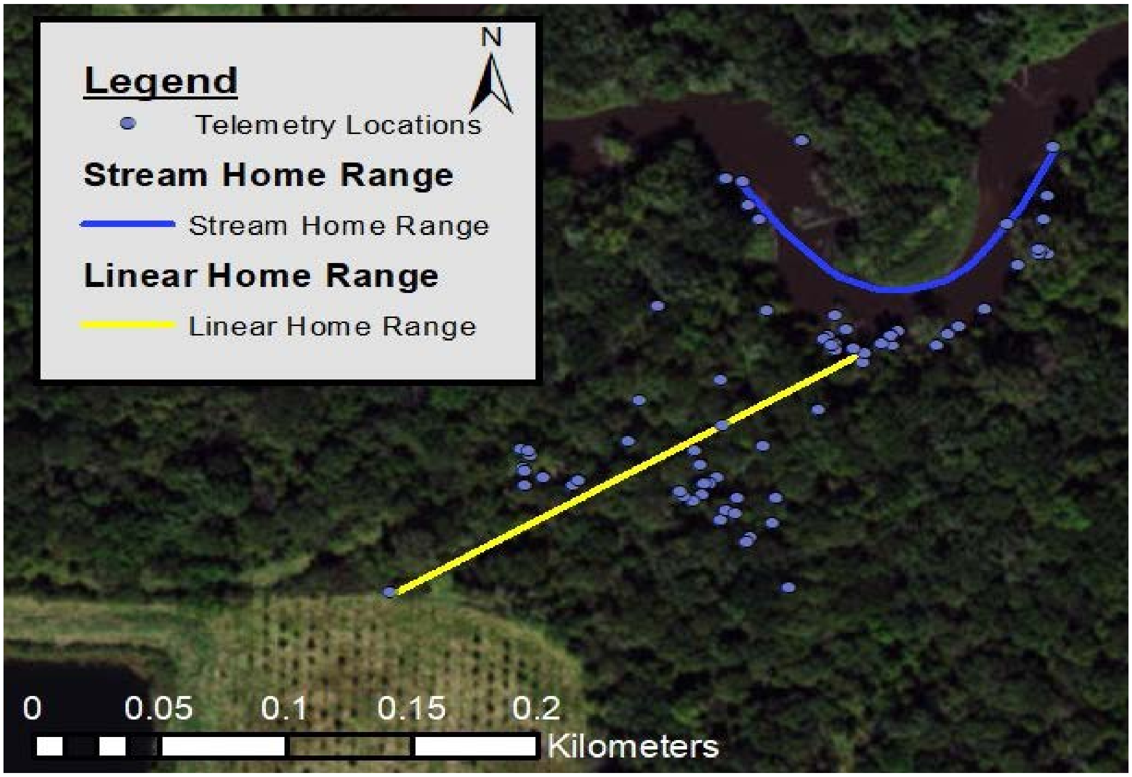

Figure 8. A representative example of wood turtle linear home range (LHR) and stream home range (SHR) calculated in this study. These are the LHR and SHR for female IA083 during 2014–2015 at the Butler County (BC) study site.

Table 5. Mean MCP home ranges (100%, 95%, and 50%) in hectares, linear home range (LHR) and stream home range (SHR) in km, plus standard deviation of female, male, and juvenile wood turtles from the BC and BH study sites during 2014 and 2015.

	No. of Individuals	**100% MCP (ha)**	**95% MCP (ha)**	**50% MCP (ha)**	**LHR (km)**	**SHR (km)**
Female	22	8.68 ±5.50	6.26 ±4.49	1.39 ±1.51	0.61 ±0.40	0.71 ±0.52
Male	18	24.69^{+}±21.04	20.65^{+}±18.42	5.43*±7.31	1.17*±0.48	1.57*±0.71
Juvenile	5	5.94 ±3.12	5.10 ±3.52	1.11 ±1.24	0.49 ±0.11	0.56 ±0.18
BC	24	14.26 ±11.79	11.65 ±10.22	3.66 ±6.59	0.74 ±0.43	0.99 ±0.68
BH	21	15.37 ±19.95	12.16 ±17.53	2.18 ±2.49	0.91 ±0.57	1.09 ±0.77

*Significant difference between males and females, and males and juveniles

$^{+}$Significant difference between males and females only

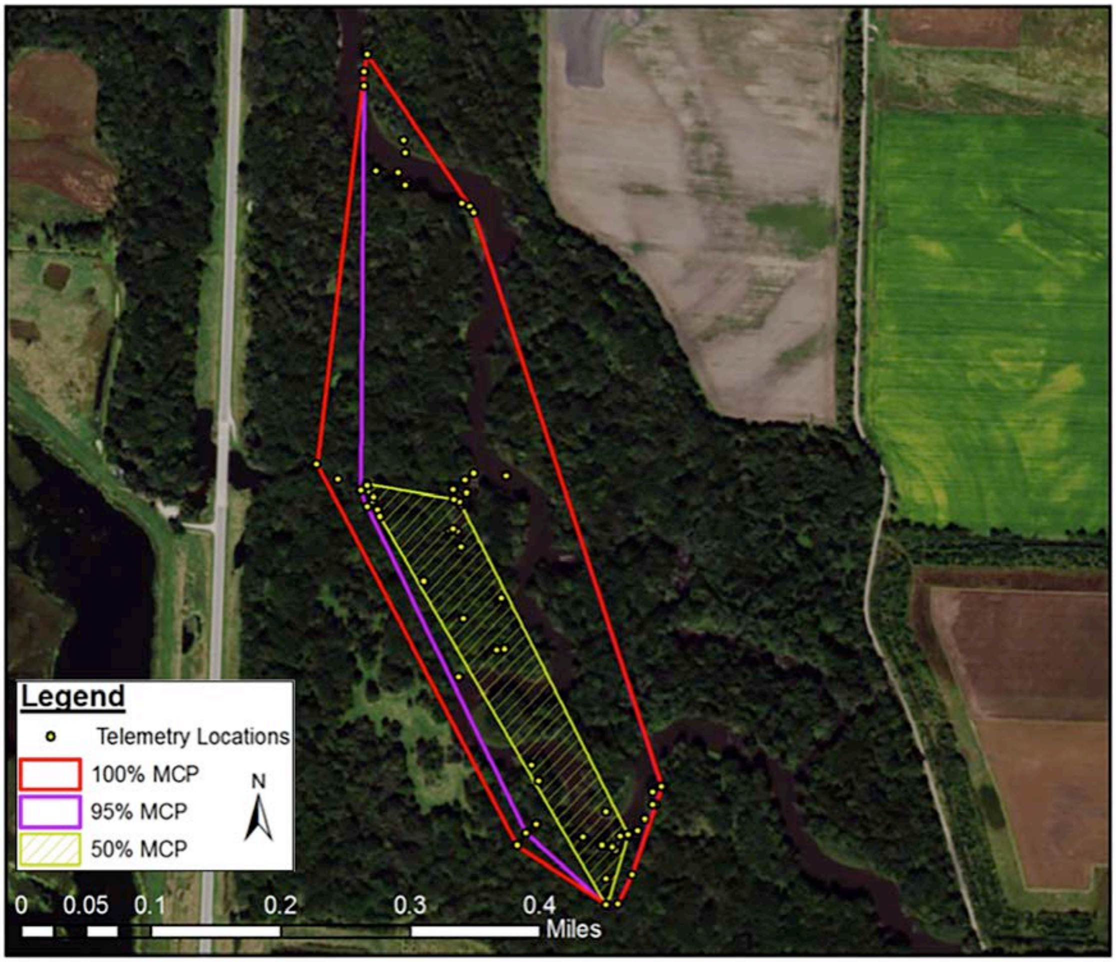

Figure 9. A representative example of wood turtle home ranges calculated for this study. These are the 100%, 95% and 50% MCP home ranges for male IA045 during 2014–2015 at the Butler County (BC) study site.

Among all turtles, there was no significant difference in LHR between pooled sexes of BH and BC turtles ($F_{39,2}$ =0.48, p-value=0.49). BH turtles had slightly larger LHR ($\bar{x}$=0.91 km ±0.57 SD, n=21) than BC turtles ($\bar{x}$=0.74 km ±0.43 SD, n=24). There was also no significant difference in LHR of male, female, and juvenile wood turtles between BH and BC (male p-value=0.99; female p-value=0.78, and juveniles p-value=0.99). Male LHR between sites was nearly identical (BH $\bar{x}$=1.15 km ±0.57 SD, n=10; BC $\bar{x}$=1.20 km ±0.133 SD, n=8) while females were somewhat similar (BH $\bar{x}$=0.754 km ±0.182 SD, n=9; BC $\bar{x}$=0.515 km ±0.38 SD, n=13). Juvenile LHR was also nearly identical between sites (BH $\bar{x}$=0.45 km ±0.12 SD, n=2; BC $\bar{x}$=0.51 km±0.13 SD, n=3), but the sample size was limited (Table 6).

Table 6. Mean MCP home ranges (100%, 95%, and 50%), linear home range (LHR), stream home range (SHR) and standard deviation of wood turtles by sex from the Butler County (BC) and Black Hawk County (BH) study sites during 2014 and 2015.

		No. of Individuals	**100% MCP**	**95% MCP**	**50% MCP**	**LHR**	**SHR**
BH	**Female**	9	8.61 ±7.13	5.28 ±4.75	1.31 ±2.07	0.75 ±0.55	0.87 ±0.70
	Male	11	22.12 ±26.37	18.79 ±23.06	3.12 ±2.66	1.15 ±0.57	1.42 ±0.79
	Juvenile	2	4.93 ±0.46	3.88 ±0.25	0.42 ±0.10	0.45 ±0.12	0.43 ±0.11
BC	**Female**	13	8.73 ±4.36	6.94 ±4.36	1.44 ±1.07	0.52 ±0.24	0.59 ±0.33
	Male	8	26.12 ±13.29	21.46 ±11.77	8.07 ±10.32	1.20 ±0.38	1.75 ±0.59
	Juvenile	3	6.61 ±4.21	5.92 ±4.72	1.57 ±1.51	0.51 ±0.13	0.66 ±0.17

Stream Home Range

The only significant difference in sizes of SHR of wood turtles in this study was between sexes ($F_{39,2}$=12.55, p-value <0.001); while study site ($F_{39,2}$=0.02, p-value=0.88) and sexes between study sites ($F_{39,2}$=1.37, p-value=0.27) had no significant difference. Male SHR ($\bar{x}$=1.57 km ±0.71 SD, n=18) was significantly larger than females (p-value<0.001, $\bar{x}$=0.71 km ±0.52 SD, n=22) and juveniles (p-value=0.004, $\bar{x}$=0.56 km

±0.18 SD, n=5). Male SHR was nearly double the length females, and three times as large as juveniles (Table 4 and 5; Figure 8).

Among all turtles, there was no significant difference in SHR between BH and BC turtles ($F_{39,2}$=0.02, p-value=0.88). BH turtles on average had slightly larger SHR, 1.09 km (±0.77 SD, n=21), than BC turtles, 0.99 km (±0.68 SD, n=24). There was also no significant difference in SHR of male, female and juvenile wood turtles between BH and BC (male p-value=0.84; female p-value=0.89; juvenile p-value=0.99). Male SHR at BC ($\bar{x}$=1.75 km ±0.59 SD, n=8) was slightly larger than males at BH ($\bar{x}$=1.42 km ±0.79 SD, n=10), while female SHR was slightly larger at BH ($\bar{x}$=0.87 km ±0.70 SD, n=9), than at BC ($\bar{x}$=0.59 km ±0.33 SD, n=13) (Table 6).

100% MCP Home Range

When data was pooled for both study sites, there was a significant difference in 100% MCP home ranges between sexes of wood turtles ($F_{39,2}$=7.11, p-value=0.002), between males and females (p-value=0.003), and between males and juveniles (p-value=0.04). Male 100% MCP was significantly larger than female and juveniles with males averaging 24.69 ha (±21.04 SD, n=18), nearly three times as large as the average of females, 8.68 ha (±5.50 ha, n=22), and four times as large as that of juveniles ($\bar{x}$=5.94 ±3.12 ha, n=5) (Tables 5 and 6).

Among all turtles, there was no significant difference in 100% MCP home ranges between BH and BC turtles ($F_{39,2}$=0.09, p-value=0.77). BH and BC turtles had similar average 100% MCP home ranges (BH=15.37 ha ±19.95 SD, n=21; BC=14.26 ha ±11.79 SD, n=24) (Table 5). There was also no significant difference in 100% MCP home ranges of male, female, and juvenile wood turtles between BH and BC (males p-value=0.99; females p-value=0.99; juveniles p-value=0.99). The average 100% MCP home ranges of males at BC ($\bar{x}$=26.12 ha ±13.29 SD, n=8) and females at BC ($\bar{x}$=8.73 ha ±4.36 SD, n=12) were slightly larger than BH males ($\bar{x}$=22.12 ha ±26.37 SD, n=10) and females ($\bar{x}$=8.61 ha ±7.13 SD, n=9) (Table 6).

95% MCP Home Range

When data was pooled for both study sites, there was significant difference in the size of 95% MCP home ranges between sexes ($F_{39,2}$=7.26, p-value=0.002), with male and female wood turtles (p-value=0.003), and male and juveniles (p-value=0.05). There was no significant difference in 95% MCP home range between female and juveniles (p-value=0.98). Males had significantly larger average 95% MCP home ranges, with 20.65 ha (±18.42 ha, n=18), nearly three times as large as females, 6.26 ha (±4.49 SD, n=22), and four times as large as juveniles ($\bar{x}$=5.10 ha ±3.52 SD, n=5) (Tables 5 and 6).

Among all turtles, there was no significant difference in 95% MCP home ranges between BH and BC turtles ($F_{39,1}$=0.18, p-value=0.67). BH turtles had slightly larger 95% MCP home ranges, 12.16 ha (±17.53 SD, n=21), than BC turtles, 11.65 ha (±10.22 SD, n=24) (Table 4). There was also no significant difference in 95% MCP home ranges of male, female, and juvenile wood turtles between BH and BC (males p-value=0.99; females p-value=0.99; juveniles p-value=0.99). The average 95% MCP home range of males at BC was 21.46 ha (±11.77 ha, n=8) while females at BC averaged 6.94 ha (±4.36 SD, n=13), both which were slightly larger than the average 95% MCP home range of BH males ($\bar{x}$=18.79 ha ±23.06 SD, n=10) and females ($\bar{x}$=5.28 ±4.75 SD, n=9) (Table 6).

50% MCP Home Range

When data was pooled from both study sites, the only significant difference in 50% MCP home range comparisons was between male and female wood turtles ($F_{39,2}$=4.09, p-value=0.02). There was no significant difference in size of 50% MCP home range between male and juveniles (p-value=0.18) or between female and juveniles (p-value=0.99) (Tables 5 and 6).

Among all turtles, there was no significant difference in 50% MCP home ranges between BH and BC turtles ($F_{39,1}$=2.22, p-value=0.15). On average, BC turtles had slightly larger 50% MCP, 3.66 ha (±6.59 SD, n=24) than BH turtles, 2.18 ha (±2.49 ha, n=21). There was also no significant difference in 50% MCP home ranges of male, female, and juvenile wood turtles between BH and BC (males p-value=0.29; females p-value=0.99; juveniles p-value=0.99). 50% MCPs of males at BC ($\bar{x}$=8.07 ha ±10.32 SD, n=8) and females at BC ($\bar{x}$=1.44 ±1.07 ha, n=13) were larger than BH males ($\bar{x}$=3.12 ±2.66 ha, n=10) and BH females ($\bar{x}$=1.31 ±2.07 ha, n=9) (Table 6).

Multiple Linear Regression

Seven criteria were analyzed to determine which factors had a significant influence on home range size of wood turtles: sex, study site, total locations, mass, SCL, age, and injuries. Sex had the greatest significant influence on all five measured home range types; for 100% MCP, LHR, and SHR, sex was the only factor that influenced home range size. The 50% MCP home range was not only significantly influenced by sex (males had the largest 50% MCP; p-value = 0.02), but also by age (older individuals had larger 50% MCP than younger individuals; p-value = 0.04). The 95% MCP home range was not only significantly influenced by sex (p-value = 0.001), but also by injuries (p-value = 0.015).

Site Fidelity

Annual 95% MCP Home Range

To compare the degree of site fidelity of wood turtles, annual 95% MCP home ranges were calculated for 53 individuals (29 BC and 24 BH turtles) for at least two years over seven years of the study period (2004, 2005, 2011–2015). At BC, home ranges of 16 females, 11 males, and 2 juveniles were calculated over a 4-year period (2004, 2005, 2014, and 2015), while at BH, home ranges of 11 females, 12 males, and 1 juvenile were calculated over a 5-year period (2011–2015). All individuals included in the site fidelity results of this study had at least two years of annual home range data (≥20 locations in one year). A greater number of annual individual home ranges were calculated at BH (n=75) than BC (n=61), and the overall pooled average annual home range size was slightly smaller at BH (9.00 ha ±9.98 SD) compared to BC (9.20 ha ± 7.29 SD).

Butler County (BC). Mean annual 95% MCP home range of turtles at BC ranged from 11.63 ha (±5.00 SD, n=10) in 2004 to 8.36 ha (±9.35 SD, n=20) in 2014. During 2014 and 2015, mean annual home range size at BC was nearly identical, 8.36 ha (±9.35 SD, n=20) in 2014, and 8.70 ha (±6.96 SD, n=20) in 2015 (Table 7).

The mean annual 95% MCP home range size of females at BC decreased over the life of the study, with the largest in 2004 (11.93 ha ±4.51 SD, n=6), nearly double the average female home range size found during 2014 (5.79 ha ±7.80 SD, n=11) or 2015

Table 7. The 95% minimum convex polygon (MCP) annual home range size of male and female wood turtles in Butler County, Iowa (BC) during the life of the study (2004, 2005, 2014, and 2015), in hectares (ha).

Turtle No.	**Sex**	**95% MCP**			
		2004	**2005**	**2014**	**2015**
IA003	Female	2.95	4.90	28.53	NA
IA004	Female	15.51	14.40	NA	NA
IA005	Female	13.62	7.38	NA	14.45
IA007	Male	18.18	19.52	NA	NA
IA009	Female	13.92	6.01	NA	NA
IA010	Female	12.78	3.82	NA	NA
IA011	Male	8.86	8.92	NA	NA
IA018	Female	12.81	9.73	NA	NA
IA019	Male	14.15	18.06	NA	NA
IA026	Male	3.55	4.79	NA	NA
IA029	Male	NA	6.27	9.21	15.59
IA040	Female	NA	NA	7.44	7.82
IA045	Male	NA	NA	12.96	17.78
IA059	Female	NA	NA	1.93	1.84
IA060	Female	NA	NA	3.77	4.23
IA083	Female	NA	NA	1.92	1.90
IA102	Male	NA	NA	19.70	16.78
IA103	Female	NA	NA	2.07	9.08
IA104	Female	NA	NA	3.18	2.14
IA105	Male	NA	NA	35.02	25.38
IA106	Female	NA	NA	3.73	3.04
IA107	Male	NA	NA	11.03	18.16
IA108	Female	NA	NA	5.87	3.69
IA110	Female	NA	NA	0.38	1.76
IA112	Female	NA	NA	4.89	5.70
IA114	Juvenile	NA	NA	8.21	9.95
IA115	Male	NA	NA	4.76	7.17
IA117	Male	NA	NA	1.41	3.01
IA118	Juvenile	NA	NA	1.22	4.59
Mean Male		11.18	11.51	13.44	14.83
Mean Female		11.93	7.71	5.79	5.06
Overall Mean		11.63	9.43	8.36	8.70

(5.06 ha ±3.99 SD, n=11). The mean annual home range size of females ranged from 2.95–15.51 ha in 2004, 4.90 –14.40 ha in 2005, 1.92–28.53 in 2014, and 2.14–14.45 ha in 2015 (Table 7).

The mean annual 95% MCP home range size of males at BC increased over the study period, with the smallest in 2004 (11.18 ha ±6.36 SD, n=4), and the largest in 2015 (14.83 ha ±7.46 SD, n=7). The mean annual home range size of males ranged from 8.86–18.18 ha in 2004, 4.79–19.52 ha in 2005, 1.41–35.02 ha in 2014, and 3.01–25.38 ha in 2015 (Table 7).

Only two individuals, male IA029 and female IA003 had more than two years of annual home ranges calculated. IA029 was radio tracked in 2005 2014, and 2015 and had the greatest difference in annual home range size of any male, 9.32 ha, between its 2005 and 2015 annual home range. IA003 was tracked in 2004 2005, and 2014 and had the greatest difference in annual home range size of any female, 25.58 ha, between its 2004 and 2014 annual home range. These were also the two turtles with the largest gap between calculated annual home range sizes, 10 years. All other BC turtles had only a one-year difference between calculated annual home range sizes. The greatest difference in home range size between two subsequent years of radio telemetry tracking for females was 8.96 ha (IA010) between 2004 and 2005; for males, it was 9.64 ha (IA105) between 2014 and 2015 (Table 7).

Black Hawk County (BH). On average, annual 95% MCP home ranges were largest for wood turtles at BH during 2014 (10.72 ha ±11.43 SD, n=16), and smallest during 2013 (6.29 ha ±8.97 SD, n=17). During 2012 and 2015, mean wood turtle annual home range size at BC was somewhat similar, 10.10 ha (±9.03 SD, n=18) in 2014, and 9.63 ha (±12.08 SD, n=15) in 2015 (Table 8).

Table 8. The 95% minimum convex polygon (MCP) annual home range size of male and female wood turtles in Black Hawk County, Iowa (BH) during the life of the study (2011–2015), in hectares (ha).

		95% MCP				
Turtle No.	**Sex**	**2011**	**2012**	**2013**	**2014**	**2015**
IA061	Female	0.99	4.04	6.44	5.30	5.28
IA063	Female	4.88	8.37	4.34	NA	NA
IA064	Female	18.90	34.72	33.33	13.07	16.38
IA065	Male	14.51	24.57	NA	NA	NA
IA066	Male	4.54	19.67	7.09	15.68	11.64
IA067	Female	0.88	5.67	1.26	4.49	3.04
IA069	Male	8.11	15.54	5.20	11.53	NA
IA073	Female	NA	11.74	3.63	5.16	4.03
IA074	Female	NA	10.79	1.89	NA	NA
IA075	Female	NA	4.94	4.35	NA	NA
IA076	Male	NA	14.95	25.32	16.98	17.44
IA077	Male	NA	5.81	2.91	NA	5.27
IA081	Female	NA	1.59	0.75	1.40	3.90
IA082	Male	NA	9.81	3.07	8.17	4.28
IA084	Female	NA	3.97	2.53	2.91	3.90
IA086	Male	NA	3.67	1.92	11.16	NA
IA087	Juvenile	NA	NA	NA	1.85	2.72
IA089	Female	NA	1.51	1.02	NA	NA
IA092	Male	NA	0.40	1.84	46.77	49.26
IA098	Male	NA	NA	NA	2.33	2.29
IA111	Male	NA	NA	NA	21.83	12.31
IA116	Male	NA	NA	NA	2.79	2.76
Mean Male		9.05	11.80	6.76	15.24	13.16
Mean Female		6.41	8.73	5.95	5.39	6.09
Overall Mean		7.54	10.10	6.29	10.72	9.63

Mean female annual 95% MCP home range size at BH varied over the course of the study; the largest was observed in 2012 (8.73 ha ±9.78 SD, n=10), nearly double the smallest mean female home range size found, 5.39 ha (±4.05 SD, n=6) in 2014. The mean male annual home range size at BH also varied during the study period, with the smallest recorded in 2013 (6.76 ha ±8.40 SD, n=7), and the largest recorded in 2014 (15.25 ha ±13.43 SD, n=9). Female annual home range size ranged from 0.88–18.90 ha in 2011, 1.51–34.72 ha in 2012, 0.75–33.33 ha in 2013, 1.40–13.07 ha in 2014, and 1.09–16.38 ha in 2015. Male annual home range size ranged from 4.54–14.51 ha in 2011, 3.67–24.57 ha in 2012, 1.84–25.32 ha in 2013, 2.33–46.77 in 2014, and 2.29–49.26 ha in 2015 (Table 8).

One male (IA066) and three females (IA061, IA064, and IA067) had annual home ranges calculated for all five years of radio tracking surveys. Seven individuals (IA069, IA073, IA076, IA081, IA082, IA084, and IA092) had annual home ranges calculated for four of five years of study. The greatest difference in annual home range size in subsequent years of radio tracking for any females was IA064 between 2013 and 2014, whose annual home range was 20.26 ha smaller in 2014. The greatest difference of annual home range size between subsequent years of surveys of any male was IA092 between 2013 and 2014, whose annual home range was 44.93 ha larger in 2014 (Table 8).

2014 and 2015 Comparison

The degree of site fidelity of wood turtles in Iowa was calculated by analyzing the percent overlap of 95% MCP home ranges between 2014 and 2015. During this time nearly every turtle was located at least once a week, and the majority of individuals were found on the same survey day during each week for each site. A similar number of locations were found for each individual in 2014 ($\bar{x}$=26.09; range = 20–37) and 2015 ($\bar{x}$=32.06; range = 20–40) (Table 9).

Table 9. The 95% MCP home range size (ha), total number of telemetry locations, and percentage of home range overlap for wood turtles at BH and BC during 2014 and 2015. Turtles are ordered by study site, sex, then by overlap percentage (smallest to largest).

Turtle No.	**Sex**	**Study Site**	No. of locations		95% MCP		Overlap %
			2014	**2015**	**2014**	**2015**	
IA061	Female	BH	27	32	5.30	5.28	67.35
IA067	Female	BH	25	20	4.49	3.04	67.72
IA081	Female	BH	29	31	1.40	3.90	67.88
IA073	Female	BH	24	33	5.16	4.03	73.31
IA084	Female	BH	27	31	2.91	3.90	85.55
IA064	Female	BH	28	31	13.07	16.38	86.50
IA087	Juvenile	BH	24	35	1.85	2.72	76.64
IA116	Male	BH	20	20	2.79	2.76	23.07
IA092	Male	BH	21	23	46.77	49.26	57.31
IA111	Male	BH	20	33	21.83	12.31	59.49
IA066	Male	BH	25	26	15.68	11.64	74.52
IA082	Male	BH	22	20	8.17	4.28	74.59
IA076	Male	BH	25	25	16.98	17.44	76.73
IA098	Male	BH	30	35	2.33	2.29	77.01
IA104	Female	BC	31	38	3.18	2.14	56.15
IA110	Female	BC	23	39	0.38	1.76	59.65
IA106	Female	BC	29	39	3.73	3.04	61.31
IA103	Female	BC	30	37	2.07	9.08	61.38
IA112	Female	BC	27	37	4.89	5.70	67.03
IA108	Female	BC	24	32	5.87	3.69	70.82
IA059	Female	BC	37	39	1.93	1.84	75.35
IA083	Female	BC	33	39	1.92	1.90	78.81
IA040	Female	BC	28	36	7.44	7.82	83.66
IA060	Female	BC	34	39	3.77	4.23	87.37
IA118	Juvenile	BC	20	20	1.22	4.59	38.81
IA114	Juvenile	BC	23	37	8.21	9.95	83.47
IA107	Male	BC	20	20	11.03	18.16	50.07
IA115	Male	BC	22	37	4.76	7.17	57.06
IA117	Male	BC	20	21	1.41	3.01	67.38
IA102	Male	BC	29	39	19.70	16.78	67.68
IA029	Male	BC	33	38	9.21	15.59	71.95
IA105	Male	BC	27	36	35.02	25.38	81.04
IA045	Male	BC	24	40	12.96	17.78	84.35
	Total Mean		**26.09**	**31.18**	**8.71**	**9.06**	**68.81**

Overall mean home range size was nearly identical in 2014 compared to 2015 (Table 9 and 10). There was no significant difference between individual 2014 and 2015 annual home range size between all turtles (t=0.53, df=32, p-value=0.60), individual 2014 and 2015 annual home range of females (t=1.15, df=15, p-value=0.27), and individual 2014 and 2015 annual home range of males (t=0.24, df=13, p-value=0.81). There were also no significant differences between individual 2014 and 2015 annual home range size between BC turtles (t=1.2, df=17, p-value=0.24) and BH turtles (t=0.76, df=14, p-value=0.46).

Based on the Minta index, average home range overlap (site fidelity) for all turtles between 2014 and 2015 was high ($\bar{x}$=68.82% ±13.99 SD). Females showed the greatest degree of site fidelity, 71.87% (±10.13 SD) overlap while males were slightly lower, with 65.88% (±15.88 SD) overlap. Mean site fidelity was nearly identical at both sites, with BH being slightly higher, 69.77% (±15.29 SD) overlap, than BC, with 68.03% (±13.21 SD) overlap. Female wood turtles at BH had the highest degree of site fidelity ($\bar{x}$=75.30% ±8.39 SD), while juveniles at BC had the lowest degree of site fidelity ($\bar{x}$=61.14% ±31.58 SD) between 2014 and 2015 (Table 10). There was no significant difference in the percentage of home range overlap between males and females (t=1.21, df=21.53, p-value=0.24) and also no significant difference in the percentage of home range overlap between BC and BH turtles (t=0.35, df=27.93, p-value=0.73).

Only two individuals had a home range overlap percentage that was <50%: IA116, a male from BH had 23.07% annual overlap, and IA118 a juvenile from BC exhibited 38.81% overlap. Three turtles had very high site fidelity, nearly identical between each year of surveys: IA084, a female from BH with 85.55% overlap; IA064, a female from BH with 86.50% overlap; and IA060, a female from BC with 87.37% overlap (Table 9).

Table 10. Percentage of home range overlap (site fidelity) for female, male, and juvenile wood turtles at BH and BC during 2014 and 2015. Values are presented by mean percentage of overlap and standard deviation.

	BH	**BC**	**Combined**
Female	75.30 ±9.03	69.19 ±10.81	71.87 ±10.13
Male	63.25 ±19.54	68.50 ±12.20	65.88 ±15.88
Juvenile	76.64	61.14 ±31.58	66.31 ±24.06
Combined	**69.77 ±15.29**	**68.03 ±13.21**	**68.82 ±13.99**

Subsequent Year Comparisons

The degree of site fidelity between subsequent years of radio telemetry surveys was also calculated for those individuals that had two years of radio telemetry data from back to back years. The mean percentage of home range overlap between subsequent years of radio telemetry surveys was compared five times over the course of the seven years in which radio telemetry surveys were conducted (2004 and 2005, 2011 and 2012, 2012 and 2013, 2013 and 2014, and 2014 and 2015) (Table 11). The only years in which both study sites had data to compare subsequent years of radio telemetry surveys was 2014 and 2015.

Site fidelity for wood turtles was highest between 2014 and 2015, in which there was 68.81% (±13.99 SD) overlap in home range (Table 11). The mean percentage of overlap was similar for 2004 and 2005 (65.25% ±11.64 SD). Site fidelity was lowest

Table 11. Mean percentage of home range overlap between subsequent years of radio telemetry surveys at BH and BC from 2004–2005, and 2011–2015.

		2004/2005		2011/2012		2012/2013		2013/2014		2014/2015	
		n	Mean %	n	Mean %	n	Mean %	n	Mean %	n	Mean %
BH	Female	NA	NA	4	62.46	11	43.88	6	48.87	7	75.31
	Male	NA	NA	3	54.30	6	57.88	5	61.41	7	63.25
	Juvenile	NA	NA	NA	NA	NA	NA	NA	NA	1	76.64
	Combined	NA	NA	7	58.96	17	48.82	11	54.57	15	69.77
BC	Female	6	63.60	NA	NA	NA	NA	NA	NA	9	69.19
	Male	4	67.73	NA	NA	NA	NA	NA	NA	7	68.51
	Juvenile	NA	NA	NA	NA	NA	NA	NA	NA	2	61.15
	Combined	10	65.25	NA	NA	NA	NA	NA	NA	18	68.03
Grand Total		**10**	**65.25**	**7**	**58.96**	**17**	**48.82**	**11**	**54.57**	**33**	**68.81**

between 2012 and 2013, in which the overall percentage of overlap between home ranges was 48.82% (±24.16 SD) (Table 11).

At BH, overall site fidelity was categorized as moderate to high based on the Minta index when comparing subsequent years of survey. Female wood turtle site fidelity dropped between 2012 and 2013, and 2013 and 2014, in which the overall percentage of home range overlap fell below 50% (43.88% ±26.84 SD and 48.87% ±26.16 SD; respectively). Site fidelity of female turtles at BH was highest during 2014 and 2015 (75.31% ±8.39 SD) and 2011 and 2012 (62.46% ±5.33 SD) nearly 20% more overlap than the years with the lowest fidelity, 2012 and 2013 (Table 11). For male wood turtles at BH, site fidelity became higher in each subsequent year of surveys, with 2014 and 2015 being the highest with 63.25% (±19.54 SD) home range overlap.

At BC, overall site fidelity was categorized as highly moderate to high based on the Minta index when comparing subsequent years of survey. The percentage of home range overlap in females ranged from 65.18% (±9.87 SD) in 2004 and 2005, to 69.19%

(±11.01 SD) in 2014 and 2015, while males ranged from 65.42% (±17.83 SD) in 2004 and 2005 to 68.51% (±12.20 SD) in 2014 and 2015. Only three individual juvenile wood turtles had enough radio telemetry data to compare site fidelity, all occurring during 2014 and 2015 in which they ranged from 38.81% to 83.47 (Table 10 and 11).

Between 2004 and 2005, turtle IA019 (male, BC) had the lowest degree of site fidelity with 47.79% overlap, while IA007 (male, BC) had the highest (83.45%). For 2011 and 2012, IA066 (male, BH) had the lowest degree of site fidelity (29.46%), while IA065 (male, BH) displayed the highest degree, 71.92% overlap. For 2012 and 2013, IA064 (female, BH) had the highest site fidelity with 81.43% overlap, while IA092 (male, BH) had no overlap of home range between years of survey. In addition, IA092 had no overlap in home range between 2013 and 2014. This individual exhibited an entirely new home range from one year to the next in these three years. IA061 (female, BH) also had almost no overlap (0.57%) in home range between 2013 and 2014. The highest site fidelity between 2013 and 2014 was displayed by IA084 (female, BH) with 75.97% overlap. The weakest site fidelity (38.81% overlap) occurred between 2014 and 2015 for a juvenile from BC, IA118, while the highest was from a female in BC, IA060 (87.37% overlap).

Multi-year Comparisons

The degree of site fidelity between multiple years of radio telemetry surveys was also calculated for those individuals that had at least two years of radio telemetry data, that did not occur in subsequent years of survey. The mean percentage of home range overlap between multiple years of radio telemetry surveys was calculated for ten different time intervals over the course of the seven years in which radio telemetry surveys were conducted, six for BH turtles (2011 and 2013, 2011 and 2014, 2011 and 2015, 2012 and 2014, 2012 and 2015, and 2013 and 2015) (Table 12), and four for BC turtles (2004 and 2014, 2004 and 2015, 2005 and 2014, and 2005 and 2015) (Table 13).

Table 12. Mean percentage of home range overlap between multiple years of radio telemetry surveys at Black Hawk County, Iowa from 2011 to 2015.

	2011/2013		**2011/2014**		**2011/2015**		**2012/2014**		**2012/2015**		**2013/2015**	
	n	**Mean %**	**n**	**Mean %**	**n**	**Mean %**	**n**	**Mean %**	**n**	**Mean %**	**n**	**Mean %**
Female	4	43.92	3	24.04	3	23.61	7	46.73	6	46.87	4	51.66
Male	2	47.55	2	55.27	1	48.43	4	68.76	4	69.30	5	49.23
Total	**6**	**45.13**	**5**	**36.53**	**4**	**29.82**	**11**	**57.05**	**10**	**55.84**	**9**	**50.20**

Table 13. Mean percentage of home range overlap between multiple years of radio telemetry surveys at Butler County, Iowa from 2004 to 2015.

	2004/2014		**2004/2015**		**2005/2014**		**2005/2015**	
	n	**Mean %**	**n**	**Mean %**	**n**	**Mean %**	**n**	**Mean %**
Female	1	55.16	1	74.09	1	58.59	1	63.18
Male	NA	NA	NA	NA	NA	NA	1	0.93
Total	**1**	**55.16**	**1**	**74.09**	**1**	**58.59**	**2**	**32.06**

At BH, the number of individual overlap calculations determined for each interval of time ranged from 4 to 11. The degree of site fidelity between non-subsequent years of study ranged from low to moderate based on the Minta index. Site fidelity for wood turtles at BH was highest between 2012 and 2014, at 57.07% overlap, with overlap between 2012 and 2015 (55.84%) being similar. Site fidelity was lowest between the largest interval of time for turtles tracked at BH 2011 and 2015. Between these years, the overall percentage of overlap between home ranges was 29.82% (Table 12).

There were only four individuals at BC that were tracked over the course of the study that allowed for multiple year comparisons of site fidelity, but these individuals had a greater interval of time between years of study (9 to 11). The degree of site fidelity between non-subsequent years of study ranged from moderate to high based on the Minta index for turtles at BC. Site fidelity was highest (74.09%) between the greatest interval of time between years (2004 and 2015) at BC, however, this calculation represents only one individual, female IA005. It was lowest between home ranges calculated in 2005 and 2015, but this was calculated for only two individuals, male IA029 and female IA005, of which IA029 had almost no overlap between years of study (0.93%) (Table 13).

Movements

Maximum Distance From Lotic Habitat

There was no significant difference in wood turtle MDLH between sexes ($F_{39,2}$=1.91, p-value=0.16), study sites ($F_{39,1}$=0.95, p=value=0.34), or sexes between study sites. Overall female mean MDLH (142.39 m ±62.24 SD, n=22) was greater than that of males (106.44 m±68.23 SD, n=18) and juveniles (101.79 m ±54.63 SD, n=5). Between both sexes, BH turtles averaged a slightly greater MDLH (131.19 m ±58.28 SD, n=21) than BC turtles (116.77 m ±71.50 SD, n=24) (Table 14). The greatest MDLH at BH was from turtle IA095, a male that was found 233.82 m from lotic water, while the greatest MDLH at BC was from turtle IA040, a female that was found 251.68 m from lotic water (Table 14 and 15).

Table 14. Mean total distance moved (TD), maximum distance from lotic habitat (MDLH), mean daily movement (MDM), and maximum distance between subsequent relocations (MDR) of female, male, and juvenile wood turtles from the BC and BH study sites during 2014 and 2015. Values are presented by mean and standard deviation.

	No. of Individuals	TD (km)	MDLH (m)	MDM (m)	MDR (m)
Female	22	2.44 ±0.73	142.39 ±62.24	12.34 ±3.45	106.00 ±83.13
Male	18	5.25^{+} ±2.96	106.44 ±68.23	27.55* ±12.79	185.08* ±115.42
Juvenile	5	2.24 ±0.37	101.80 ±54.63	16.26 ±5.83	69.75 ±32.03
BC	24	3.45 ±2.30	116.77 ±71.50	20.66 ±11.51	129.65 ±85.35
BH	21	3.56 ±2.45	131.19 ±58.28	16.81 ±10.69	138.12 ±120.87

*Significant difference between males and females, and males and juveniles
$^{+}$Significant difference between males and females only

Mean Daily Movement

For MDM there was a significant difference between wood turtle sexes ($F_{39,2}$=17.76, p-value <0.001), with males moving significantly farther daily on average than females (p-value <0.001) and juveniles (p-value=0.02). Males averaged a greater MDM (27.55 m ±12.79 SD, n=18), nearly twice that of females (12.34 m ±3.45 SD, n=22) and juvenile turtles (16.26 m ±5.83 SD, n=5). Turtles at BC exhibited a greater MDM (20.66 m ±11.51 SD, n=24) than BH turtles (16.81 m±10.69 SD, n=21) (Figure 10; Table 14 and 15).

Table 15. Total number of individual turtle locations found during 2014–2015. Locations only include the first and last known hibernation locations during each year. For each turtle, total distance moved (TD), maximum distance from lotic habitat (MDLH), mean daily movement (MDM), and maximum distance between subsequent relocations (MDR) were calculated.

Turtle No.	Sex	Study Site	No. of locations	TD (km)	MDLH (m)	MDM (m)	MDR (m)
IA061	Female	BH	59	2.71	171.71	11.86	44.09
IA064	Female	BH	59	3.83	88.00	17.41	326.59
IA067	Female	BH	42	1.45	115.26	10.84	50.39
IA073	Female	BH	57	3.09	115.76	14.41	106.16
IA081	Female	BH	60	3.27	207.26	15.33	261.73
IA084	Female	BH	58	2.71	207.08	12.72	169.6
IA094	Female	BH	34	1.52	75.02	6.74	56.37
IA119	Female	BH	39	1.17	80.75	4.90	25.4
IA122	Female	BH	27	1.90	148.10	8.54	24.39
IA085	Juvenile	BH	27	1.91	86.58	11.03	37.05
IA087	Juvenile	BH	59	2.23	178.11	11.50	60.64
IA066	Male	BH	51	10.07	111.04	45.06	476.64
IA069	Male	BH	20	3.85	31.04	22.11	106.87
IA076	Male	BH	53	10.00	212.43	46.43	232.45
IA082	Male	BH	38	3.27	168.73	15.53	287.34
IA086	Male	BH	32	2.94	132.94	14.08	75.43
IA092	Male	BH	34	5.83	98.81	24.88	230.62
IA095	Male	BH	31	2.59	233.82	13.10	64.28
IA098	Male	BH	65	3.36	134.22	16.40	79.12
IA111	Male	BH	53	3.57	137.42	18.86	124.3
IA116	Male	BH	30	1.08	21.00	11.20	61.01
IA005	Female	BC	29	2.95	242.12	17.06	185.92
IA040	Female	BC	64	3.70	251.68	17.63	54.64
IA059	Female	BC	76	1.78	124.63	8.68	66.91
IA060	Female	BC	73	2.67	207.89	13.27	113.7
IA083	Female	BC	72	2.17	173.70	11.09	107.52
IA103	Female	BC	67	2.41	137.67	12.27	63.7
IA104	Female	BC	69	2.44	32.15	12.12	57.21
IA106	Female	BC	68	2.24	114.30	11.54	85.25
IA108	Female	BC	56	2.75	98.00	15.08	50.51
IA110	Female	BC	62	1.35	97.27	7.72	77.25
IA112	Female	BC	64	2.47	114.54	13.20	260.86
IA120	Female	BC	35	3.06	245.71	15.15	62.35
IA121	Female	BC	23	2.05	83.87	13.96	81.53
IA114	Juvenile	BC	60	2.63	132.83	14.41	84.24
IA118	Juvenile	BC	28	1.85	74.10	24.68	117.81
IA129	Juvenile	BC	21	2.60	37.36	19.67	48.99
IA029	Male	BC	73	6.50	93.83	31.33	109.13
IA045	Male	BC	66	6.18	71.68	31.56	213.1
IA102	Male	BC	70	9.18	88.63	44.31	299.76
IA105	Male	BC	66	9.48	218.04	47.61	252.84
IA107	Male	BC	25	NA	28.38	40.86	337.12
IA115	Male	BC	59	4.65	57.35	26.05	178.48
IA117	Male	BC	32	1.29	24.64	14.59	68.25
IA123	Male	BC	28	5.47	51.99	31.98	134.63
Total Mean			**49.2**	**3.50**	**123.50**	**18.86**	**133.60**

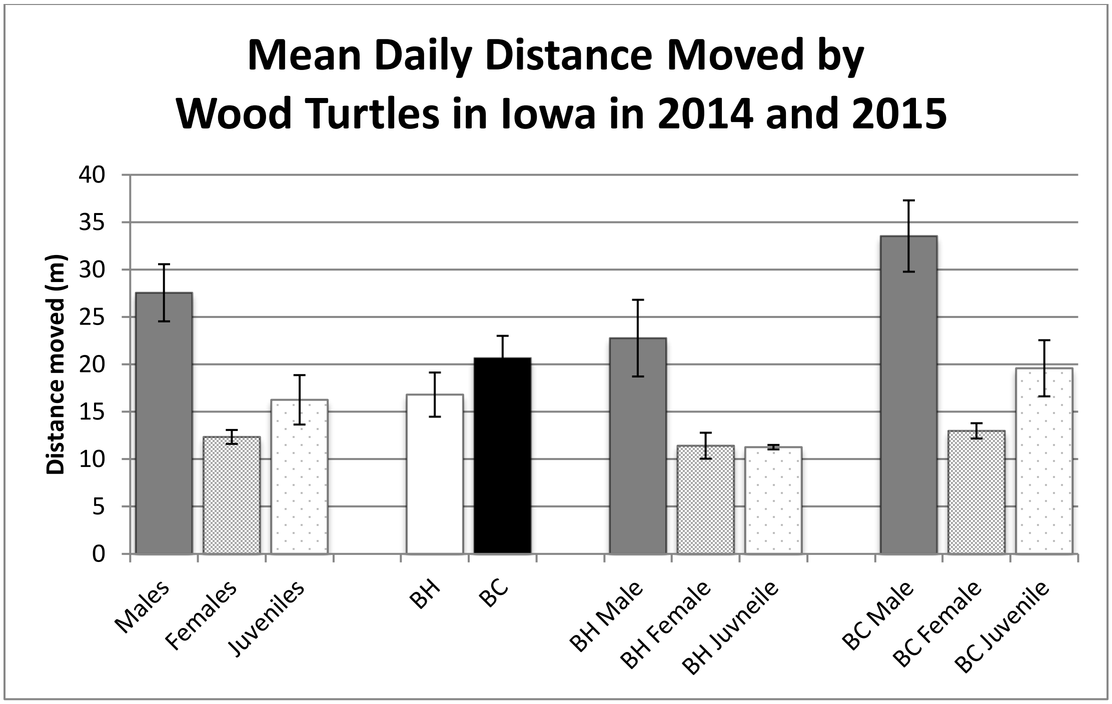

Figure 10. Mean daily distance moved (MDM) in meters of wood turtles in Iowa during 2014 and 2015. MDM's were averaged for each study site (BH and BC), each sex, and each sex at each study site.

Table 16. Mean total distance moved (TD), maximum distance from lotic habitat (MDLH), mean daily movement (MDM), and maximum distance between subsequent relocations (MDR) of wood turtles by sex from the BC and BH study sites during 2014 and 2015.

		No. of Individuals	TD (km)	MDLH (m)	MDM (m)	MDR (m)
BH	**Female**	9	2.41 ±0.93	134.33 ±62.24	11.42 ±4.11	118.30 ±110.76
	Male	10	4.66 ±3.07	128.15 ±68.23	22.77 ±12.79	173.81 ±133.98
	Juvenile	2	2.07 ±0.37	132.35 ±54.63	11.27 ±0.33	48.85 ±16.68
BC	**Female**	13	2.46 ±0.60	147.96 ±70.07	12.98 ±2.91	97.49 ±61.01
	Male	8	6.11 ±2.79	79.32 ±61.42	33.54 ±10.65	199.16 ±94.16
	Juvenile	3	2.36 ±0.44	81.43 ±48.16	19.59 ±5.14	83.68 34.41 ±

Maximum Distance Between Subsequent Relocations

The average time between MDR was 3.58 days (BH = 3.86; BC = 3.33). There was only a significant difference in wood turtle MDR between sexes ($F_{39,2}$=4.48, p-value=0.02), and not between study sites ($F_{39,1}$=0.89, p-value=0.89), or sexes between study sites. Males had a significantly greater MDR (185.08 m ±115.42 SD, n=18) than females (106.00 m ±83.13 SD, n=22), and juveniles (69.74 m ±32.03 SD, n=5) (Figure 11; Tables 15 and 16). BH turtles averaged slightly greater MDR (138.12 m ±120.87 SD, n=21) than BC turtles (129.65 m ±85.35 SD, n=24), but there was no significant difference in the distances between the two (p-value = 0.89) (Tables 15 and 16).

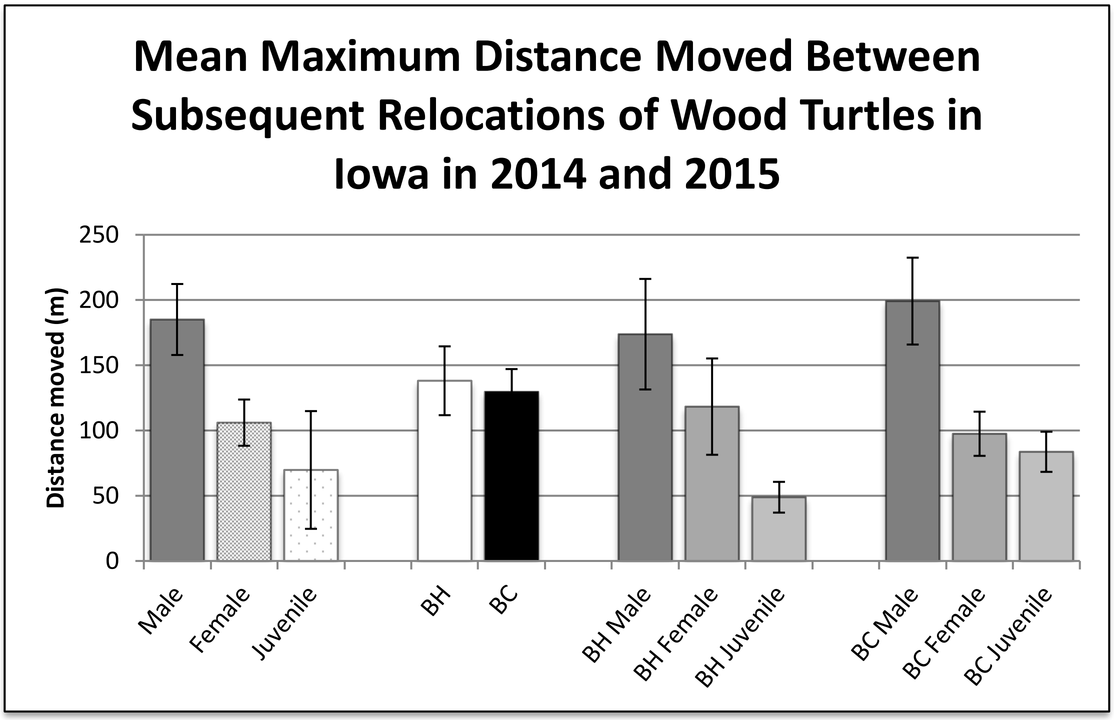

Figure 11. Mean maximum distance moved, in meters, between subsequent relocations (MDR) of wood turtles in Iowa during 2014 and 2015. Means were calculated for both study sites (BH and BC), each sex, and sexes at each study site.

The majority of individuals' (82.2%) MDR occurred during the months of April (n=14), June (n=14), and September (n=9). Females made up 92.9% of the June occurrences (n=13), while males made up 71.4% of April occurrences (n=10), and 44.4% of September occurrences (n=4). September had the most juvenile MDR's (n=3) (Figure 12).

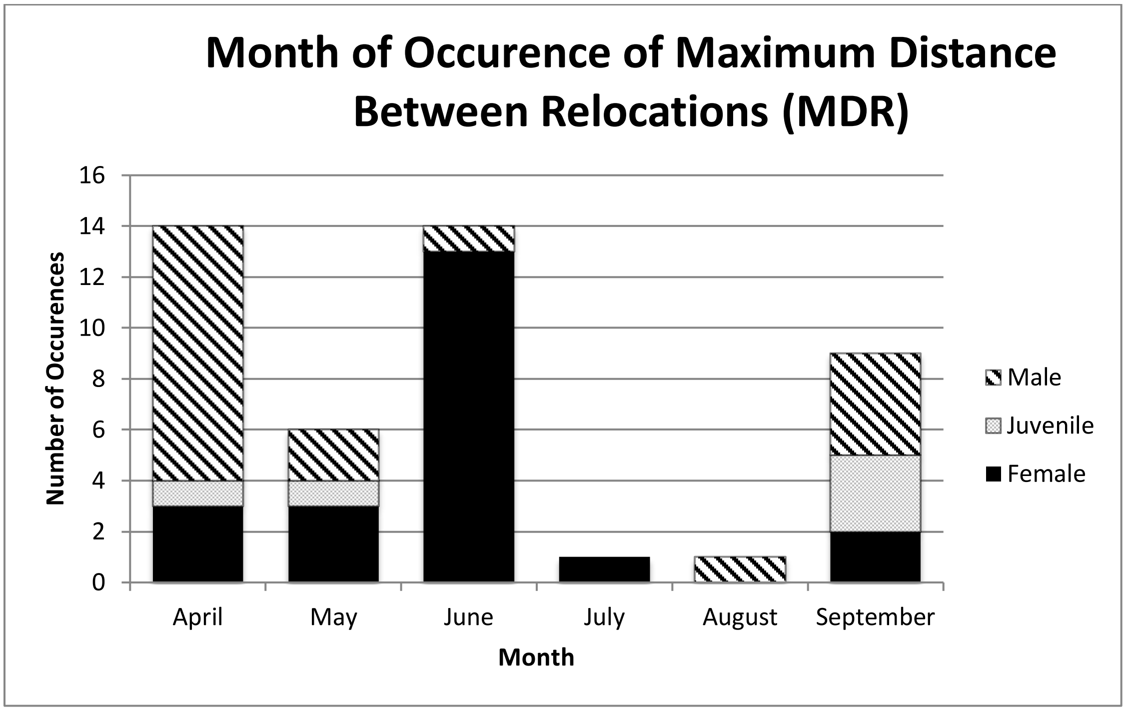

Figure 12. Month in which the maximum distance between subsequent relocations (MDR) was found for each individual turtle, by sex.

<u>Total Distance Moved</u>

The difference in the TD between sexes of wood turtles in this study was significant ($F_{39,2}$=11.27, p-value <0.001), with males being significantly larger than females (p-value <0.001) and juveniles (p-value=0.01). There was no significant difference in TD between years (t=0.03, df=72, p-value=0.98), or between sites ($F_{39,1}$=1.10, p-value=0.30) (Table 14; Figure 13).

Males on average had nearly twice the TD during each year of surveys than females or juveniles (Table 17). BH turtles averaged slightly larger TD during each year compared to BC turtles. TD's of sexes were similar for both sites in both years. Turtles on average had larger TD's during 2015 than 2014, but were similar for both years for males, females, and juveniles (Figure 13, Table 17).

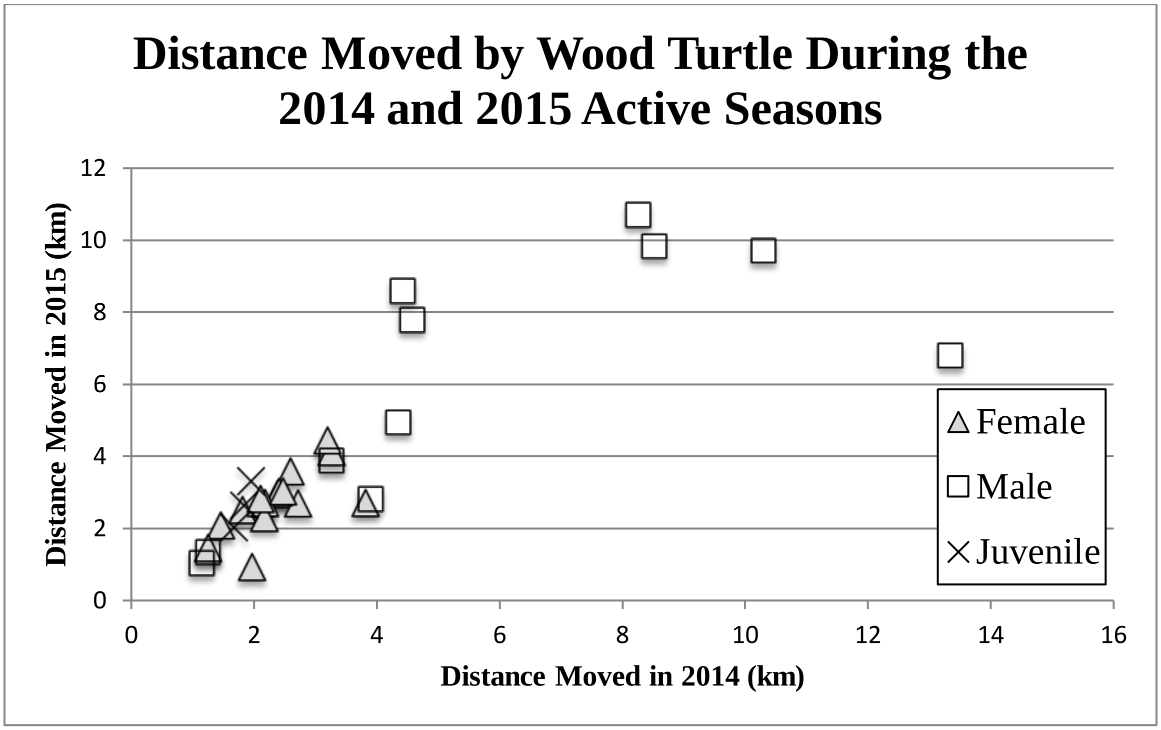

Figure 13. Comparison of total distance moved in an active season (km) for individuals that were tracked during both 2014 and 2015. Individual females are marked with triangles, males are marked with squares, and juveniles with x's.

Table 17. Mean total distance (TD) moved, by study site (BC and BH), sex, and sex by study site. Means were calculated for each season (2014 and 2015) as well as combined. Values are presented with SD.

	2014		**2015**		**Combined Years**	
	n	**TD (km)**	**n**	**TD (km)**	**n**	**TD (km)**
Female	16	2.36 ±0.66	22	2.59 ±0.88	38	2.49 ±0.79
Male	15	5.28 ±3.41	13	5.80 ±3.41	28	5.52 ±3.33
Juvenile	3	1.81 ±0.13	5	2.50 ±0.56	8	2.24 ±0.56
BC	17	2.80 ±1.77	24	3.53 ±2.39	41	3.23 ±2.16
BH	17	4.40 ±3.30	16	3.76 ±2.73	33	4.09 ±3.01
BC Female	6	2.11 ±0.56	7	2.53 ±0.73	13	2.36 ±0.69
BC Male	10	4.57 ±2.49	7	6.47 ±3.28	17	5.61 ±0.65
BC Juvenile	2	1.81 ±0.19	2	2.65 ±0.64	4	2.24 ±0.56
BH Female	10	2.78 ±0.65	15	2.71 ±1.19	25	2.74 ±0.94
BH Male	5	5.64 ±3.86	6	5.23 ±3.56	11	5.47 ±3.63
BH Juvenile	1	1.82	3	2.28 ±0.52	4	2.13 ±0.45

Multiple Linear Regression

The seven criteria were also analyzed to determine what factors had a significant influence on the four movement measurements analyzed for wood turtles in Iowa. Sex was found to have the strongest impact on three movement measurements: MDM, MDR, and TD. The location of the study site also had a significant influence on MDM. The number of locations a turtle was found also had a significant influence on the TD a wood turtle moved at both sites. Only the MDLH found to not be significantly influenced by any of the seven criteria.

CHAPTER 4

DISCUSSION

I investigated the differences in age class, mortality rates, and five different types of home range size of wood turtles (100%, 95%, and 50% MCP's, LHR, and SHR) from two study locations (BH and BC) in Iowa. I also investigated movement patterns and behaviors (MDLH, MDR, MDR, and TD) of individual turtles from these sites. These study locations represent contrasting population settings, one in a suburban human fragmented environment (BH), with nearly seven times the amount of human development than the other, a rural environment (BC), with larger landscape connectivity and fewer human residences.

For the second part of this study I compared home range sizes and percentage of overlap for individuals in subsequent years of radio telemetry surveys, as well as in multiple years of radio telemetry surveys. The overlap in home ranges was used to determine the degree of site fidelity that individuals have between years, and at what rate it changes over time. Because wood turtles are long-lived animals, it may be necessary to evaluate the change in site fidelity after several years versus subsequent years of study.

Age Structure

Age structure at both study sites was similar, with the majority of captures being adults over the age of 20. Only 8 individuals (6.2%) out of the 129 wood turtles captured in Iowa during the 12 years of study were non-adults, or under the age of 15. These results as well as anecdotal reports suggests that most populations of wood turtles in Iowa have similar age structure, however, juveniles are more often difficult to capture, but capture rates at this study were lower than those reported in similar studies (Compton 1999; Daigle and Jutras 2005; Jones 2009; Parren 2011). Observations from this study also show that juveniles spend more time hiding under woody debris and leaf litter than adults, perhaps a predator-avoidance behavioral adaptation.

From 2003 to 2015, recruitment of wood turtles was extremely low in BC and BH populations as evidenced by the low number of hatchlings and juveniles encountered. Although these age classes may be difficult to locate and capture, similar studies in other areas with populations of more than 100 marked turtles found hatchling and juvenile numbers to range from 66% (N=209) to 18% (N=72) of individuals in the population (Farrel and Graham 1991; Harding 1991; Neiderberger and Seidel 1999). In this study, only 6% (8 of 128) of turtles located and captured were hatchlings or juveniles.

Iowa populations of wood turtles are best defined as “ghost populations” (Compton 1999; Berg 2014)—populations that consist mostly of older adults with low mortality rates, but also have low numbers of young individuals, primarily due to little or no recruitment from high rates of egg, hatchling, and juvenile mortality. For wood turtles, flooding, anthropogenic changes in habitat, and/or increased pressure on nests from predators are the likely causes of elevated egg and juvenile mortality (Spradling et al. 2010). Although successful long-term conservation of wood turtle populations is presumed to rely primarily on the conservation of adult wood turtles (Foscarini and Brooks 1997; Compton 1999), empirical evidence indicates that wood turtle population declines are currently being experienced throughout much of their range (Compton 1999; Foscarini and Brooks 1997; Garber and Burger 1995; Daigle and Jutras 2005; Saumure

2004; Jones and Willey 2015), including the Iowa sites in this study (and are unlikely to be reversed without increasing recruitment).

I monitored nesting behavior to determine the locations and habitat associations of nesting wood turtles in Iowa. The vast majority (>90%) of wood turtles nested on the edge of vegetation on open sandy soils, approximately 10–20 m from the edge of lotic habitat (personal observation; Tamplin, personal observation; Berg, personal observation). During this 13-year period of monitoring, flood events occurred during post-nesting and pre-hatchling emergence at levels that nest sandbars were completely submerged for more than two days during every year of study except 2012, a drought year. While some turtles may have nested in locations other than the observed sandbars along lotic habitat, those that did nest there experienced 100% mortality of eggs, as wood turtle embryos cannot survive inundation for more than 24 hours (Harding 2008).

Mortality

Adult mortality increased drastically during this study (late 2013 through 2015) compared to a similar study conducted in the same area immediately prior to the current study (late 2011 to early 2013 [2.5 years]) (Williams 2013; Berg 2014). During studies conducted by Williams (2013) and Berg (2014), only one adult was found deceased, a rate of approximately 0.5 adult mortalities per year. During a similar time period (late 2013 through 2015 [2.5 years]) and search effort (multiple observers, multiple days a week), 13 individuals used for radio telemetry in this study were found deceased. In addition, four individuals that had never previously been captured were discovered deceased, a combined rate of approximately 6.8 adult mortalities per year. Studies conducted from 2003 to 2009 in similar areas in BC found seven individuals deceased, a rate of approximately 1.0 a year.

At BH from 2009–2012, one deceased turtle was observed, while from 2013–2015, 11 individuals were found dead, either through predation or unknown causes. Losing nearly one third (30.0%) of the known reproducing individuals in a population over such a short period of time is a substantial loss, especially for those long living, late maturing vertebrates like turtles. Mortality rates of BC turtles has followed a somewhat similar trend, with seven individuals found deceased from 2003–2012, most to unknown causes, while from 2013 through 2015, six individuals were found deceased, the majority to predator and unknown causes. The 13 known mortality cases of turtles at BC represent only 15.5% of the known adult population, however, more than half of these represented turtles that were not previously marked or used for radio telemetry surveys, rather they were just empty shells found during the first location. For this population to sustain either mortality rates need to decrease or fecundity rates need to increase. Although, human disturbance and encroachment may not be directly related to known instances of mortality, human influenced secondary factors (e.g., flood events, increased predator population) have caused substantial declines in adult populations at both sites, an example of how both populations have been negatively influences by human encroachment.

All wood turtle mortalities observed during studies from 2003 to 2015 were caused by natural (15) or unknown causes (10), with the majority caused by predation from raccoons and otters (12). The loss of only a few adults in a population of a long-lived species such as the wood turtles can lead to negative consequences for a population. Taking only a few reproducing individuals from a population that takes a long time to reach sexual maturity, will reduce the number of eggs and potential juveniles each season that may reach maturity. For a population to persist the loss of adults must be balanced by high survivorship and recruitment of juvenile and hatchling turtles (Brooks et al. 1991; Congdon et al. 1993; Garber and Burger 1995; Saumure et al. 2007). Other studies have directly related anthropogenic activity (e.g., haying and other agricultural practices, road development, and illegal collection) to declines in wood turtle populations. In my study, the indirect effects of anthropogenic changes in habitat affect (or appear to affect) wood turtle populations more than the direct effects. The indirect effect that causes the greatest negative impact to populations of Iowa wood turtles is increased predation rates from mesopredators that can be subsidized by human development. Mesopredators such as raccoons, skunks, and fox are opportunistic omnivores, which will eat a variety of food such as human garbage, compost, and gardens. The increase in human development would see an increase of these potential food sources, which could increase population sizes by reducing a factor involved in limiting population growth. The increase in these mesopredators could mean an increase in the amount of predation on wood turtles, hatchlings and eggs. In addition, increased frequency and severity of flood events (during and after nesting) through changing agricultural practices and land development, as well as potentially due to climate change, negatively impacts populations. Not only do these two indirect effects pose threats to adults in the population, but also negatively impact nest success and the recruitment of hatchlings.

Home Range

Overall, the movement patterns and home range sizes of wood turtles in two Iowa populations (one suburban, one rural) within the Great Plains ecoregion (Ornernik 1987) were fairly similar, however, several factors differed between the study sites with respect to the hypotheses tested.

Differences in Sexes

The first hypothesis that males will have larger home ranges (MCP's, LHR, and SHR) than females was supported by the data from both populations. Male wood turtles, had significantly larger mean home ranges than females for all home range types analyzed (100% MCP, 95% MCP, 50% MCP, SHR, and LHR). A significant difference was determined for all five home range measurements between male and female wood turtles at both sites in Iowa. Male wood turtles in this study had a greater mean home range size for all five criteria compared to females. Males had nearly twice the length of SHR and more than three times the area of 95% MCP than females. The centralized lotic habitat at both sites connects habitat and home ranges of all turtles, which may have facilitated movement of male turtles, causing an increased length of SHR, which ultimately may have led to larger overall home range sizes. Maintaining larger home range size where extensive suitable habitat is available may increase the frequency of mating opportunities (Morreale et al. 1984; Rowe and Moll 1991; Piepgras and Lang 2000) and help maintain social hierarchy (Kaufmann 1992a).

The females at both sites maintained significantly smaller home ranges than males. Having multiple mates is more beneficial for male turtles than female turtles

(Pearse and Avise 2001), so males may travel greater distances and occupy larger home ranges throughout the year to increase mating opportunities. Female turtles are known to conserve energy during the prenesting period, facilitating egg development, potentially explaining the difference in size of home ranges between males and females, however, some turtle species have been known to move long distances to lay eggs in suitable nesting locations (Refsnider and Linck 2012), which may inflate a females home range size. Throughout both study sites, suitable nesting habitat (open sandy soils free of vegetation and canopy cover) was found at numerous locations; suitable nesting habitat at BC was confirmed at nearly three times the locations as BH, indicating that more suitable nesting habitat may be available at BC. The greater the number of suitable nesting sites eliminates the need for females to make long distance nesting forays. Females at both sites traveled greater daily distances during the nesting period (presented later) than males; however, it was not a large enough increase to keep the sexes from having significantly different home range sizes.

Multiple Linear Regression

Iowa wood turtles are thought to exhibit similar behaviors as other populations of wood turtles throughout their range, therefore, it was predicted that sex would have the greatest effect on home range size, with males occupying larger areas than females. Although some studies have found a positive correlation in the linear dominance hierarchy with age and mass (Kaufman 1992a), others have found no correlation in size and dominance rank with the size of home range (Kaufmann 1995; Tuttle and Carroll 1997). For this study, it was predicted that the body size (SCL, mass) and age of the individual would be positively correlated with home range size, meaning the larger and older the individual, the larger the home range. I predicted a stronger correlation in the age or size (mass and/or SCL) of a turtle and their home range size compared to any other variables measured.

This hypothesis was rejected for all measurements of home range size of turtles in this study. Of the seven candidate predictors in linear regression models, sex had the strongest correlation on the size of home ranges for all five types measured (100% MCP, 95% MCP, 50% MCP, LHR, and SHR), and was the only variable that had a significant impact on 100% MCP, LHR, and SHR. Specifically, males were found to have larger home ranges for all five criteria than females or juveniles. The only home range measurement that was significantly correlated to age or size was the 50% MCP, which showed that older turtles had significantly larger 50% MCP home ranges. If age really had a significant influence on overall home range sizes, it would be expected to have a significant influence on more than one of the five home range criteria measured.

The study results may have been influenced by both populations largely consisting of older individuals, with very found or radio-tracked individuals under the age of 20. As older individuals are difficult to age, older turtles are grouped into broader age classes. This could make it difficult to accurately determine the influence of age on home range size. In addition, more than 90% of individuals studied are considered adult turtles, which have already established a home range, and therefore have less potential for any substantial variation from year to year. Younger turtles may have more variability in the size of home ranges as they are establishing areas in which to feed, thermoregulate and overwinter. Older individuals may skew the population to larger turtles, with little variation in SCL and mass of individuals studied, which potentially increases the difficulty in determining if there was a correlation between size and age of turtles, and their home range size. If more individuals under the age of 20 were studied, there may have been a stronger correlation between the size and age of turtles and the size of their home range size.

The level of injuries a wood turtle had sustained also significantly influenced the size of the 95% MCP home range. Four turtles were missing the majority of one foot, two had nearly all of one limb gone, and two had limited vision. Although these were the most severe injuries observed, they only significantly influenced one of the five home range measurements. If a turtle suffered an injury that may have limited its mobility and decreased the size of one home range measurement, similar outcomes should have been observed for the other four measurements

Comparison Between BH and BC

In BH, where wood turtle habitat is found on the fringes of human development within a suburban environment, available habitat may be less productive in terms of primary productivity due to human pressures and encroachment. Because of this I hypothesized that male and female wood turtles at BH would require larger home ranges to satisfy their resource requirements and to maximize mating opportunities, unless the development constrained their movement ability. Conversely, in BC, where larger areas of habitat are protected and connected, it is anticipated that smaller home ranges would be found for both sexes, due to fewer human disturbances and less anthropogenic change in available habitat. This would equate to higher productivity in available habitat, providing ample resources and mating opportunities in a smaller area.

The results of this study were contrary to what was predicted; there was no significant difference in any of the five home range measurements between BH and BC turtles. Both populations had nearly identical 95% MCP's (BC = 12.16 ha ±17.53 SD, n=21; BH = 11.65 ha ±10.22 SD, n=24) and SHR (BH = 1.09 km ±0.77 SD, n=21; BC = 0.99 km ±0.68 SD, n=24), suggesting that all resources (including mating opportunities) were being met within approximately the same amount of habitat. BH turtles had slightly larger 100% MCP, 95% MCP, LHR, and SHR than BC turtles, but the values between populations were nearly identical for those four criteria, which may be a result of the two sites having similar amounts of available habitat for wood turtles to meet their necessary requirements for survival.

The majority of available data on anthropogenic influences on reptiles and amphibians have focused on changes in abundance, species diversity, recruitment and mortality (Arraes et al. 2016; Gibbons et al. 2000), with little focus on how specific species may alter home range size and habitat utilization with increasing human development and encroachment. For this study, previous classifications of the two study sites, rural for BC and suburban for BH, were used (Williams 2013; Berg 2014). These designations were given based on the presence of human development in the form of houses and roads for a suburban population, and the presence of agricultural habitat and lack of other human development for rural. The BH site was considered suburban habitat due to it being within city limits, where it is bisected by city streets, roads, a rail line, and having residential homes in the vicinity, and being surrounded by land cover types with little suitable habitat for wood turtles to utilize, such as agriculture, pasture, and development (Figures 3 and 4). For these studies, habitat classifications from only BH were quantified using land cover data (Williams 2013), without ground-truthing, and with boundaries defining the study site being vague, thus potentially creating an inaccurate measure of the degree of human development/ encroachment. In addition, it was unclear what land cover types were quantified to determine the amount of human development within the study site.

For this study, study site boundaries were defined by evaluating the distance from lotic habitat of more than 6000 wood turtle location points in Iowa to reveal that a 300 m buffer around utilized lotic habitat contains 100% of the terrestrial wood turtle radio-locations. GIS land cover analysis and ground-truthing within this buffer found that BH, the suburban site had nearly seven times the amount of human development (e.g. residential, roads, and pasture) when compared to BC, the rural site, however, roads (paved and gravel) made up approximately 1.0% of the available habitat at each site. In addition, 10 times the amount of human residences were found at the BH site than BC, indicating that the classification of suburban habitat provided from previous studies (Williams 2013 and Berg 2014) was accurate based on this studies land cover data, as this is a site that is found within or along the outskirts of cities with excessive human interaction.

Williams (2013) and Berg (2014) classified the BC site as rural based on the relation to agriculture fields and its distance from the nearest city limits. Although this study found that there is far less human development within the BC study site, a highway and several gravel and dirt roads also bisect the area. The site does fit the definition of a rural habitat as it exists away from excessive human interaction, approximately 6.8 km from the nearest town, however, it is also surrounded by land cover types with little suitable habitat for wood turtles to utilize, such as agriculture in the form of row crops (Figure 5 and 6). Agricultural development has as much of a negative impact on wood turtle populations (Saumure and Bider 1998; Saumure 2004) as roads and human development, so a more accurate comparison of the amount of human development at each site would include all road, pasture, agricultural, and residential habitat within a 300 m buffer of the lotic habitat. Using this classification found that the sites have nearly identical amount of human development, with BH having 53.5 ha (18.0%), and BC having 75.5 ha (17.4%), which may explain why no significant differences between home range sizes of the two populations were found in this study.

For this study no measurement was taken to determine what impact the differing population densities near the two study sites may have on wood turtle populations, but at both sites the agricultural and residential habitat occurs at the fringes of the 300 m buffer, which are areas that are typically visited less frequently by wood turtles, so impacts on populations may not be as severe. Because human development at the two sites is nearly identical, wood turtles being opportunistic omnivores, and their ability to utilize a variety of edge habitat for thermoregulation, turtles at both sites would meet their necessary requirements for survival and mating within a similar amount of area, accounting for nearly identical home range sizes for all five categories between the rural and suburban sites.

It is difficult to determine at what level either population of wood turtles are being or have been negatively impacted by humans, as the majority of the Iowa landscape has been altered, destroyed, converted, or impacted at some point by people in the last 200 years. At the landscape/microhabitat level, based on wood turtle home range sizes, the impacts from human disturbance may be negligible, as the findings from this study fall within the lower half of home range sizes reported from similar studies in the United States and Canada, some of which occurred on more remote stretches of rivers. However, when looking at other factors such as population structure, mortality rates, and recruitment, human development and encroachment may have much greater negative impacts than what can be measured through evaluating home range size. Both populations studied in Iowa are skewed heavily towards adults, with little to no successful recruitment occurring, resulting in functioning “ghost populations”.

Comparison to Other Studies

My results are similar to other home range studies conducted in other ecoregions and habitats (Kaufmann, 1995; Tuttle and Carroll, 1997; Arvisais et al., 2002; Jones, 2009). Only two studies that compared 95% MCP home ranges of sexes found no significant differences between males and females (Saumure, 2004; Williams, 2013).

Studies throughout the distribution of wood turtles report great variability in mean home range size (Appendix A, Table A1). In addition, individual variability was reported within each study (Arvisais et al. 2002; Saumure 2004; Jones 2009; Williams 2013). The

95% MCP home ranges at both sites reported here generally fall with the ranges reported in other studies (1.5–16.9 ha for females, 3.0–80.6 ha for males, and 1.5–10.9 ha for juveniles). The results of this study are consistent with the observation made by Arvisais et al. (2002) that wood turtle home range size increases with latitude. The study sites fall at approximately the same latitude as the Deerfield River (DR), Massachusetts site from Jones' (2009) study, and has similar home range sizes for females (7.1 at DR; 8.7 ha this study) and males (23.1 at DR; 24.7 ha this study).

Site Fidelity

Wood turtles, like many other species of herpetofauna, may exhibit little change in home range size from one year to the next. Adult turtles develop a high degree of site fidelity, or "home," where all their basic needs of life are being met. These areas are oftentimes large enough that they encompass many habitat types required to meet their basic needs (e.g., numerous basking sites, hibernation areas, nesting habitat, foraging sites). Wood turtles have been found to move often, throughout the year, and at great distances within their home range (Otten, this study). This coupled with their strong observational ability (learning where there may be habitat to meet their needs) (Tamplin, personal observation), makes wood turtles highly responsive to dynamic habitat changes in the environment, especially those that naturally occur in a riverine system (e.g., flooding, channel widening, basking site alteration). For example, if a log used for basking is washed away during a flood, an individual "knows" where others are within their home range to meet the needs of thermoregulation.

If habitat alteration occurs between years of survey due to natural causes, such as those often occurring in a dynamic riverine system, home range sizes would be expected to be nearly identical from one year to the next. Only when habitat alterations occur due to extreme events (e.g., road construction, wetland draining/drying, human development) between years of study would there be a significant change expected in the size of an individuals' home range. Both study sites were impacted by normal habitat alteration events that occur within a dynamic riverine system during studies, drought in 2012 and major flooding in 2013. In 2012, many lotic and lentic water sources dried up completely, and in 2013 small openings in the canopy occurred when trees were displaced due to floods. Additionally, large amounts of sand were moved around and deposited to new areas along the banks of Beaver Creek in 2013. No extreme events (e.g., road construction, wetland draining/drying, human development) occurred during the study. Because of this it was predicted that home ranges would remain relatively unchanged from one year to the next, and that turtles would have high degrees of site fidelity.

95% MCP Home Range Size

The results of this study were as predicted; there was no significant difference between 2014 and 2015 annual 95% MCP home range sizes. Overall, wood turtles had nearly identical sizes of 95% MCP's between 2014 (8.71 ±10.12 ha, n=33) and 2015 (9.06 ±9.57 ha, n=33), suggesting that all resources (including mating opportunities) were being met within approximately the same amount of habitat from one year to the next. For Iowa wood turtles, neither sex nor study site made a significant difference on 95% MCP home range sizes between 2014 and 2015, as both males and females were similar from one year to the next, and turtles at BC and BH had similar size 95% MCP home range sizes between years.

To date, no studies were conducted on the changes in size of wood turtle home ranges in time spans greater than two years. For the current study I calculated the average size of 95% MCP home ranges for 4 years of study over an 11-year period at BC and 5 years of study at BH, sometimes utilizing the same individual for all five years of study. The study conducted at BC occurred with a 9-year break between surveys (2004, 2005, 2014, and 2015), while BH studies occurred continuously from 2011–2015.

At BC, overall average 95% MCP home ranges remained relatively consistent through the study (8.36–11.63 ha), signifying that even though a nine-year gap occurred between studies, wood turtles were still utilizing approximately the same amount of habitat to meet their basic needs. The differences in sizes between years could be a result of the number of relocations each year (more relocations generally means large home ranges), studies being conducted on slightly different sections of the river (2004 and 2005 had more individuals studied with larger portions of home ranges on oxbows and side channels), or a result of potential dynamic changes that occur along a riverine system from one year to the next. Because microhabitat information was not mapped along the study area for each year, it is difficult to determine if individuals were traveling further for a specific thermoregulation or feeding location than in subsequent years. Average male home range size at BC increased over the course of the study, while females generally decreased. For males, this may have been a result of turtle IA105, which had a home range size that was nearly double that of any other males studied at BC. The decrease in average female home range size over the course of the study may have been a result of the dynamic changes in habitat between years. Flooding events tend to deposit large amounts of sand in new areas along the banks of the river, areas that become suitable nesting sites for females. In addition, these flood events scour the sand from areas that had once been suitable nest sites, removing it entirely, making the area no longer suitable for nesting. Although females have shown high levels of nest site fidelity (Walde 1998; Arvisais et al. 2002), changes in soil and vegetation structure could impact nesting areas, which in turn may influence home range size from one year to another. Fewer suitable nesting areas could result in larger female home ranges.

At BH overall average 95% MCP home range size had greater variation from one year to the next (6.29–10.10 ha) than BC. There was a greater change in average male home ranges (6.76–13.96 ha) than females (4.89–8.73 ha) from 2011–2015. These changes may have been a result of the frequency of relocations (least number of relocations in 2013 which had some of the smallest home ranges), or because of weather patterns in 2012 and 2013, which experienced severe drought one year and severe flooding the next. Flooding events may move turtles into areas they do not typically utilize, causing larger home ranges, while droughts keep turtles closer to deeper pools in lotic habitats which may shrink home ranges. In addition, because several individuals were radio-tracked while they matured into adulthood, their home range size may shift to include areas that are either occupied by females (mating opportunities), or areas that contain suitable nest sites, which may alter sizes in home range.

Degree of Site Fidelity

The results of this study were as predicted: there was a high degree of site fidelity between 2014 and 2015 annual 95% MCP's home ranges. This was observed at both sites; BH and BC had nearly identical degrees of site fidelity between 2014 and 2015 (69.77% and 68.03%; respectively). Overall, females had a slightly higher degree of site fidelity than males (71.87% and 65.88%; respectively), potentially due to males having a much more linear home range than females; this can alter the MCP depending on how far upriver or downriver a turtle may travel and how many bends in lotic habitat. Only 2 of the 33 individuals evaluated had below 50.0% fidelity: a juvenile, IA118, (38.81%) and a male, IA116, (23.07%). The low fidelity may be from a dramatic shift in the individual's home range area, which could be caused by an encounter with a larger individual within the habitat (Kaufmann 1992a).

Any of the following factors could contribute to the differences in the degree of site fidelity over the course of several years: the difference in number of relocations from each year (more relocations could result in larger, more defined home ranges); the days surveys were conducted (home ranges may be slightly altered if part of nesting season was missed in one year); or slight seasonal variations in weather and habitat. The high degree of site fidelity between 2014 and 2015, coupled with the size of the home ranges, indicates that wood turtles in Iowa are utilizing similar habitat sizes, oftentimes the exact same area from one year to the next, to meet their ecological needs.

Nearly every study evaluating the degree in site fidelity of herpetofauna has compared home ranges in subsequent years of survey. Because of this, site fidelity of wood turtles in Iowa was compared for those individuals in which two years of successive 95% MCP home range was calculated. The degree of site fidelity changed slightly over the course of the study, ranging from slightly moderate (48.82% between 2012 and 2013) to high (68.81% between 2014 and 2015). The years in which environmental conditions may have changed the landscape (drought in 2012 and major flooding in 2013) had the lowest degrees of site fidelity (48.82% between 2012 and 2013, and 54.57% between 2013 and 2014). This indicates that other environmental factors, which occur year to year, may influence the degree of site fidelity in wood turtles. Years in which general environmental conditions remained consistent had a high degree of site fidelity, showing that wood turtles utilize almost the exact same areas of habitat from one year to the next. This suggests that moving or relocating individuals out of their known home range could have negative impacts on the survival of the species as they learned where to travel within their home range to meet all ecological needs. Translocated turtles could be at risk of higher levels of mortality as a result of unusual movement patterns or habitat use. In addition, destruction of areas of habitat that are utilized consistently over several years could have negative impacts on the survival of individuals as turtles would be forced to move to areas that may be less than ideal for their survival.

Further analysis evaluated the degree of site fidelity of wood turtles over multiple years. No previous studies have been completed evaluating the degree of wood turtle site fidelity over multiple years. Although sample size was small, this study had 3 individuals from BC in which there were at least 10 years between home range studies. One female, IA003, had almost the same degree of site fidelity between 2004 and 2014 (55.16%), and between 2005 and 2014 (58.59%), signifying that even though 10 years occurred between surveys, this individual was still utilizing a majority of the same habitat areas. In addition, another female, IA004, had a 63.18% overlap in home ranges between 11 years of study (2005 and 2015) and a 74.09% overlap in home ranges between 12 years of study (2004 and 2015). These results suggest that there are core areas that are important to the survival of female wood turtles at this site. Although studies evaluated the degree of site fidelity of wood turtles over a small time period (Walde 1998; Arvisais et al. 2002), some noted that turtles were located in the exact same area from one year to the next over multiple years (Harding and Bloomer 1979). These results suggest that not only do wood turtles exhibit a high degree of site fidelity between subsequent years, but they also may maintain this through much longer periods of time, and indicates the importance of conservation and protection of known areas that wood turtles inhabit.

While only a small number of individuals at BC had multiple years of home range data, numerous turtles at BH had multiple years of subsequent data to compare how time influences the degree of site fidelity for individuals. Turtles at BH experienced a moderate degree of site fidelity for all years compared (3 to 4 years between calculations), except between 2011 and 2015. The four individuals calculated across these years had the lowest degree of site fidelity (29.82%) among all other multiple year comparisons. This may be a result of the time elapsed between surveys, the potential change in microhabitat at the site between years, or it may be a result of home ranges occupied in 2011. Comparing these home ranges revealed that in addition to the above low degree of site fidelity, results between 2011 and 2014 were the next lowest (36.53%), just barely ranking in the moderate classification of site fidelity. Based on the available weather, habitat, and home range data from 2011, it is impossible to discern what may have caused such a discrepancy in site fidelity in home ranges between 2011 and 2014/2015.

Movements

In BH, where wood turtle habitat is found on the fringes of human development and is may be less productive due to human interactions, disturbance, and degradation, I expected that male and female wood turtles would move more frequently and at a greater distance throughout their home range than at BC, searching for mates, nesting locations, open canopy for thermoregulation, and food. Therefore, BH turtles were predicted to have significantly larger TD and MDM than BC turtles. In addition, because a wider buffer of protected habitat is found around the lotic water sources in BC compared to BH, I expected to find significantly larger MDLH from BC turtles compared to BH turtles. Males are known to have linear home ranges as they use lotic water sources as corridors to find mates, so I predicted that male wood turtles would have significantly smaller MDLH when compared to female wood turtles.

Comparison Between BH and BC

The results of this study were contrary to what was predicted; I found there was no significant difference in any of the four movement measurements between the two study sites. Both sites had similar MDM, and BC had a slightly larger MDM (20.66 m ±11.51 SD, n=24) than BH (16.81 m ±10.69 SD, n=21); however, TD moved in a season for BH (4.09 km ±3.01 SD, n=33) was slightly larger than BC (3.23 km ±2.16 SD, n=41).

This suggests that BH turtles may make longer moves of short duration, either to or from hibernacula, searching for mates, or to and from nesting sandbars, causing their overall TD moved in an active season to be larger than BC. This is consistent with other results found during the study between the two sites; on average BH turtles had a slightly greater MDR (138.11 m ±120.87 SD) than BC turtles (129.65 m ±85.35 SD).

Finally, I expected BC turtles to have a greater MDLH than BH turtles because BC has a greater width of suitable habitat surrounding lotic water sources than BH. However, my results did not support this prediction. BH turtles had a greater MDLH (131.19 m ±56.88 SD) than BC turtles (116.77 m ±70.00 SD), but these values were not significantly different. This may be a result of BH turtles having to travel slightly further distances from lotic water sources for areas of thermoregulation, but not far enough to cause the difference in distances to be significantly different. Overall, one individual from BC (male IA102) had the largest MDLH, 251.68 m from the West Fork of the Cedar River. The largest MDLH found at BH was slightly less (male IA095), 233.82 m from Beaver Creek.

On average, during an active season BH turtles moved approximately 100 m more than BC turtles; however, the MDM of BC turtles was slightly greater than BH turtles. In addition, BH turtles had slightly larger MDR than BC turtles. These results may be explained by the number of relocations each turtle had, or by how linear (straight) the lotic habitat was within each study site. The more relocations a turtle had, the more calculations between points, potentially causing larger distances calculated during an active season. In addition, a more linear lotic habitat could cause a turtle that is closely associated with utilizing this habitat to move further through their home range in a linear fashion, causing a more inflated TD, MDM, and MDR. A lotic habitat with more bends and backwaters could have an individual moving just as much, if not more, throughout an active season, but because measurements are taken in a straight-line method, those individuals in a more linear habitat would have larger TD, MDM, and MDR. These differences are more a factor of the shape of habitat, not the relation to human development. Wood turtles in the BC population had greater average MDLH than BH turtles, another factor that may be better explained by the shape of available habitat and not the relation to human encroachment. Turtles were found to move across roads and utilize agricultural landscapes and suburban yards, a sign that human encroachment in a suburban landscape may not limit the distance an individual moves from the lotic habitat, but the shape and structure of the habitat may factor more in the distance individuals are found from lotic habitat.

Most of the available data on wood turtle home ranges focuses on calculating kernels and MCP’s, with little focus on how the animals are actually moving through their habitat. In recent years, scientific literature contains numerous examples of species in urban environments modifying their behavior such that it differs from their rural counterparts (McClennen et al. 2001; Etter et al. 2002; Tigas et al. 2003; Riley et al. 2003). Behavioral or life history modifications made by urban wildlife may be in relation to movement, diet, reproduction, density, disease, and survival. These modifications may be necessary to determine as they pose additional challenges to resource and land managers.

As noted above, the two study sites had been previously defined as rural for BC and suburban for BH (Williams 2013; Berg 2014), given from a human perspective based on the presence of human development in the form of houses and roads for a suburban population, and the presence of agricultural habitat and lack of human development for rural. From a wood turtle perspective, the habitat of the two sites may be nearly identical (e.g., woodlands for foraging, open grass for thermoregulation, sandbars for nesting, and lotic water for movement and hibernation), and human encroachment may be limited enough to not influence behavior or movement. At both sites, wood turtles were found to frequently use open canopy areas along roads with heavy traffic, signaling that the human development in this instance did not dissuade use or alter behavior. Although no turtles fatalities or observations on the roadways were found during studies, anecdotal reports from neighbors moving turtles with transmitters off the roads suggests that they may use them infrequently (Tamplin, personal observation).

These results suggest that the amount of human encroachment in the “suburban” population is not great enough to affect behavior or movement of wood turtles, that the natural habitat surrounding the centralized lotic water bodies at both sites is large enough to not impede natural movement or behavior of wood turtles, or that both populations are experiencing the same degree of human encroachment, altering their behavior in similar ways, causing no significant difference between the two populations. A limited amount of human development occurs within 300 m of lotic habitat at BH while virtually none is found at BC. If there was a negative impact on wood turtles by the amount of human encroachment, wood turtles might remain closer to lotic water sources and away from human development at BH, while venturing further from lotic water at BC. The results indicate the opposite, that, on average, BH turtles' MDLH was greater than that of BC turtles, indicating that the presence of human development was not impeding turtle movement away from water.

Differences in Sexes

There was a significant difference in three of the four movement measurements between male and female wood turtles in Iowa, with only MDLH being insignificant. Similar to what was found with home range sizes, I observed greater singular distances moved and greater mean distances moved for males compared to females for all four measurement categories.

BC males had the largest MDM compared to any other group, more than twice that of females. Because females need to conserve energy for egg production during the first few months of the active season, and they do not usually seek mates (Pearse and Avise 2001), they had the smallest MDM (nearly identical at both study sites). For this study it was found that females do travel longer daily distances during the nesting period than males, but not enough to increase overall average TD or MDM. It was hypothesized that female wood turtles would have greater MDR than males due to their need to locate suitable nesting sites, which may be infrequent in the habitat they utilize. Contrary to what was predicted, on average, males had a greater MDR, nearly twice that of females. It was found that the month of occurrence for MDR differed between sexes, with the majority of males making their longest distance movements in the month of April, while females during the month of June. This may be a result of males hibernating further away from their core home range and traveling further to get back, while females make long distance movements immediately prior to nesting season (late May, early June) to suitable nesting locations.

The significant differences in movement categories between males and females may be a result of males maintaining larger home range sizes to increase the frequency of mating opportunities and search for potential rivals, which requires them to move farther and more frequently than females (Harding and Bloomer 1979, Morreale et al. 1984; Rowe and Moll 1991; Piepgras and Lang 2000; Parren 2013). Many turtle species are perceived as sedentary organisms, having limited movement; however, wood turtles in this study have been found to move between 1.25 and 10.71 km in a single active season.

Iowa wood turtles may display similar behaviors as other populations of wood turtles throughout their range; therefore, it is thought that sex has the greatest significant correlation to movement patterns, with males moving throughout their home range more frequently and farther than females. For this study, it was hypothesized that the larger and older the individual (SCL, mass, and age), the larger the home range size; therefore, it was predicted that there would be a positive correlation between the age and size (SCL and mass) of the turtles and the distances that they are moving throughout their home range.

Similar to the results of home range size, sex had the strongest significant correlation on movement patterns of Iowa wood turtles; sex was a significant factor on the MDM, MDR, and TD. The sex of the turtle influenced the distances wood turtles moved throughout their home range each year, with males moving farther daily, moving farther between subsequent relocations, and moving farther on average in an active year than females and juveniles.

The number of locations a turtle was found in an active season had a significant influence on the TD, meaning if a turtle was found more often in the active season then the greater the TD the turtle moved throughout the year. The influence of total locations on TD was probably due to sampling issues between the two populations (e.g., one site being surveyed more than the other in the active season due to scheduling issues). The only movement criteria that had no variables that had significant influence on individual movement was the MDLH. Sex, study location, injury level, or size of a turtle was not a significant factor in the MDLH of individual turtles.

Comparison to Other Studies

Few studies have analyzed the movement patterns of wood turtles throughout the active season. Jones (2009) and Brown (2016) found that females and males differed significantly between distances from water (MDLH), with females being found further from lotic water than males. Although, this study found no significant difference in MDLH between sexes, the mean MDLH of males (106.44 m) and females (142.39 m) was similar to those found by Jones (115 m for males and 207 m for females) and Brown (120 m for males and 160 m for females).

The only other movement pattern measured in any wood turtle study was daily distance traveled (MDM), assessed by Jones (2009). He found a significant difference in MDM between sexes, with males averaging 19 m a day and females averaging 30 m a day. These results are opposite of the current study; male daily movement distances were significantly further on average (27.55 m) compared to females (12.34 m). The differences in results may have been impacted by availability of habitat between the two studies (e.g., females may have moved further distances in Jones (2009) to find suitable nesting habitat).

No wood turtle studies have evaluated the total distances that turtles move in a season. Most focus on distances moved during seasons, distances from lotic water sources, or movement between relocation points. This study found that wood turtles move between 1.25 and 10.71 km in an active season. Other studies on riverine (*Graptemys geographica* and *Apalone spinifera*) and semi-aquatic turtle species have found that turtles may not be as sedentary as they are perceived, and have similar TD values as those found in this study. A population of *G. geographica* in Pennsylvania averaged a stream length home range of 1.21 km in females and 2.11 km in males. An individual during this study moved 5.83 km in four days (Pluto and Bellis 1988). Ten individuals from a study of *A. spinifera* in Montana moved more than 10 km from May–July (Tornabene et al. 2017). In addition, a study of *E. blandingii* in Massachusetts found 20 long distance movements (1–2.6 km) by males and females during the active season, which would give the potential for these individuals to have similar TD during an active season as what was found in this study (Grgurovic and Sievert 2005).

CONCLUSIONS

Home Range

The primary objective of this study was to investigate the differences in mortality rates, movement patterns, and home range sizes of two populations of wood turtles in Iowa, a suburban population set in Black Hawk County (BH) and a rural population in Butler County (BC). Both populations experienced a similar number of mortalities over the course of studies conducted at each site, 12 from 2009–2015 at BH and 13 from 2003–2015 at BC; however, mortality rates increased drastically later in the study. From 2003–2009 mortality rates were approximately 1.0 adults per year, 2011 to early 2013 were 0.5 adult mortalities per year, and late 2013 through 2015 were 6.8 adult mortalities a year. While the majority of mortalities were attributed to predators or other unknown factors, losing nearly one third of the known reproducing adult population to any factors over such a short period of time has extremely detrimental cascading effects on the population as a whole. This coupled with the low recruitment rates of wood turtles in Iowa, and increases in flooding events that destroy whole wood turtle nests has compounding negative impacts of Iowa wood turtle populations.

Overall, the home ranges of male wood turtles were larger than those of females, while both study sites had nearly identical sizes. The first hypothesis, that males will have larger home ranges (100% MCP, 95% MCP, 50% MCP, LHR, and SHR) and move throughout their home range farther, and more often than females, was supported by the data from this study, as males had significantly large home ranges for all five categories, and three of the four movement variables than females. Because males search for mates and patrol their home range for rivals more than females, it is more beneficial for them to have larger home ranges and move throughout their home ranges more than females. The only movement variable where there was no significant difference between sexes was MDLH, which may be a result of males utilizing lotic habitat to move throughout their home range more often than females, keeping them closer to the rivers and streams. This study suggests that males move farther and more often than females throughout their home range because they are more closely tied with lotic habitat.

The second hypothesis that wood turtles in a suburban habitat will have larger home ranges and movement variables than those from a rural habitat was not supported by the results of this study. There were no significant differences between any of the five home range types or four movement variables between the suburban site, BH, and the rural site, BC. Home ranges and movements at both sites were nearly identical indicating that habitats may not be as fragmented or degraded due to human disturbance as thought. Although BH has nearly seven times the amount of human development habitat than BC, both sites have similar percentage of combined habitat that is agriculture, roads, pasture, and human development. In addition, this habitat is mainly found at the fringes of habitat wood turtles utilize, limiting exposure of turtles to negative human impacts, which may result in similar results of home range sizes between both study sites.

Site Fidelity

Overall, the site fidelity rates and home range sizes between the two years of this study (2014 and 2015) are high and similar; the 95% MCP areas are nearly identical between years, and the degree of site fidelity (overlap) was 68.81%.

The first hypothesis of the study’s secondary objective, that adult wood turtles will have a high degree of site fidelity between 2014 and 2015, was supported by the data. Because wood turtles may use the same areas from one year to the next for successful mating, nesting, foraging, and hibernating opportunities, they will exhibit a high level of home range overlap between 2014 and 2015, indicating a high degree of site fidelity. This was observed during this study, for both sexes and for both sites studied. This observation was similar to other wood turtle studies conducted in other ecotones (Harding and Bloomer 1979; Walde 1998; Arvisais et al. 2002). Only one study comparing 95% MCP home ranges has been completed, and this found wood turtles to have a moderately high degree of site fidelity (Arvisais et al. 2002).

The second and third hypotheses of this objective, that wood turtles would have high degree of site fidelity between several years of study, and that the size of home ranges would change little over time, was marginally supported by this study. Overall the mean home range size between years remained somewhat consistent throughout the study period; however, individual variation between years occurred for a few turtles of each sex from each site. This may have been a result of changes in social hierarchy, turtles maturing during the study, or other environmental factors that could not be measured during this study. Site fidelity was moderate to high in the majority of individuals with more than nine years between surveys, but was the lowest for individuals tracked in 2011 and 2015, a result that may be explained through alteration in habitat after 2011 due to environmental conditions. For the years (2014 and 2015) with the most consistent environmental conditions, methods, and largest sample size, mean home range sizes were nearly identical while the turtles exhibited a high degree of overall site fidelity.

Management Recommendations

The single most important factor in the conservation of wood turtles in Iowa is the protection of habitat surrounding occupied lotic habitats. In more than 6,000 encounters over a 13-year period in Iowa, no wood turtles were found further than 300 m from lotic habitat. This suggests that a buffer of at least 300 m around known or potential wood turtle lotic habitat will create the necessary upland habitat needed for survival. These buffer zones would improve the water quality of the wetland habitats they surround, and can mitigate effects of potential human encroachment. Oftentimes farming practices, suburban development, and road construction in Iowa will utilize habitat up to the edges of creeks and streams. Where this occurs within the range of wood turtles, the species may be negatively impacted by the combined effects of reduced habitat availability and diversity, altered home range shape and size, and potential changes to movement patterns. Conserving riparian/lotic habitats will not only protect and improve habitat for wood turtles, but also other species of plants and animals that utilize edges, riparian areas, upland habitat, or lotic wetlands.

The conservation and survival of adults in a population is important to study, but little focus has been placed on improving the recruitment of wood turtles in Iowa. A top down approach (adult focus) in turtle conservation may facilitate adult survivorship and allow them to continue to breed and lay eggs, but if these eggs are never able to hatch there will be no future generations to sustain populations in the state. Therefore, a bottom up (nest/hatchling focus) approach to conservation is vital in the survival of this species.

At both study sites at least three wood turtle nesting sites were confirmed. Suitable nesting habitat occurred at unconfirmed locations, suggesting nesting habitat was available to wood turtles sporadically at both study sties. However, throughout the last 50 years, the upper Midwest has experienced a 27% increase in days with very heavy precipitation (Karl et al. 2009). During periods of normal water level conditions when wood turtle eggs are in the ground, one rain event of at least 2.5 cm, or multiple rain events over the course of a two-week period with approximately 4.0 cm of precipitation, would inundate nesting areas for several days (Otten, this study), resulting in 0% annual recruitment of those turtles known to nest in those locations. Flooding conditions such as these have increased over the years, potentially from climate change combine with anthropogenic changes in the surrounding habitats, to the point where nest destruction has occurred at both study sites during six of the last seven years. During studies at BH and BC, females deposited eggs in early- and mid-June, followed by at least one rain event of >2.5 cm precipitation, and sometimes as high as 9.5 cm. In four of the last five years (2011–2015), multiple rain events have occurred over the few weeks following nest deposition, which has inundated nesting areas for periods of one to four weeks. During these years (except 2013), the total monthly rainfall for both June and July almost equaled the historical average, however, fewer and more severe rain events occurred during this time, which caused substantial flooding of the study sites.

Habitat alteration of known and potential nesting areas would need to occur in Iowa to return the “ghost populations” of wood turtles to those with a healthy age distribution. The use of artificially-created nesting areas (mounds) have proven to be a successful mitigation tool for the loss of suitable nesting habitat in other species of turtles (Paterson et al. 2013; Grosse et al. 2015; Quinn et al. 2015) as well as in wood turtles (Buhlmann and Osborn 2011; Patterson et al. 2013). While the heart of the problem may lie in upstream land practices, creating any number of these nest structures near known nesting habitat, but far enough from potential flood risks, may increase recruitment of wood turtles in in Iowa. Protecting areas utilized by wood turtles for nesting through the use of wing dams, riprap, or other structures, may be another method in increasing wood turtle recruitment levels.

Reduced erosion of stream banks and pollutant run-off may be significantly decreased with the creation of appropriate riparian buffers around all nearby agricultural fields (Schultz et al. 2004; Zaimes et al. 2004). These practices would not only benefit habitat, but also improve water quality for all animals, plants, and humans that utilize those water bodies. During flood events at both sites, erosion occurs in the form of sand from nesting areas being moved around and deposited to other sites, sometimes those areas that are unsuitable nesting habitat (e.g., limited solar exposure, abundant plant roots). At times, enough sand is relocated in a year to alter the flow of water throughout the area, which results in the complete elimination of some suitable nesting areas. If enough flood control and mitigation measures are put into practice in the form of wetland and grass buffers throughout the drainage basin, then water runoff from surrounding agricultural fields and suburban landscapes may be slowed or eliminated, causing lotic water levels during rain events to rise at either a slower rate or at lower levels. Decreasing the amount of water that is immediately released into lotic habitat during normal or above average rain events may keep nesting sites above the water line long enough for successful hatching, increasing the annual recruitment of wood turtles.

Head-starting, a conservation strategy that involves rearing hatchling turtles in captivity for a period of time to allow turtles to attain sizes that may increase survival rates in the wild, may be a method to increase recruitment rates in Iowa wood turtles. Turtle head-starting programs differ in methods or in what is defined as a "successful" program (Burke 2015). We witnessed repeated flood events destroying >90% of nests in nearly every year of studies conducted at BC and BH. Head-starting wood turtles would involve the collection of eggs from gravid females or nests likely to be inundated by floods or destroyed by predators, artificially incubated and reared in the lab, then released at 9–12 months of age at turtle nesting locations. Because Iowa wood turtle populations have such low percentage of nest success, it would only take a small number of successfully released hatchlings from head started nests each year to be a mark of a successful program. Additional studies could be completed via radio telemetry to determine the success and survival rates of head started individuals. Studies could even investigate the survival of various age classes of released head started turtles.

Little effort is needed to raise hatchlings to a size that would increase survival rates. Programs such as these have been successful in other states and with other species (Buhlmann et al. 2015; Green 2015). This was also observed in a concurrent study regarding movement patterns of hatchling wood turtles in Iowa. In 2015, 63 wood turtle eggs from 6 nests that would have been destroyed by floodwaters were artificially incubated and 52 of the hatchlings were later released. A subset of these individuals was released with radio transmitters to track movement, behavior, and survival rates. Of these, seven of eight turtles survived to hibernation, a result that would not have been possible without human involvement. If nothing had been done, no known wood turtle nests from the 2015 season would have had a chance to hatch, and 0 hatchlings would have made it to hibernation (Otten, personal observation)

Habitat management, at both BC and BH, was completed during late 2014 early 2015. The IADNR, Butler County Conservation, and Black Hawk County Conservation created gaps in the canopy of deciduous trees and completed edge feathering of woodlands to promote grass and forb growth, which in turn would benefit wood turtles and create more areas for thermoregulation and protection from predators. These types of management practices may have limited impact on adults in Iowa, however, immediately following alteration, a small number of individuals (5) from both study sites utilized areas that were actively managed (tree clearing and edge thinning). These were individuals that were already known to be utilizing adjacent similar habitat, and the managed areas fell within known turtle home ranges. Older turtles in Iowa have successfully survived for many years utilizing the same areas from one year to the next for thermoregulation, mating, feeding, and overwintering. Creating or altering habitat within already suitable or utilized wood turtle habitat may slightly alter movement patterns and potentially shrink home range sizes, but within these areas of study, habitat for adult turtles does not appear to be a limiting factor in the survival of the species.

Prior to this study, known mortality rates experienced by wood turtles in Iowa may not warrant altering habitat to increase survival of adults. In addition, the time just after habitat alteration was when wood turtles at BH experienced an extreme increase in mortality rates due to predation, potentially due to increased mesopredator abundance and human alteration of the landscape, or perhaps this observation is a coincidence in timing that occurred during a period of increased monitoring.

If conservation of adult turtles in these areas remains a primary focus of conservation agencies, then counties should consider taking steps to control or reduce the mesopredator densities that occur within wood turtle habitats. An increase in annual furbearer licenses for the counties, or targeted trapping surveys by local conservation agencies would not only reduce adult turtle predation, but it would also decrease the nest predation rates of all turtle species at the study sites. The majority of studies evaluating the effectiveness of removing predators (raccoons) to increase the survival of various turtle species have observed success in the first year of removal, including populations of Iowa turtles (Christiansen and Gallaway 1984), sea turtles (Engeman et al. 2005; Engeman et al. 2010), and other turtle and tortoise species (Munscher et al. 2012; Smith et al. 2013). In addition, studies involving the culling of mesopredators have found that forest patch size, location, and timing of removal have positive impacts on controlling populations of raccoons and red foxes (Beasely et al. 2013; Lieury et al. 2015; Conner and Morris 2015), species known to prey upon adult turtles, hatchlings, and their eggs.

One study demonstrated that predator control had a more dramatic impact on turtle population dynamics than does habitat protection (Browne and Hecnar 2007).

Head start, and hatch and release programs present potentially cheaper, localized, and more viable options to wood turtle conservation when compared to methods of altering human land-use practices. Future research and management practice needs to focus on increasing annual recruitment rates, improving nest success, defining nesting habitat preferences, and how the above-described mitigation measures can alter population trends of wood turtles in Iowa.

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APPENDIX A

COMPARISON OF WOOD TURTLE STUDIES

Table A1. Comparison of mean home ranges of wood turtles from several studies across their range. Home ranges for each study were calculated as either integral (100% MCP), statistical (95% MCP), linear (LHR), or stream (SHR). A few studies also calculated the mean max distance from water, which was calculated by taking the mean max distance to lotic water for each individual in the study.

State	Site	Sex	Year	Integral (100% MCP; ha)	Statistical (95% MCP; ha)	LHR (m)	SHR (m)	Max Distance from H20 (m)	n	Source
MA	Conneticut Valley	F	2004	-	5.8 ± 5.6	565 ± 303	514 ± 430	216 ± 194	23	Jones (2009)
MA	Conneticut Valley	F	2005	-	14.8 ± 30.9	823 ± 742	895 ± 1165	218 ± 220	29	Jones (2009)
MA	Conneticut Valley	F	2006	-	13.8 ± 25.0	866 ± 614	1033 ± 902	222 ± 120	26	Jones (2009)
MA	Conneticut Valley	F	2007	-	3.9 ± 3.7	449 ± 137	546 ± 276	135 ± 105	12	Jones (2009)
NH	Merrimack Valley	F	2007	-	7.7 ± 9.5	502 ± 323	611 ± 427	163 ± 195	8	Jones (2009)
ON	Huron County	F	1991	6.4 ± 3.7	-	-	-	-	4	Foscarini (1994)
QC	Brome County	F	1998	11.6 ± 16.4	9.6 ± 7.2	741 ± 251	-	-	9	Saumure (2004)
QC	Brome County	F	1999	16.4 ± 13.3	13.0 ± 10.0	797 ± 397	-		11	Saumure (2004)
QC	Mauricie	F	1996	-	25.9 ± 32.9	-	-	-	14	Arvisais et al. (2002)
QC	Mauricie	F	1997	-	29.4 ± 37.8	-	-	-	14	Arvisais et al. (2002)
PA	Centre	F	1988	3.3 ± 0.5	2.6 ± 0.5	435 ± 74	-	-	4	Kaufmann (1995)

State	Site	Sex	Year	Integral (100% MCP; ha)	Statistical (95% MCP; ha)	LHR (m)	SHR (m)	Max Distance from H20 (m)	n	Source
VA	Rockingham Site 1	F	2006-07	7.9 ± 6.5	-	-	-	-	6	Sweeten (2008)
VA	Rockingham Site 2	F	2006-07	16.8 ± 27.8	-	-	-	-	14	Sweeten (2008)
WI	-	F	-	-	0.5 ± 0.3	-	-	-	4	Ross et al. (1991)
IA	BH	F	2011-12	-	9.5 ± 11.9	-	-	-	11	Williams (2013)
MI	Au Sable River	F	1998	10.4	-	-	-	-	-	Asmus et al. (1999)
IA	BH	F	2014-15	8.6 ± 7.1	5.3 ± 4.8	750 ± 550	870 ± 700	118 ± 37	9	This study
IA	BC	F	2014-15	8.7 ± 4.4	6.9 ± 4.4	520 ± 240	590 ± 330	97 ± 17	13	This study
MA	Conneticut Valley	M	2004	-	17.8 ± 25.0	1138 ± 938	1670 ± 1498	114 ± 90	18	Jones (2009)
MA	Conneticut Valley	M	2005	-	16.0 ± 17.0	1109 ± 778	1478 ± 1100	97 ± 89	22	Jones (2009)
MA	Conneticut Valley	M	2006	-	20.3 ± 44.8	976 ± 954	1343 ± 1341	97 ± 63	25	Jones (2009)
MA	Conneticut Valley	M	2007	-	24.3 ± 33.8	1014 ± 594	1436 ± 955	85 ± 59	9	Jones (2009)
NH	Merrimack Valley	M	2007	-	6.6 ± 5.5	673 ± 485	921 ± 653	66 ± 59	8	Jones (2009)
ON	Huron County	M	1991	5.0 ± 2.9	-	-	-	-	6	Foscarini (1994)
QC	Brome County	M	1998	19.4 ± 13.1	16.7 ± 11.3	1301 ± 564	-	-	5	Saumure (2004)
QC	Brome County	M	1999	36.0 ± 51.9	32.2 ± 50.0	1531 ± 1412	-	-	9	Saumure (2004)
QC	Mauricie	M	1996	-	32.1 ± 38.7	-	-	-	4	Arvisais et al (2002)
QC	Mauricie	M	1997	-	29.1 ± 20.0	-	-	-	6	Arvisais et al. (2002)

State	Site	Sex	Year	Integral (100% MCP; ha)	Statistical (95% MCP; ha)	LHR (m)	SHR (m)	Mean Max Distance (m)	n	Source
PA	Centre	M	1988	5.0 ± 1.5	3.8 ± 1.4	481 ± 75	-	-	6	Kaufmann (1995)
VA	Rockingham Site 1	M	2006-07	33.0 ± 34.8	-	-	-	-	8	Sweeten (2008)
VA	Rockingham Site 2	M	2006-07	19.3 ± 34.9	-	-	-	-	15	Sweeten (2008)
WI	-	M	-	-	0.3 ± 0.2	-	-	-	3	Ross et al. (1991)
IA	BH	M	2011-12	-	13.3 ± 9.6	-	-	-	11	Williams (2013)
MI	Au Sable River	M	1998	9.1	-	-	-	-	3	Asmus et al. (1999)
IA	BH	M	2014-15	23.5 ± 26.4	20.0 ± 23.1	1150 ± 570	1420 ± 790	174 ± 42	10	This study
IA	BC	M	2014-15	26.1 ± 13.1	21.5 ± 11.8	1200 ± 370	1750 ± 590	199 ± 33	8	This study
MI	Au Sable River	Both	1999	-	7.3	-	-	-	3 male, 5 female, 2 juv.	Wilson et al (2000)
ON	Algonquin Park	Both	1990	-	24.3	-	-	-	2 male, 6 female	Quinn and Tate (1991)
MI	Northern MI	Both	1998-2000	-	30.2	-	-	-	20 females 8 males 1 juv	Remsberg et al. (2006)

APPENDIX B

WOOD TURTLE HOME RANGE FIGURES

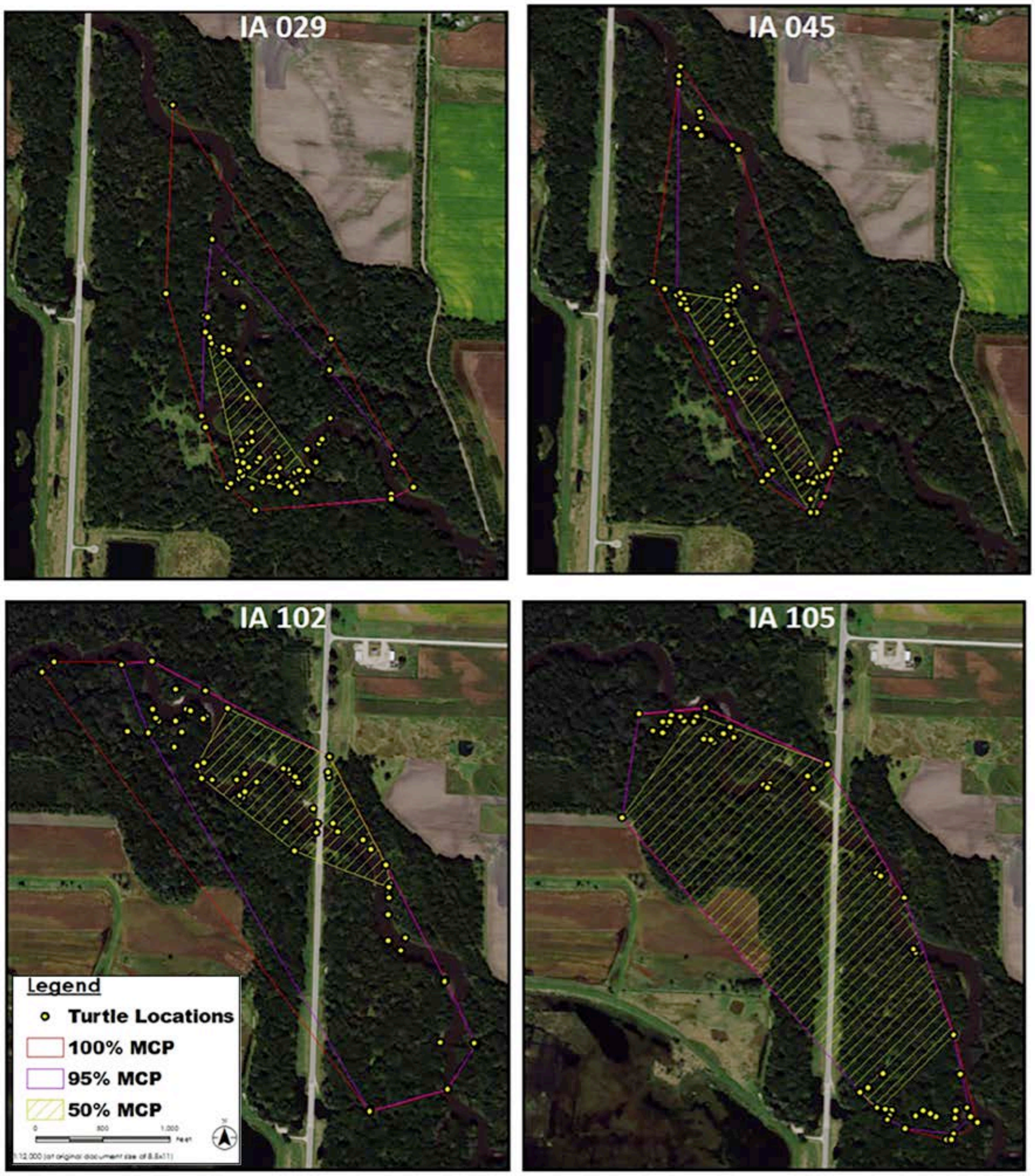

Figure B1. Calculated wood turtle home ranges (100%, 95%, and 50% MCP's) of male turtles IA029, IA045, IA102, and IA105, from the Butler County (BC) study site.

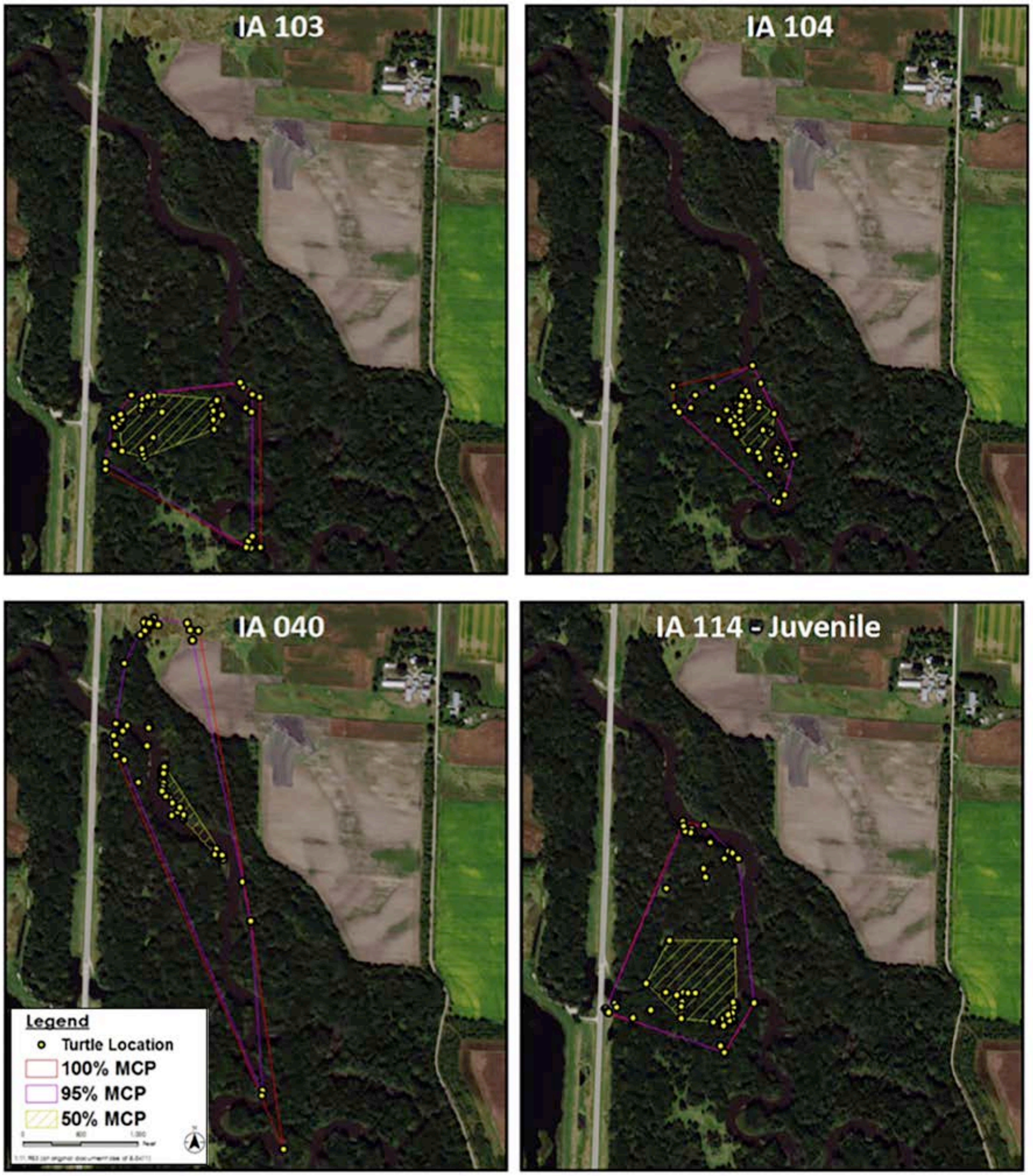

Figure B2. Calculated wood turtle home ranges (100%, 95%, and 50% MCP's) of female turtles IA103, IA104, IA040, and juvenile IA114, from the Butler County (BC) study site.

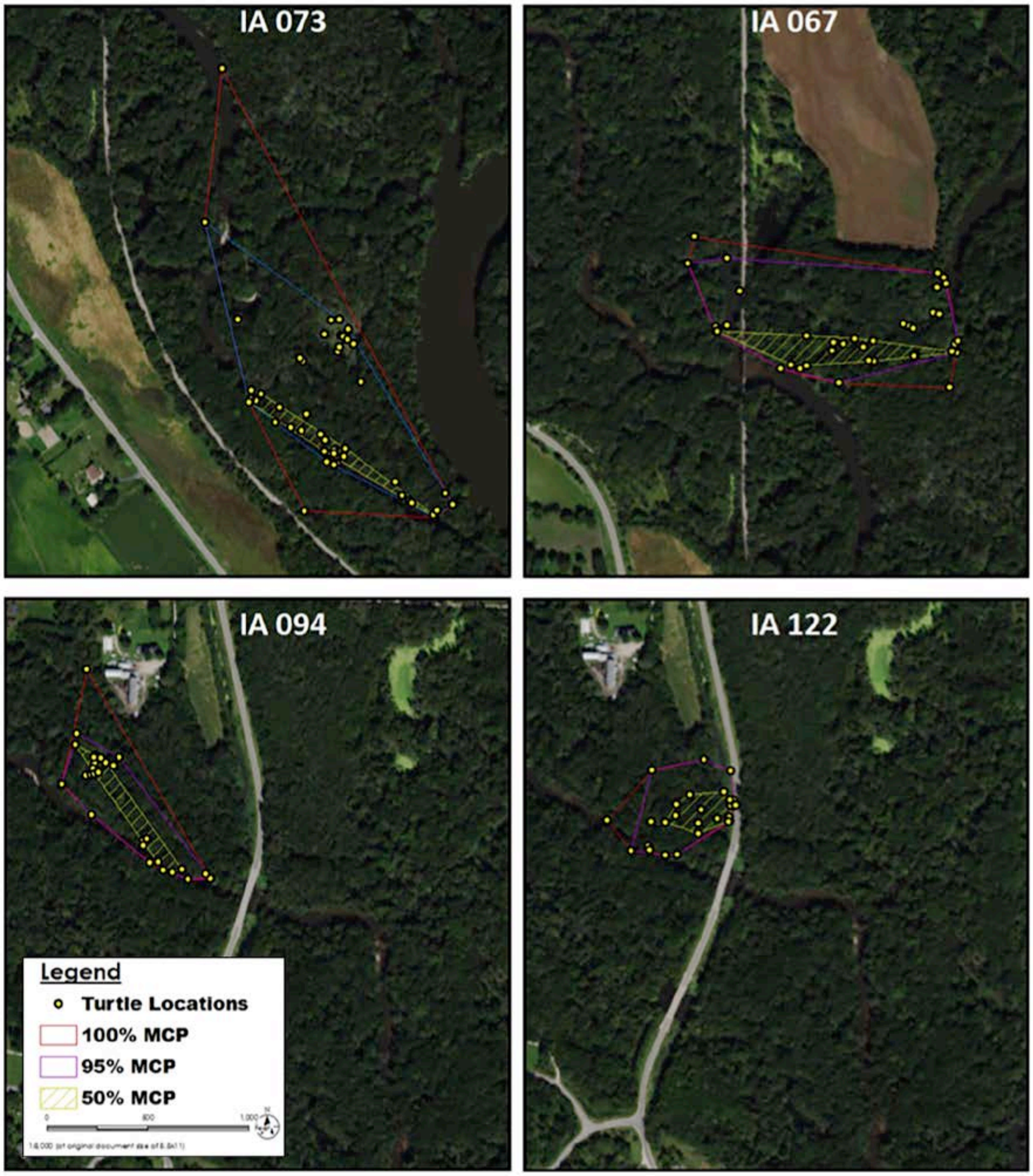

Figure B3. Calculated wood turtle home ranges (100%, 95%, and 50% MCP's) of female turtles IA073, IA067, IA094, and IA122, from the Black Hawk County (BH) study site.

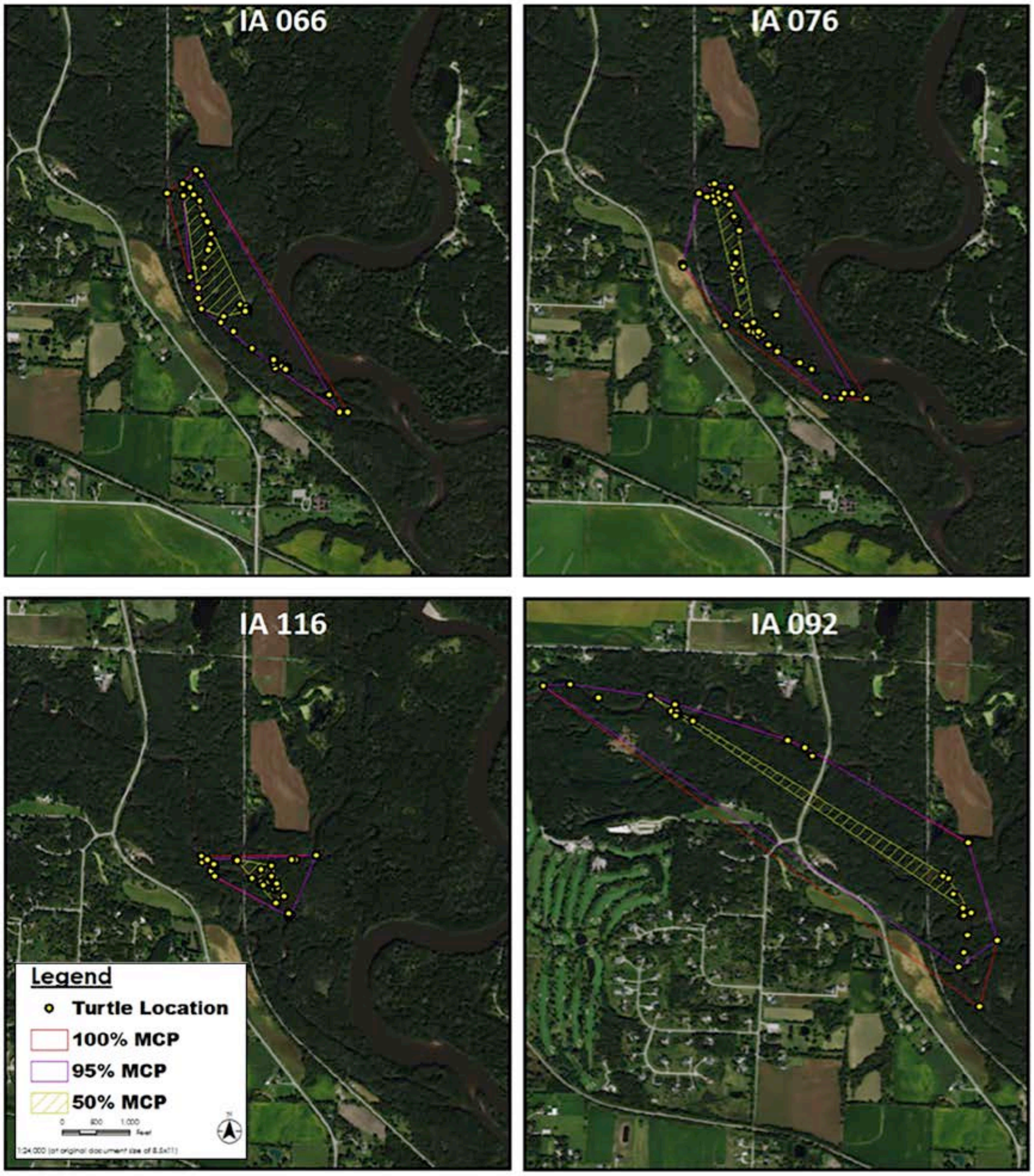

Figure B4. Calculated wood turtle home ranges (100%, 95%, and 50% MCP's) of male turtles IA066, IA076, IA116, and IA092, from the Black Hawk County (BH) study site.

APPENDIX C

WOOD TURTLE HOME RANGE OVERLAP FIGURES

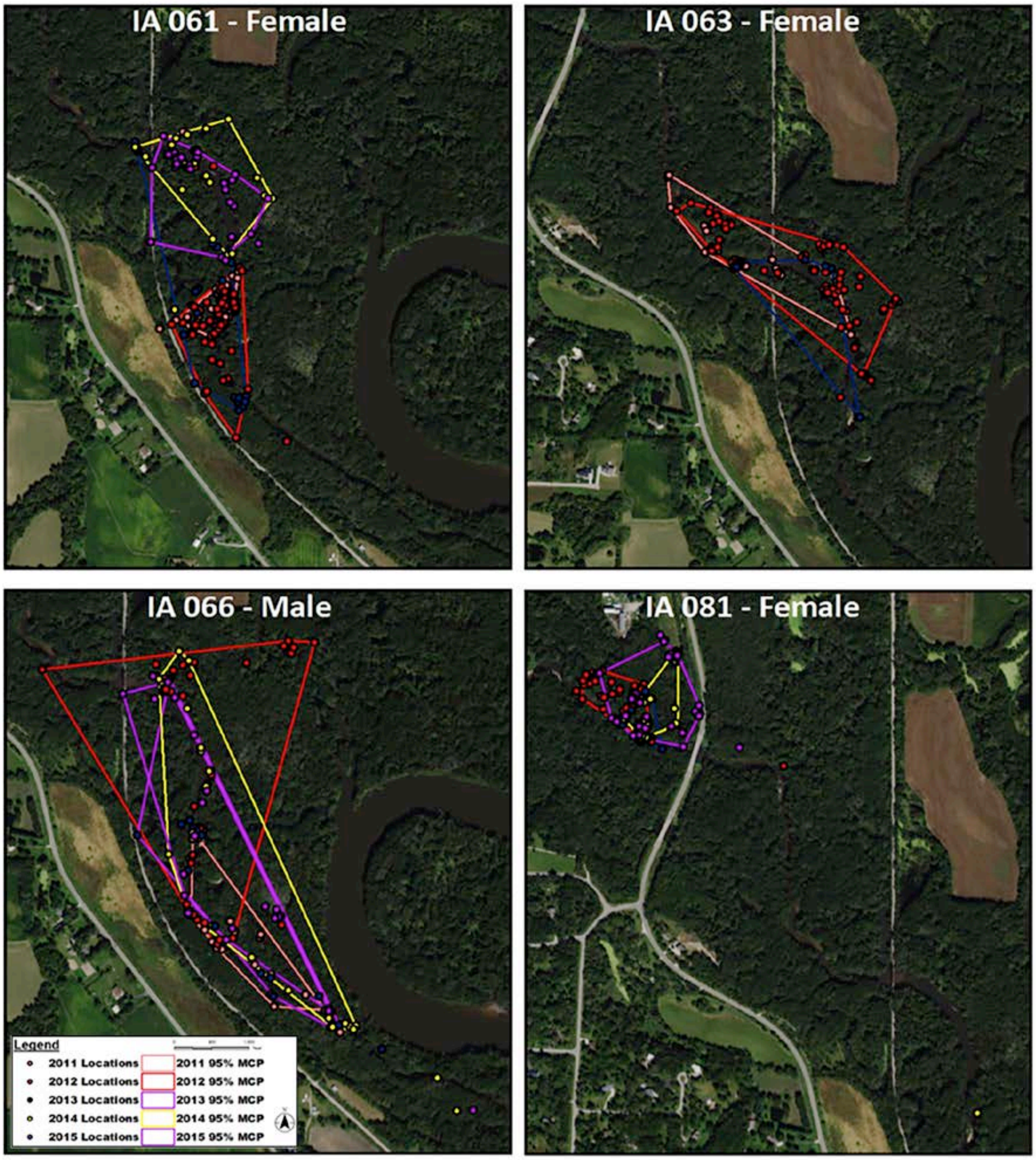

Figure C1. Yearly 95% MCP home range overlap from 2011–2015 of female turtles IA061, IA063, IA081, and male IA066, from the Black Hawk County (BH) study site.

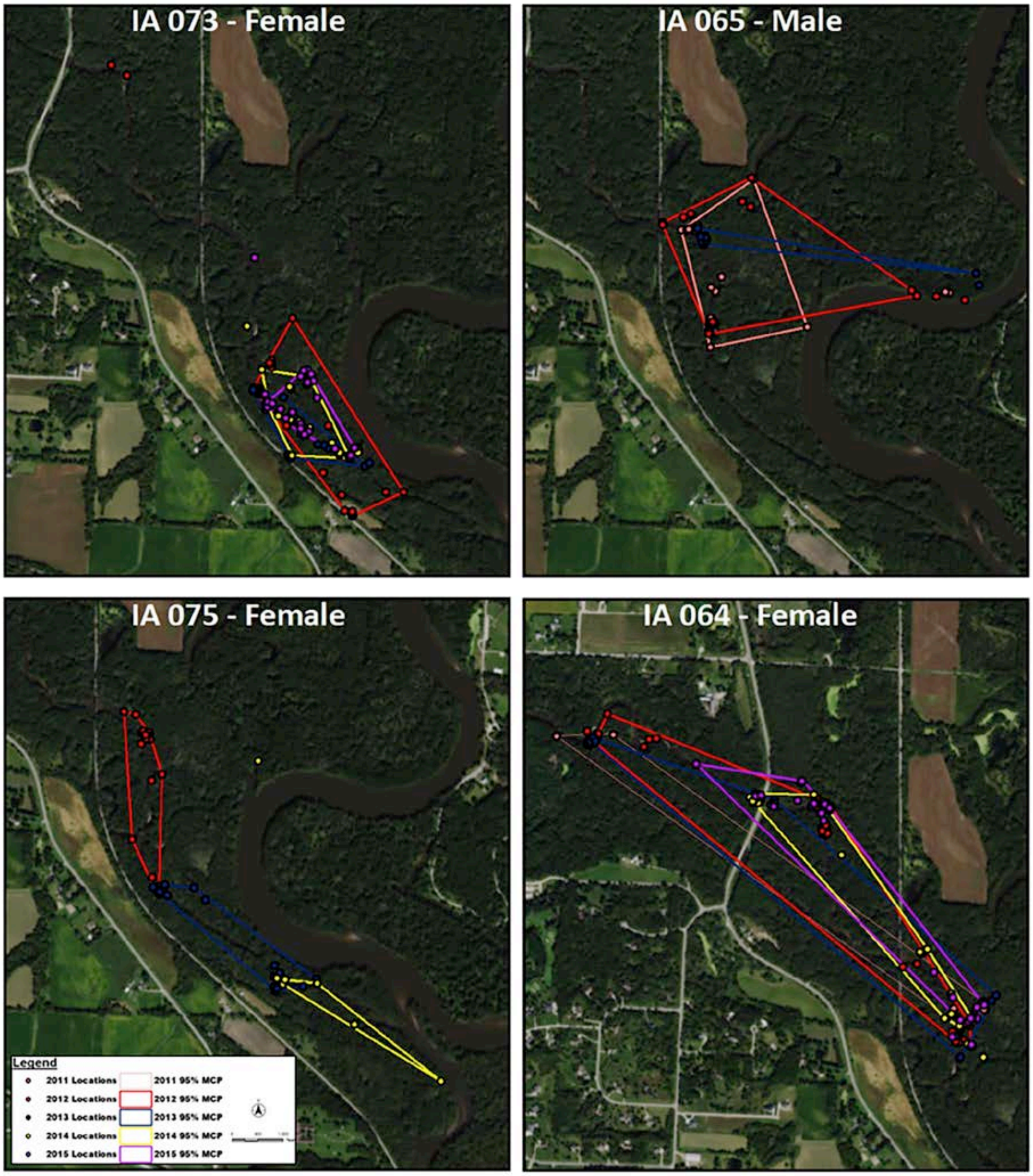

Figure C2. Yearly 95% MCP home range overlap from 2011–2015 of female turtles IA064, IA073, IA075, and male IA065, from the Black Hawk County (BH) study site.