TRANSLOCATION OF THE COPPERHEAD (*Agkistrodon contortrix*) IN NEBRASKA

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This study investigated translocation as a conservation strategy for the Copperhead (*A. contortrix*) in Nebraska. Nebraska represents the northwestern extreme of the range for the Copperhead and the snake is recognized as a species in need of conservation. In the spring of 2007, 6 Copperheads were translocated to a site with mixed riparian and prairie habitats and compared with 6 resident Copperheads on survival, habitat utilization, and activity measures. All snakes were implanted with radiotransmitters and tracked from the time of release until fall ingress. Translocated Copperheads foraged successfully and experienced less mortality than residents. As a whole, Copperheads spent significantly less time in prairie habitat than in forested or edge habitat and both resident and translocated groups preferred locations that provided near total to total immediate cover (cover below 2 meters) and near total to total canopy cover (cover above 2 meters). Translocated Copperheads did not differ in habitat preference or immediate cover when compared to resident snakes but did prefer near total to total canopy cover. Although not statistically significant, translocated Copperheads made longer movements and had larger activity ranges than resident Copperheads. Lastly, male Copperheads were found in edge habitat more often than females, made longer movements, and had larger activity ranges than females. Based on the overall data from this study, the Copperhead appeared to be a suitable candidate for translocation in Nebraska. A plan for the conservation of the Copperhead was developed based on the data.

Neonate Osage Copperhead (*Agkistrodon contortrix phaeogaster*) in leaf litter.

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INTRODUCTION

Translocation

Translocation is the movement of organisms from one location and release in a different location (IUCN, 1987; Griffith, *et al*., 1989; Reinert, 1999; Germano and Bishop, 2009). It is a popular yet controversial strategy for the management of animal populations and has been used with mammals, birds, reptiles, amphibians, and other organisms (Griffith, *et al*., 1989; Dodd and Seigel, 1991; Wolf, *et al*., 1996; Fischer and Lindenmeyer, 2000; Germano and Bishop, 2009). Translocation provides a quick and simple way to mitigate human-animal conflicts, conserve at-risk species, and supplement populations of game species (Fischer and Lindenmayer, 2000). The popularity of translocation is due to its perceived humane approach to animal management, good publicity, and political and land development expediency (Dodd and Seigel, 1991). Despite its popularity, the overall effectiveness of translocation is unclear.

Several reviews of translocation outcomes provided inconclusive results regarding the effectiveness of translocation as a management tool. Variable definitions of what constituted a successful translocation make translocation studies difficult to compare. Although the most common definition of success was the establishment of a viable, self-sustaining population (Griffith, *et al*., 1989; Dodd and Seigel, 1991; Germano and Bishop, 2009), this definition was not universal. For example, King, *et al*. (2004) defined success in terms of mortality between translocated and resident snakes while Germano and Bishop (2009) argued against definitions that defined success as simple overwinter survival of an organism. Success rates found in translocation review studies varied from

19–44% (Griffith, *et al*., 1989; Dodd and Seigel, 1991; Fischer and Lindemayer, 2000; Germano and Bishop, 2009) while failure rates ranged from 23–28% (Dodd and Seigel, 1991; Fischer and Lindenmayer, 2000; Germano and Bishop, 2009). A consistent criticism in these reviews was that the outcome of most translocation studies remained unknown (29–58%; Dodd and Seigel, 1991; Fischer and Lindenmayer, 2000; Germano and Bishop, 2009). Finally, Fischer and Lindenmayer (2000) noted that it is often the case that the results of unsuccessful translocations are never published. Thus, the true failure rate of translocation might be much higher. Conversely, Burke (1991) argued that when the unknown cases are removed from consideration, the success rate found by Dodd and Seigel (1991) rose from 19% to 45%. Similarly, when removing the unknown cases from Fischer and Lindenmayer (2000), the success rate of known outcomes rises to 49% as opposed to the reported 26% success rate for all cases (personal observation). Burke (1991) also argued that if successful invasive species events were included in these analyses the success rate of translocation would be even higher. Thus, the true effectiveness of translocation remains unclear.

Despite the lack of consensus on the effectiveness of translocation, several factors have been found to predict translocation success. One of the strongest factors predicting translocation success was improved habitat quality (Griffith, *et al*., 1989; Wolf, *et al*, 1996; Wolf, *et al*., 1998). Release within the animal's historic range and releasing more animals also predicted success (Griffith, *et al*., 1989; Wolf, *et al*., 1996; Wolf, *et al*., 1998; Fischer and Lindenmayer, 2000). Additional factors were less consistently identified. These factors included herbivory (Griffith, *et al*., 1989, but see Wolf, *et al*., 1998) and animal status (Wolf, *et al*., 1996, but see Wolf, *et al*., 1998). A lack of competitors and early breeders with large clutch sizes were also found to predict translocation success among birds and mammals (Griffith, *et al*., 1989).

Translocation and Reptiles

There are few comprehensive studies investigating translocation among reptiles. Although Fischer and Lindenmayer (2000) included several reptile, amphibian, and invertebrate studies in their review (7% of the total sample size), several researchers noted that success rates may vary between taxa and comparisons between taxa may not be valid (Wolf, *et al*., 1996; Platenberg and Griffiths, 1999). Additionally, one often cited review critical of translocation with reptiles and amphibians evaluated only one study involving snakes (Dodd and Seigel, 1991). Despite the paucity of reviews, factors relevant to success and failure have been found in reptile translocations.

Germano and Bishop (2009) found that most reptile translocations were conducted for conservation purposes and translocation for conservation predicted successful outcomes. Germano and Bishop (2009) also noted that the number of animals released predicted success for amphibians but not for reptiles. Further, although Fischer and Lindenmayer (2000) determined that the use of wild caught animals led to better translocation outcomes, Germano and Bishop (2009) reported no effect on success between wild caught and captive amphibians and noted that it was not possible to test this variable using the existing reptile literature. Burke (1991) suggested that artificially manipulating the sex ratio of translocated reptiles and amphibians may also lead to increased success. Factors predicting failure for translocation studies with reptiles included: poor habitat, translocation for conflict mitigation, poaching and collecting, predation, food scarcity, and disease (Fischer and Lindenmayer, 2000; Germano and Bishop, 2009).

Studies of translocated reptiles detailed several consistent observations. Most notably translocated reptiles demonstrated longer movements and larger home ranges than resident reptiles although not all differences were statistically significant (Reinert and Rupert, 1999; Plummer and Mills, 2000; Nowak, *et al*., 2002; Sullivan, *et al*., 2004; Butler, *et al*., 2005; Rittenhouse, *et al*., 2007; Brown, *et al*., 2009). The increased movements may expose the animal to increased energy use (Sullivan, *et al*., 2004) and increased risk of predation (Plummer and Mills, 2000; Sullivan, *et al*., 2004). Additionally, reptiles moved a short distance for conflict mitigation often returned to their original location or a new, undesirable location (Sullivan, *et al*., 2004; Butler, *et al*., 2005; Brown, *et al*., 2009). Mortality among translocated reptiles was generally higher or occurred at a faster rate than among resident reptiles (Reinert and Rupert, 1999; Plummer and Mills, 2000; Sullivan, *et al*., 2004). Dodd and Siegel (1991) also found one translocated snake to be a victim of disease and suggested translocated animals may spread disease. However, the possible bias in favor of discovering this radiotracked snake over finding untracked resident snakes with disease was not addressed. Still, other researchers also cautioned that translocation puts resident reptile populations at risk of new diseases (Storfer, 1999; Shine and Koenig, 2001). Additional risks not specifically studied in reptiles but noted in other taxa included reduction of genetic fitness (Stockwell, *et al*., 1996; Storfer, 1999) and physical and cognitive impairments (Teixeira, *et al*., 2007).

Despite the risks posed by translocation there are situations when translocation may be a suitable option. Small or isolated populations may benefit from the introduction of new genetic material (Dodd, 1993; Storfer, 1999). In situations where reptiles face potential eradication or habitat destruction, translocation should be considered (Reinert and Rupert, 1999). Sealy (2002) noted that some Timber Rattlesnakes (*Crotalus horridus*) may equate capture with predators making the snakes less likely to return to the same location. Site fidelity among translocated gopher tortoises (*Gopherus polyphemus*) was improved through the use of penning and young tortoises (Tuberville, *et al*., 2005). Such techniques may improve translocation success for other reptile species. Additionally, the risks observed in translocated reptiles may be temporary. Translocated snakes appeared to acclimate to the new location over time as evidenced by reduced movements and reduced home range sizes that approached equivalency with residents (*C. horridus*, Reinert and Rupert, 1999, Walker, pers. comm.; *Notechis scutatus*, Butler, *et al*., *2005*; *Crotalus atrox*, Brown, *et al*., 2009). Finally, translocated snakes demonstrated some of the same key behaviors as resident snakes that suggest the potential for long-term successful outcomes, including the same frequency of movements, similarity in habitat preference, following other snakes to hibernacula, mating, and body mass increase (Reinert and Rupert, 1999; Butler, *et al*., 2005).

Copperhead

The Copperhead (*Agkistrodon contortrix*) is a small to medium sized venomous snake native to the eastern half of the United States (Gloyd and Conant, 1990; Conant and Collins, 1998). Five subspecies of Copperhead are currently recognized: Southern

Copperhead *A. c. contortrix* (Linnaeus, 1766), Northern Copperhead *A. c. mokasen* (Palisot de Beauvois, 1799), Broad-Banded Copperhead *A. c. laticinctus* (Gloyd and Conant, 1934), Trans-Pecos Copperhead *A. c. pictigaster* (Gloyd and Conant, 1943), and Osage Copperhead *A. c. phaeogaster* (Gloyd, 1969). Males tend to be longer than females, with an average total length of 724 mm for males and 660 mm for females (Fitch, 1960). Although coloration varies slightly by geographic region, Copperheads are cryptically colored with a cream colored base color, dark reddish brown cross bands occurring laterally down the body, and ventral scales ranging from cream colored to gray and black (Fitch, 1960; Gloyd and Conant, 1990). The crossbands are narrowest at the spine and are widest near the ventral scales although not all crossbands are symmetrical or complete (Fitch, 1960). The scales are dorsally keeled and young Copperheads have bright yellowish green tails that fade with age (Fitch, 1960) (Fig. 1).

The geographic range of the copperhead extends from New York to Georgia and the northern panhandle of Florida and extends westward to Nebraska, Kansas, Oklahoma, and Texas (Conant and Collins, 1998) (Fig. 2). Copperheads are found in deciduous, rocky habitats near streams and rivers although they are found in some open areas (Fitch, 1960; Fitch and Shirer, 1971; Reinert, 1984; Gloyd and Conant, 1990; Conant and Collins, 1998; Smith, *et al*., 2009). In the northern portion of their range, Copperheads may spend up to 6 months in hibernation with spring emergence usually occurring in April and fall ingress occurring in October (Fitch, 1960; Smith, *et al*., 2009). Copperheads utilize rocky dens and may share these dens with *Crotalus horridus, Coluber constrictor, Pantherophis obsoletus, Thamnophis spp.,* and other snakes (Fitch, 1960; Gloyd and Conant, 1990). Rodents constitute the primary prey items for adult

Figure 1. Copperhead coiled on oak leaf litter. This Copperhead still has a yellowish green tail.

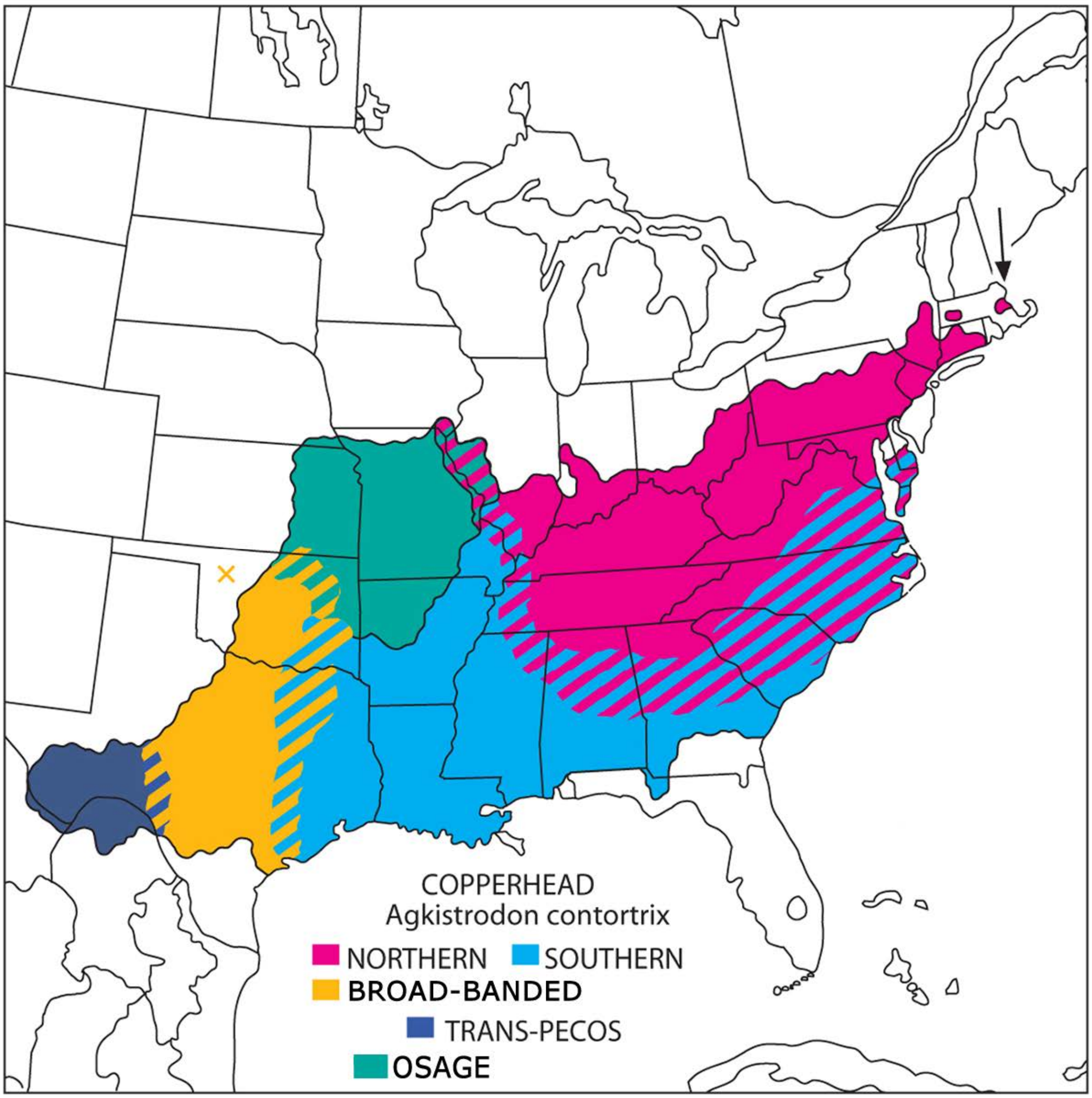


Figure 2. The geographic range for all five subspecies of *A. contortrix*.The Osage Copperhead (*A. c. phaeogaster*) is represented in green. Nebraska represents the northwestern periphery of the copperhead's range. From Conant and Collins, 1998.

Copperheads, with voles and mice constituting the bulk of rodent prey (Fitch, 1960; Gloyd and Conant, 1990; Greenbaum, 2004; Safer and Grace, 2004). Copperheads utilize ambush strategies and hemotoxic venom delivery to subdue prey (Fitch, 1960; Gloyd and Conant, 1990; Greenbaum, 2004). Predators include birds, snakes, rodents, bullfrogs (*Lithobates catesbiana*) and mammals (Fitch, 1960; Gloyd and Conant, 1990). Females generally reach sexual maturity around three years of age with males reaching maturity at the end of their second year (Fitch, 1960; Gloyd and Conant, 1990). Mating generally occurs in the spring although some fall mating does occur (Fitch, 1960; Gloyd and Conant, 1990, but see Smith, *et al*., 2009). Males may engage in ritualized combat with the dominant male initiating mating (Fitch, 1960; Schuett, 1982; Schuett and Gillingham, 1988; Gloyd and Conant, 1990; Schuett, *et al*., 1996). Females also demonstrate some sexual selection against subordinate males (Schuett and Duvall, 1996). Gravid females will generally remain near a hibernaculum among rocky areas (Fitch, 1960; Reinert, 1984; Smith, *et al*., 2009). Parturition from spring matings occurs in the fall prior to fall ingress (Fitch, 1960). Copperheads give live birth to approximately 5 young (Fitch, 1960; Gloyd and Conant, 1990), although clutch sizes of 17 have been reported (Fitch, 1960).

In Nebraska, the Copperhead (*A. c. phaeogaster*) is listed as a "nongame species in need of conservation" per Nebraska Administrative Code 010.02 (Nebraska Administrative Code, 2004). Nebraska is considered the northwest extreme of the Copperhead's range (Fitch, 1960; Gloyd and Conant, 1990; Conant and Collins, 1998). It is found in only two southern counties in Nebraska: Richardson County, the most southeasterly county in Nebraska, and Gage County, along the Nebraska-Kansas border south of Beatrice (Lynch, 1985) (Fig. 3). Appropriate Copperhead habitat in Nebraska is limited and threatened. Fogell (2000) noted that suitable habitat and hibernacula for the timber rattlesnake, *C. horridus*, are under threat of destruction and degradation in Nebraska. Fire suppression, invasive species, and the destruction of limestone hibernacula threaten the continued existence of *C. horridus* in Nebraska. These same threats apply to Copperheads due to the sympatric nature of the species.

Conservation

Ideally, the process of conserving a species should begin before the species is threatened (Dodd, 1993). Further, the conservation plan must be based on the behavior and ecology of the particular species (Reinert, 1993). A number of factors have been identified as important to understanding the ecology of a species and developing a conservation plan, including: habitat use, spatial arrangement, movement, life history, and intraspecific variation (Gregory, *et al*., 1987; Dodd, 1993; Reinert, 1993). Further, species with specific dens warrant monitoring as do those species on the periphery of their range (Dodd, 1993). Thus, the Copperhead makes an ideal candidate for conservation study.

Although some authors do not support the use of translocation (Reinert and Rupert, 1999; Nowak, *et al*., 2002; Seigel and Dodd, 2002; Sullivan, *et al*., 2004) others offer some support for translocation (Burke, 1991; Reinert, 1991; Lubow, 1996; Trenham and Marsh, 2002). A successful translocation plan must be specific to the needs of the species and consider appropriateness of the site, ecology of the species, source of the species, and provide ongoing monitoring (Gordon, 1994; Lubow, 1996). The availability

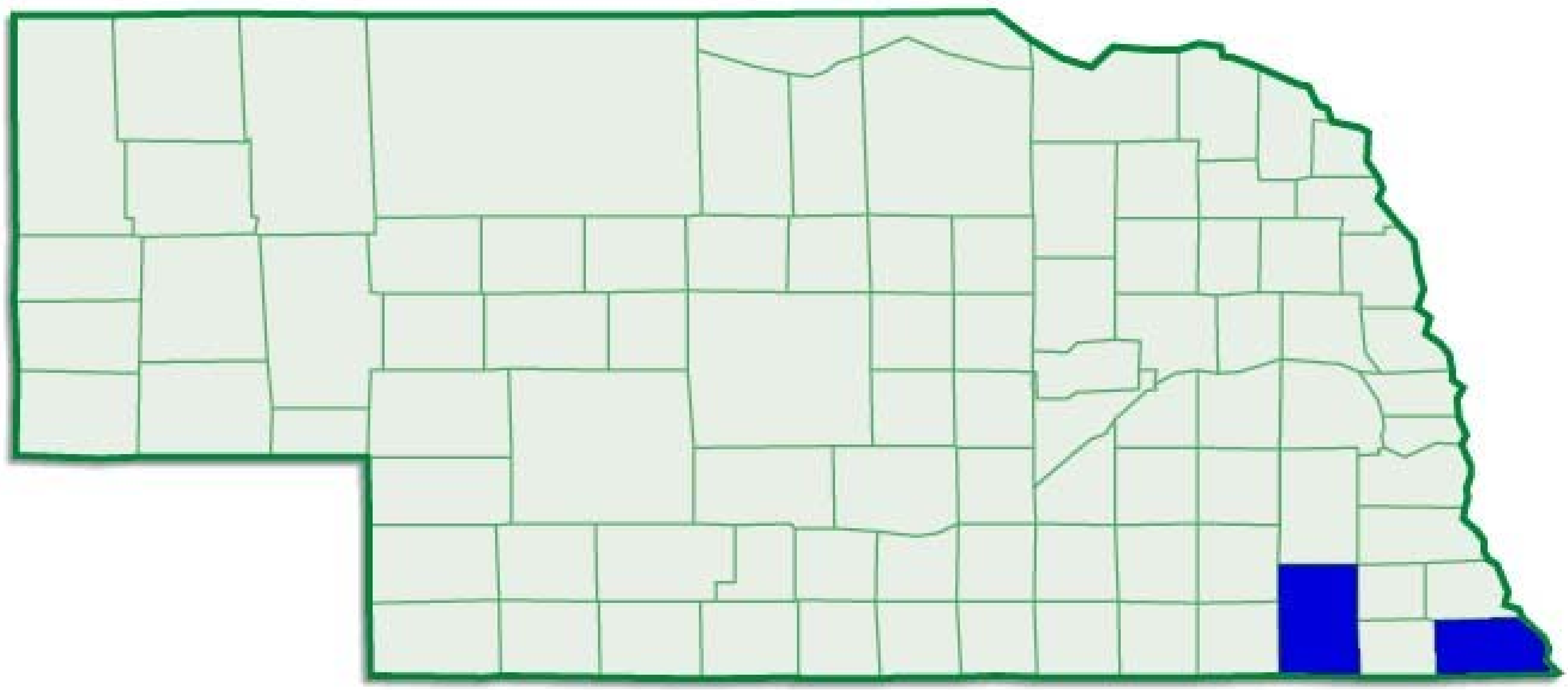


Figure 3. County map of Nebraska. Copperheads are known from two southeastern Nebraska counties (colored blue). Richardson County is the extreme southeast county and Gage County is further to the west than Richardson County.

of both a source site and a seemingly suitable translocation site suggests that the Copperhead is a suitable test subject for a preliminary translocation study.

Study Objectives

The objectives of the present study were 1) to measure the spatial usage and movement for resident and translocated Copperheads, 2) to measure the spatial usage and movement for male and female Copperheads, 3) to identify habitat usage for conservation recommendations, and 4) to determine if Copperheads are a suitable translocation candidate. It was predicted that translocated Copperheads would experience higher mortality and less foraging success than resident Copperheads. Translocated Copperheads were also expected to demonstrate greater home ranges, larger core ranges, and have greater overall movements than resident Copperheads. No differences were expected between the type of habitat preferences of translocated and resident Copperheads. Finally, it was predicted that male Copperheads would demonstrate larger home ranges, larger core ranges, and greater movement than female Copperheads. These details will provide information for the management and conservation of Copperheads in Nebraska.

MATERIALS AND METHODS

Study site

The present study occurred in southern Gage County, Nebraska from April 2007 through October 2007. Gage County is located in southeast Nebraska and borders Kansas. Both the source site of the translocated Copperheads and the translocation site lie entirely on private property. The source site of the translocated Copperheads was approximately 106 hectares (ha) comprised rocky ledges and hills, row-crops, heavy forest, and open grasslands (Fig 4). This site was a former quarry with remnants of buildings and roads. The Big Blue River defined the southwestern edge of the site and a gravel road provided the main access to the site. At this time, the land is primarily used for hunting. Based on discussions with the landowner and several years of mark-recapture surveys, it was believed that this source site could accommodate the loss of 6 adult Copperheads. There were at least 4 known hibernacula on this site and numerous Copperheads ranging from juveniles to large adults have been marked at this site.

The translocation site was located approximately 9-10 km to the southeast. The site was approximately 227 ha and included the private property of several landowners (Fig. 5). Land composition included riparian forest, prairie, and row-crops (Fig. 6A and 6B). The prairie is grazed some years and hayed in other years. The land was formerly the site of a hydroelectric plant and related structures. Several foundations and overgrown dirt roads still exist on the land and the dam still spans the river. Some human utilization of the riparian areas continues with a dirt access road, mowed area in the forest for camping, and hunting in the fall. Two occupied houses are situated on the study site and

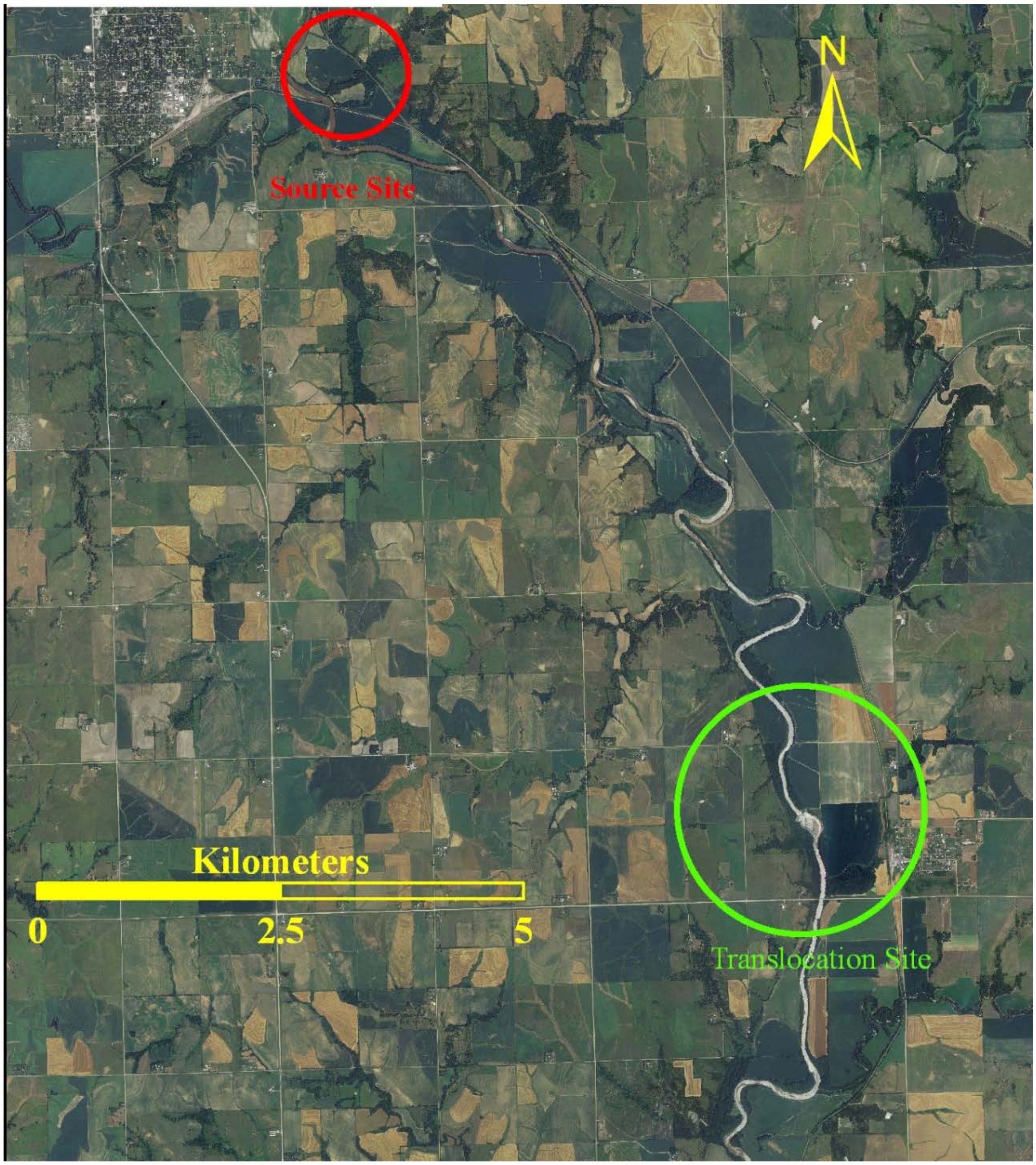


Figure 4. Location of the source site and translocation site. Wymore, Nebraska is to the west of the source site and Barneston, Nebraska is to the east of the translocation site.

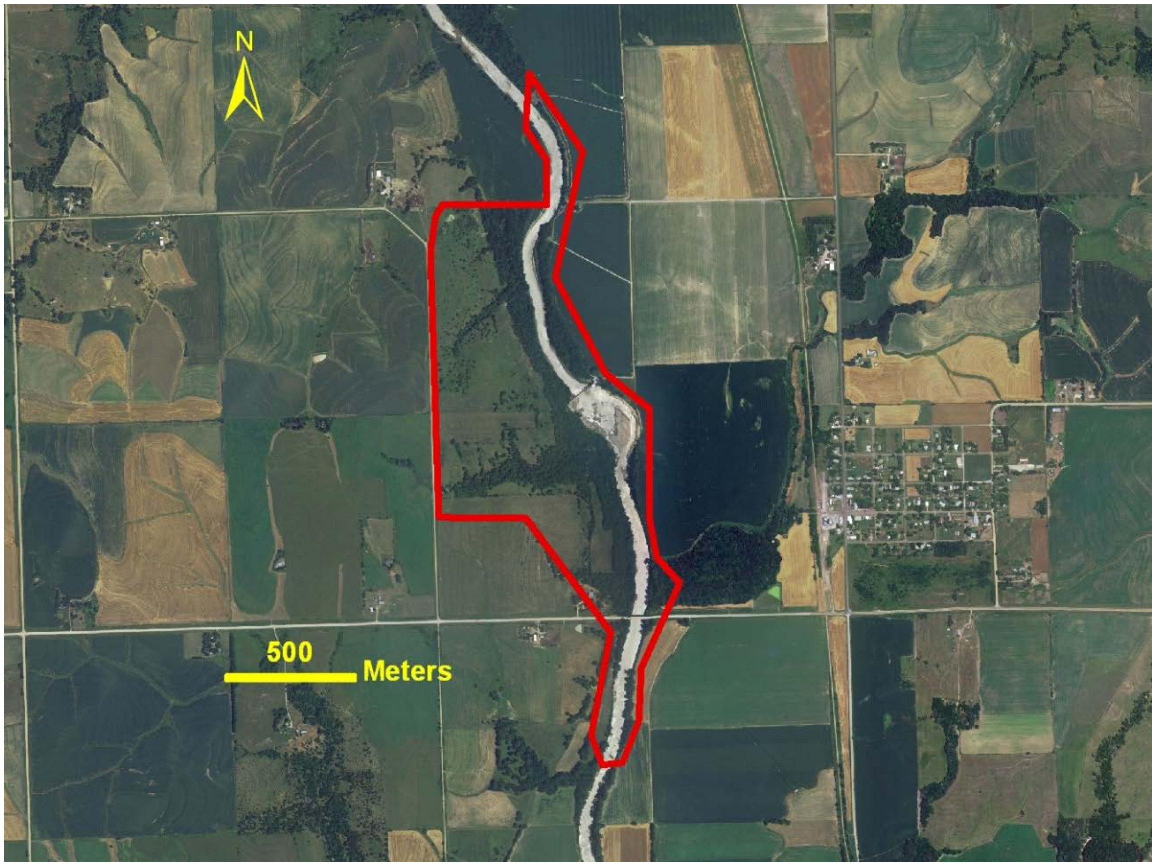


Figure 5. Satellite image of the translocation site. The area contained within the red line indicates the approximate boundary of accessible private property. The Big Blue River runs north to south through the center of the map. Barneston, Nebraska is located to the east of the Big Blue River.

A.

B.

Figure 6. (A) Forested habitat of the translocation site in the early spring; (B) Edge habitat of the study site in early spring. This particular edge was a unique area at the translocation site due to the combination of a moderate density of trees and a variety of prairie vegetation.

occasionally snakes (including both *A. contortrix* and *C. horridus*) are found near the houses (Peterson, pers. comm.). The riparian areas were dominated by oak (*Quercus* spp.), honey locust (*Gleditsia triacanthos*), and red cedar (*Juniper virginiana*). Ground vegetation was characterized by shining bedstraw (*Galium concinnum*). The prairie consisted primarily of switchgrass (*Panicum virgatum*), milkweed (*Asclepias* spp.), and Big bluestem (*Andropogon gerardii*).

Snake acquisition

Copperheads were captured following spring emergence in April, May, and June. Visual searching occurred at and around known and suspected hibernacula (Fig. 7A and 7B). Nearby railroad timbers were lifted at the source site and resulted in several captures. Rocks, fallen tree limbs, and metal sheeting were also lifted at both sites to increase the chances of encounters. All Copperheads were captured using snake tongs designed for such purposes (MidwestTongs.com).

Data Collection

Following each capture, the Copperhead was placed in a suitable cloth bag for holding. Copperheads were captured each time visual contact was made unless the snake escaped to an inaccessible location or capturing it would require the destruction of the location. The latitude and longitude of the snake was recorded with a handheld Global Positioning System unit (GPS; Magellan Gold, MiTAK Digital Corporation, Santa Clara, California). The temperature of the air was recorded with a handheld infrared temperature device (PE-1, Pro-Exotics, Littleton, Colorado 80125) and the ground temperature was

A.

B.

Figure 7. (A) Southern facing hibernaculum in the spring. Two translocated Copperheads used this hibernaculum in the fall; (B) Newly identified, north facing hibernaculum in the summer. Three resident Copperheads likely came from this hibernaculum.

recorded with a handheld infrared temperature device (PE-1; or Raytek Minitemp MT6, Raytek, Santa Cruz, California). Habitat type was determined by surveying the vegetation in the area surrounding the observation point. An observation point was determined to be located in forested areas if it was located within a high density of trees. A point was determined to be located in the prairie if there were few to no trees and it occurred primarily in grassy areas. Edge areas were defined as those areas where the prairie met the forested areas and contained some tree cover but also prairie vegetation. Immediate cover was defined as cover available less than 2 meters above the snake. It was categorized (0-25%, 26-50%, 51-75%, 76-100%; Patten, 2006) by visual survey of the vegetation covering the Copperhead's location. Snakes found under an object (e.g., metal sheeting) were placed in the 76-100% category. Canopy cover was defined as cover 2 meters or more above the snake and was determined by visually estimating tree cover over the snake's location. Canopy cover was also categorized using the 0-25%, 26-50%, 51-75%, 76-100% divisions. Snakes were weighed while in the bag using a digital hanging scale (Digipen-500, American Weight Scales, Inc., Norcross, Georgia 30092). The empty weight of the bag was subtracted from the weight of the bag with the snake to determine the Copperhead's weight. Although Reinert (1992) recommended a minimal amount of interference with the snakes after initial release, capture was the only way to gauge foraging success. The snake was assumed to have foraged successfully if it gained weight from the previous capture.

Following the initial measurements, the Copperhead was then coaxed into a clear plastic tube designed for venomous snakes (MidwestTongs.com) (Fig. 8). These tubes prevented the snake from turning around or biting the researcher during handling. It also

Figure 8. Copperhead coaxed into a tube at the translocation source site.

reduced the risk of injury to the snake by reducing the amount of manipulation needed to gather additional information. The snout-vent length (SVL) was measured using a non-stretch cloth tape measure from the tip of the snout to the anal end of the anal scale. Tail length was also measured from the end of the anal scale to the tip of the tail. Total length (TL) was determined by adding SVL and tail length. Sex was determined through the use of probes designed for sexing snakes. The snake was determined to be male when the probe extended more than a few millimeters into the tail base before encountering resistance. The snake was determined to be female when the probe encountered resistance immediately or within a few millimeters of entering the tail. No force beyond that necessary to slide the probe was used and probing stopped immediately upon encountering resistance. The dorsal cross bands were counted and recorded. Upon completion of all measurements previously unmarked snakes were implanted with a Passive Integrated Transponder tag (PIT tag; Biomark, Boise, Idaho 83702). PIT tags can be safely injected subcutaneously, using a spring-loaded syringe (Jemison *et al*., 1995), and allow for the collection of mark-recapture data (Figure 9).

Surgical Procedure

Twelve snakes (6 translocated and 6 resident) were selected for the present study. This number was determined following the recommendation of Reinert (1992) that a single researcher should limit the number of subjects to 10-15 and include at least 5 snakes per study group. In May 2007, 3 male and 3 female snakes were captured at the source site for translocation. In May and June 2007, 4 male and 2 female snakes were captured at the translocation site to serve as the resident comparison group. Due to the

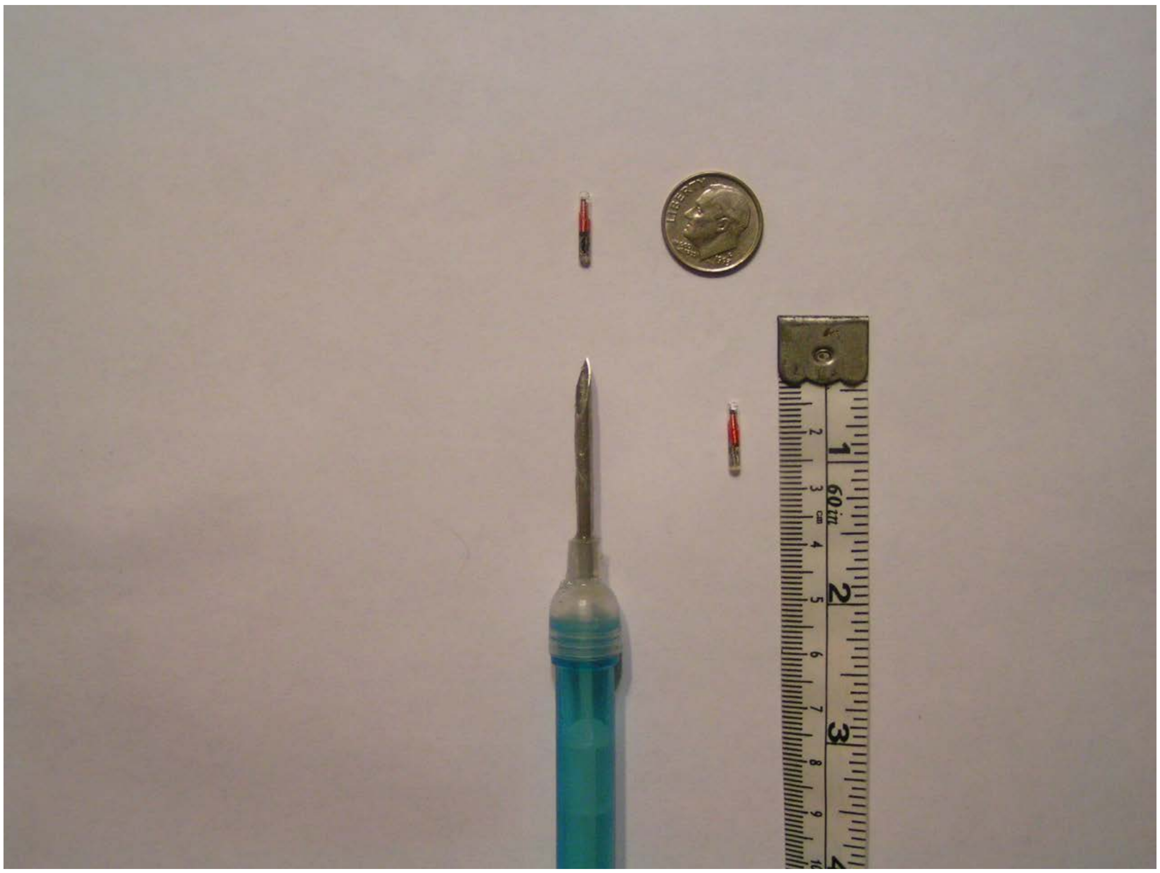


Figure 9. Spring loaded syringe and Passive Integrated Transponder (PIT) tag.

potential challenges of finding enough snakes that met the implantation criteria, it was not possible to randomly pick snakes for inclusion at either site. Reinert and Cundall (1982) recommended that transmitters not exceed 5% of the total weight. Therefore, the criteria for inclusion in the study were 1) a total weight of at least 100 grams, and 2) an outward healthy appearance and behavior.

All surgeries occurred in the Herpetology Laboratory, Allwine Hall, Room 527 at the University of Nebraska at Omaha. Snakes were placed into a clear plastic tube for the surgery. Snakes were temporarily anesthetized with an inhalant anesthetic (Isoflurane, USP, Baxter Healthcare Corporation, Deerfield, IL 60015). Surgical procedures followed Reinert and Cundall (1982), which were specifically developed for *A. contortrix*. One end of the tube was sealed with only a small opening for the administration of the anesthetic. The snakes were kept at temperatures between 25º C and 29º C prior to the surgery. This temperature range allowed for safe and quick regulation of induction and emergence from anesthesia. The surgical plane of anesthesia was achieved when the body was completely limp and no reaction occurred to tactile stimulation of the tail. When the plane of anesthesia was obtained, the external surgical site was cleansed with a topical antiseptic (Providone-iodine solution, Clay-Parks Labs, Inc., Bronx, NY 10457). The area of incision was approximately three fourths the SVL just anterior to the gonads. An approximately 1.5 cm incision was made between the first and second dorsal scale rows. The transmitter (SB-2, Halohil Systems, Ltd., Ontario, Canada) (Fig. 10) was then inserted into the body cavity through the incision. A second, small incision was made in the dermis approximately 22 cm anterior of the transmitter. An approximately 2.38 mm (3/32 inch) hollow brass tube (Stock #8126, K & S Engineering, Chicago, IL) was gently

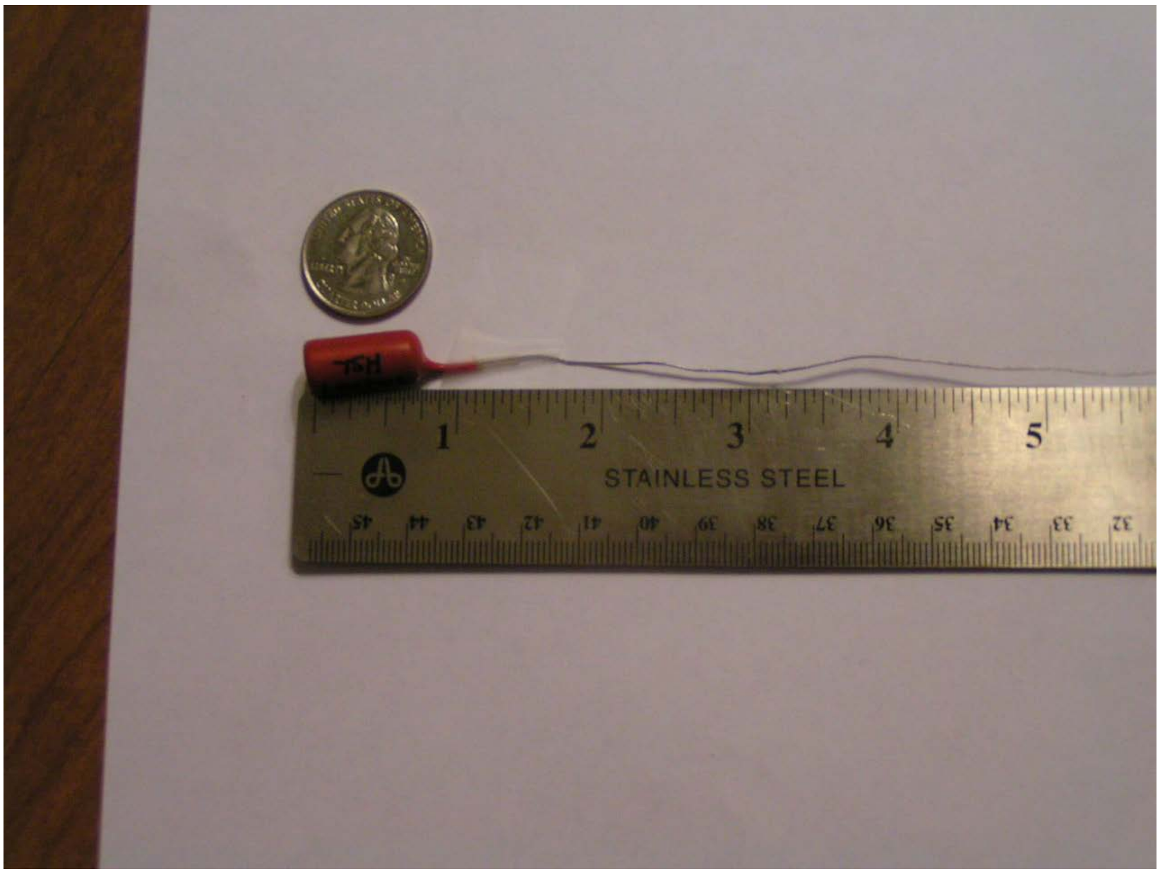


Figure 10. Halohil Systems, Ltd., SB-2 transmitter.

inserted immediately beneath the dermis from the transmitter incision through the anterior incision to allow the antenna to be threaded through the tube. Once the antenna was fully extended the tube was pulled out through the anterior incision leaving the antenna fully extended beneath the dermis. All incisions were closed using absorbable sutures (Dexon* S, 3-0, 7744-41) and then coated with liquid bandage (New Skin, MedTech, Jackson, WY, 83001) (Fig. 11A and 11B). Postoperative monitoring lasted a minimum of 24 hours. No fatalities occurred during or immediately after the surgeries (Fig. 12A and 12B).

Release and radiotelemetry

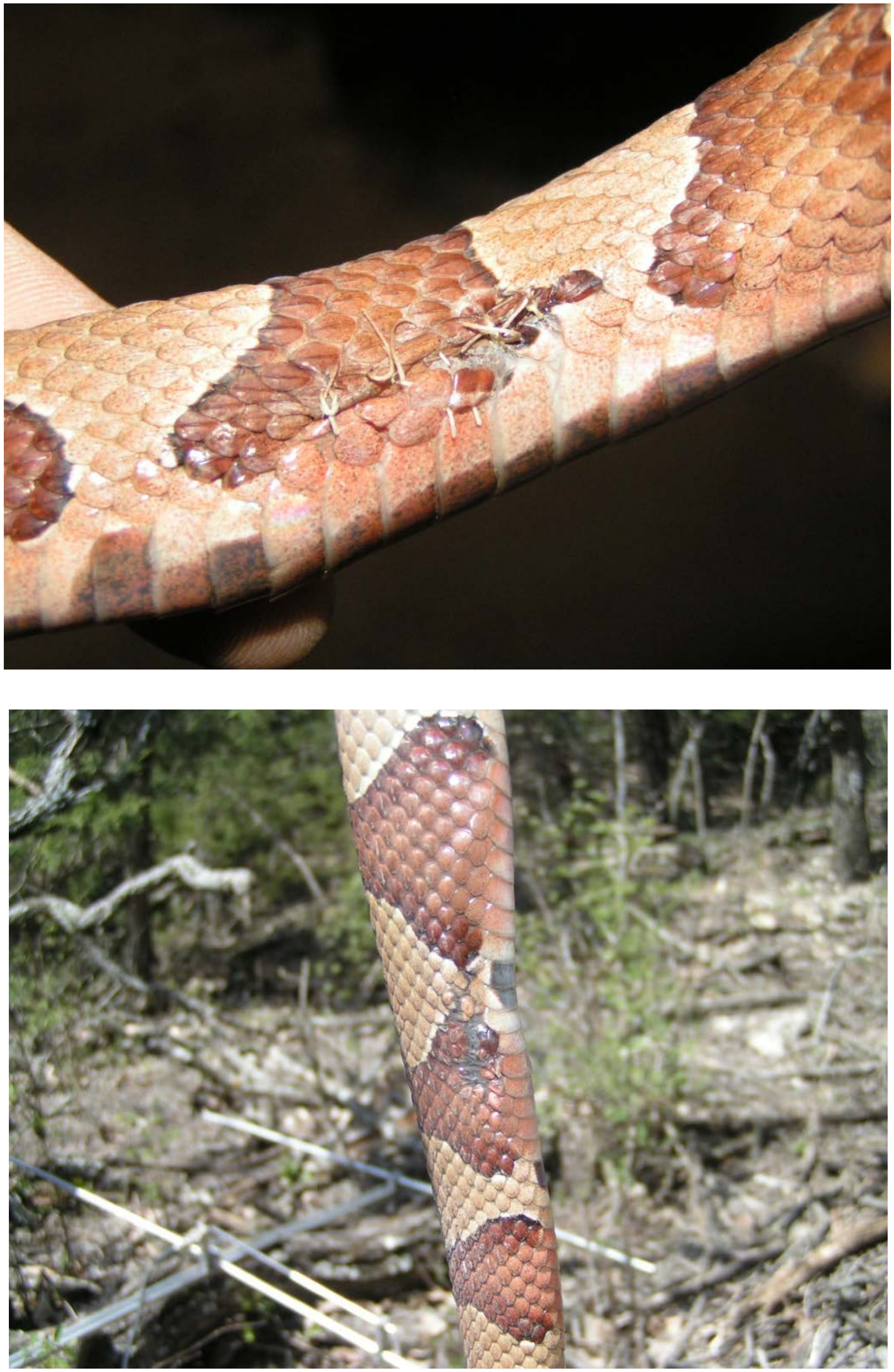
Translocated Copperheads were released at the entrance of what was believed to be a hibernaculum. The site was a rocky ledge beneath 100% canopy cover with thick leaf litter and several pieces of metal sheeting that had been at the site for many years. Historically, this area is one of the first locations at the study site where Copperheads and other snakes are found. The released Copperheads entered a rock hole shortly after deposition near the entrance (Fig. 13). It was later determined that this site was not a hibernaculum. Resident snakes were released at the site of capture. Three of the resident snakes were not captured at hibernacula, although one was approximately 10-12 meters from a hibernaculum area. The last resident snake was released at the site of capture on July 1, 2007.

Snakes were radiotracked once per week. Reinert (1992) recommended tracking snakes a minimum of every 2 days; however, this regimen was not possible. Snakes were

A.

B.

Figure 11. (A) Placement of the transmitter into the body cavity; (B) Insertion of the tube for extending the antenna beneath the dermis.



A.

B.

Figure 12. (A) Main incision stitched with absorbable sutures shortly after completion of surgery; (B) Surgical site 1 year following implantation of transmitter.

Figure 13. Three translocated Copperheads at release site. Each snake retreated into an opening in the rock (mid-upper left of the photo)

tracked with a radio telemetry receiver (TR-2E, Telonics, Mesa, Arizona 85204 and later an LA12-Q, AVM Instrument Company, LTD, Colfax, California 95713) (Fig. 14A and 14B).

Analyses

Data were entered into Microsoft Excel (Microsoft Corporation, Mountain View, California 94043) and analyses were conducted in SPSS 14.0 (SPSS, Inc., Chicago, IL 60606). All significance tests were set at $P < 0.05$. Spatial data were entered and analyzed in a Geographic Information System (GIS) program (ArcView 3.2 and ArcView 9.3.3, ESRI, Redlands, California 92373). The Animal Extension (P. N. Hooge and B. Eichenlaub. 1997. Animal movement extension to arcview. ver. 1.1. Alaska Science Center - Biological Science Office, U.S. Geological Survey, Anchorage, AK, USA.) for ArcView 3.2 was also used to calculate home range and activity areas.

Following the recommendations of Reinert (1992) and Gregory, *et al*. (1997), the following measurements were identified as informative for spatial activity and comparisons: total distance moved (sum of all linear distances), average movement per move (sum of all linear distances divided by the number of observations), mean daily movement (sum of all linear distances divided by the number of days from first observation to last observation), and range width (difference between two most distant points). The activity area was calculated using two separate methods. The Minimum Convex Polygon (MCP) measured the area contained within a polygon connecting all the outermost GPS locations. The MCP is a simple and common method of calculating activity area but it is sensitive to low sample sizes (Reinert, 1992; Seaman, *et al*., 1999).

A.

B.

Figure 14. (A) Radiotracking on the prairie; (B) Radiotracking next to the Big Blue River.

Additionally, the MCP does not account for the amount of time spent in any given area and does not allow for possible areas outside the polygon to be included in the activity area (Powell, 2000). However, MCP may be an accurate estimate of home range area for reptiles when sufficient data points are measured across the entire active season (Row and Blouin-Demers, 2006). The second method used to estimate activity areas was the fixed kernel density estimator. The fixed kernel density estimator determines an animal's activity using probability estimates of activity usage (Warton, 1989; Powell, 2000). Kernel estimates account for the amount of time spent, based on the number of observations, within the home range (Seaman, *et al*., 1999). The 95% kernel density defined the snake's home range and the 50% kernel density defined the core range. The core range is the area within the home range that is used most extensively by the snake (Reinert, 1992; Powell, 2000). These percentages are generally accepted estimates of a home range and core range, respectively (Powell, 2000). Additionally, Powell (2000) noted that fixed kernel estimates are generally more accurate than adaptive kernels. Lastly, no correction was directed toward the problem of autocorrelation. Seaman *et al*. (1999) and Powell (2000) noted that autocorrelation may not be a serious problem for home range estimates.

RESULTS

Demographics

Resident and translocated Copperheads did not differ significantly in snout-vent-length (SVL), tail length, total length (TL), or weights (Table 1). Copperheads in the translocation group were involved in the study for significantly more days ($\bar{x}$ = 145.5 days ± 11.73 days) than the resident Copperheads ($\bar{x}$ = 96.00 days ± 39.01 days; t_{10} = -2.977, P = 0.014). This difference remained significant even after removing the resident C272 (resident snakes = 109.60 days ± 22.69 days; t_9 = -3.39, P = 0.008). The snakes were tracked at least once per week from May 30, 2007, through October 20, 2007. Additional tracking days occurred in some weeks for a total of 23 field days.

Observations

Despite the maximum 23 data points for each snake, no snake was located 23 times. The range of observations, excluding C272, was 9 to 17 observations. The number of recorded observations made was significantly higher for translocated Copperheads ($\bar{x}$ = 14.17 observations ± 2.14 observations) than for resident Copperheads ($\bar{x}$ = 10.40 observations ± 1.67 observations; t_9 = -3.199, P = 0.011). However, limiting the comparison of observations to July 1, 2007 through the end of the study, translocated Copperheads were observed 9.2 ± 1.7 times compared to 8.2 ± 1.1 times for resident Copperheads. This difference was not significant (t_9 = -1.081, P = 0.308).

Table 1. Comparison of Copperhead demographics by origin.

Snake	Sex	Origin	SVL (mm)	Tail length (mm)	TL (mm)	Weight (g)
C020	Male	Translocated	800	115	915	192
C071	Female	Translocated	588	82	670	218
C140	Female	Translocated	540	86	626	104
C180	Female	Translocated	596	84	680	168
C219	Male	Translocated	556	94	650	104
C279	Male	Translocated	639	106	745	184
Mean			619.83	94.50	714.33	161.67
(SD)			*(94.72)*	*(13.35)*	*(106.11)*	*(47.50)*
C043	Female	Resident	572	87	659	152
C158	Male	Resident	831	112	943	281
C249	Female	Resident	476	71	547	116
C272	Female	Resident	600	91	691	162
C321	Male	Resident	702	108	810	No data
C340	Female	Resident	483	72	555	102
Mean			610.67	90.17	700.83	162.60
(SD)			*(136.33)*	*(17.34)*	*(153.19)*	*(70.67)*
			t = -0.0135	t = -0.485	t = -0.177	t = 0.026
			df = 10	df = 10	df = 10	df = 9
			P = 0.895	P = 0.638	P = 0.863	P = 0.980

At least two Copperheads temporarily entered areas that were off-limits to this investigator. Resident Copperhead, C158, was lost following a visual observation on July 1, 2007, and was not located again until July 28, 2007. It was suspected that C158 moved north but it was not possible to track it to the north without damaging the crops of a private land owner. A similar problem occurred for translocated Copperhead C279. It was lost following an observation on July 25, 2007, until August 25, 2007, and likely moved further south than the investigator was able to follow without damaging crops or risking equipment by walking in the river. Overall, 4 of the 5 resident Copperheads were lost for more than 2 weeks at some point during the study despite active searching, with C158 and C249 having 2 missing periods exceeding 2 weeks. The average time that resident Copperheads were lost was 30.80 days ± 10.83 days. Five of the 6 translocated snakes were lost during the study, with C219 and C279 missing for 3 separate periods, for an average of 22.38 days ± 6.09 days. There was no significant difference between the average time missing between resident and translocated Copperheads (t_{11} = 1.816, P = 0.097).

Many of the data points were collected without making visual contact with the snake. Copperheads were frequently located beneath some sort of cover. It was decided that the habitat would not be disturbed for fear of causing damage to the site's future suitability for snakes. Other locations were potentially unstable with limited visibility. Additionally, several Copperheads utilized habitat close to the river edge on steep embankments. Access to these sites ranged from precarious to inaccessible. Finally, C249, a resident female, appeared to make use of subterranean shelters while on the prairie. Despite very careful and intensive searching in the grasses no visual contact was made. However, on at least two occasions, small mammal burrows were discovered during the searches. In cases when the snake could not be visually observed, location data was collected when the snake's location could be reasonably estimated (e.g., in the case of debris, the location where the transmitter made the loudest sound was used to estimate the snake's location).

Mortality

No translocated snakes were observed to perish during the study period. Two resident Copperheads were predated during the study period. The transmitter for C272, the largest female in the study, was located on a dirt road on August 4. The dirt road separated the snake's most recent confirmed location and a corn field. There were no bite or chew marks on the transmitter but the antenna was shorter than at the time of implantation. No corpse was located. C272 was removed from some spatial analyses due to the relatively short tracking period before predation. C158, a male and the largest Copperhead in the study, was likely lost in the fall of 2007. Its last known location in 2007 was between two known hibernacula. The transmitter was found in the spring of 2008 near the snake's last known location from 2007. A small piece of tissue was stuck to the transmitter but no corpse was located and no chew marks were observed on the transmitter. Data for C158 was used in all analyses due to its survival for nearly the complete season. One resident, C321, a male, was suspected of being lost to predation at the end of the fall but was located alive in the spring of 2008. It was unclear at the end of 2007 if translocated snake, C279, found a suitable hibernaculum at fall ingress, but it was located alive and in apparent good health in the spring of 2008. There was no significant difference in survival between translocated and resident Copperheads (χ^2 = 2.40, df = 1, P = 0.121).

Activity and Movement Data

Maps of the MCP, 95% home range, and 50% core range for each Copperhead are provided in Appendix A. The MCPs, 95% home ranges, and 50% core ranges were not statistically different between the resident and translocated Copperheads (Table 2). However, the MCP for translocated snakes ($\bar{x}$ = 6.94 ha) averaged about 1.6 times the size of the resident snakes ($\bar{x}$ = 4.25 ha). The 95% home range for translocated snakes was also about 1.6 times greater than the resident snakes ($\bar{x}$ = 24.69 ha and $\bar{x}$ = 15.33 ha, respectively). The average range width for translocated snakes ($\bar{x}$ = 733.99 meters ± 317.96 meters) was wider than resident snakes ($\bar{x}$ = 553.44 meters ± 301.05 meters) but this difference was not significant (t_{10} = 0.960, P = 0.362). Resident and translocated Copperheads did not differ significantly on total movement, average movement per move, or average daily movement (Table 3). However, translocated snakes moved an average of approximately 1.5 times further than resident snakes and an average of approximately 33% further per move.

Insufficient data were collected to make meaningful foraging comparisons. However some qualitative observations were made. Five of the 6 translocated Copperheads gained mass during the study. C071 lost 38 grams between May 19, and

Table 2. Comparison of translocated and resident Copperhead MCPs, home ranges (HR), and core ranges (CR).

Snake	Sex	Origin	Days	Observations	MCP (ha)	Fixed Kernel Density (ha) 95% HR	50% CR	Range Width (m)
C020	M	T	144	14	8.84	34.87	5.11	1012.75
C071	F	T	155	17	4.54	11.74	3.21	514.57
C140	F	T	155	16	3.35	5.98	1.04	305.50
C180	F	T	127	14	3.28	14.45	2.79	572.01
C219	M	T	137	11	14.87	44.51	9.07	879.75
C279	M	T	155	13	6.75	36.60	7.41	1119.56
Mean			145.50	14.17	6.94	24.69	4.77	733.99
(SD)			*(11.73)*	*(2.14)*	*(4.44)*	*(15.88)*	*(3.03)*	*(317.96)*
C043	F	R	91	9	3.77	10.23	1.79	700.50
C158	M	R	133	10	9.04	46.43	14.72	900.73
C249	F	R	133	13	0.84	2.59	0.50	378.18
C272	F	R	28	8	--	--	--	--
C321	M	R	106	13	7.19	16.48	2.25	657.23
C340	F	R	85	9	0.39	0.90	0.17	130.58
Mean			96.0	10.40	4.25	15.33	3.89	553.44
(SD)			*(39.01)*	*(1.67)*	*(3.82)*	*(18.48)*	*(6.12)*	*(301.05)*
			t = -2.98	t = -3.2	t = -1.065	t = -0.906	t = -0.314	t = -0.960
			df = 10	df = 9	df = 9	df = 9	df = 9	df = 9
			P = 0.014	P = 0.011	P = 0.315	P = 0.389	P = 0.761	P = 0.362

M=male; F=female; T=translocated; R=resident

Table 3. Comparison between translocated and resident Copperhead movements.

Snake	Sex	Origin	Total Distance (m)	Average per Movement (m)	Average Daily Movement (m)
C020	M	T	2,666.06	190.43	18.51
C071	F	T	1,324.16	77.89	8.54
C140	F	T	1,079.72	67.48	6.97
C180	F	T	1,540.26	110.02	12.13
C219	M	T	1,770.82	160.98	12.93
C279	M	T	2,495.26	191.94	16.10
Mean			1,812.71	133.13	12.53
(SD)			*(639.69)*	*(55.52)*	*(4.37)*
C043	F	R	1,067.84	118.65	11.74
C158	M	R	2,110.27	211.03	15.87
C249	F	R	1117.74	93.15	8.40
C272	F	R	--	46.73	10.01
C321	M	R	1,635.77	125.83	15.43
C340	F	R	247.92	27.55	2.91
Mean			1,235.91	103.82	10.73
(SD)			*(696.91)*	*(65.40)*	*(4.83)*
			t = -1.431	t = -0.837[a]	t = -0.677[b]
			df = 9	df = 10	df = 10
			P = 0.186	P = 0.422	P = 0.514

a: *t*-score included the average per movement for C272. Removal of the data for C272 resulted in t_9 = -0.489, P = 0.637

b: *t*-score included the average daily movement for C272. Removal of the data for C272 resulted in t_9 = 0.565, P = 0.586

M=male; F=female; T=translocated; R=resident

July 28; however, no further weights were collected in the remaining 3 months of the study. Two translocated Copperheads (C140 and C279) successfully foraged at least twice, as evidenced by quantitative increases in mass, during the study period.

Habitat

Copperheads spent significantly less time in prairie habitats than in forested or edge habitats (χ^2 = 46.662, df = 2, $P < 0.001$; Fig. 15). Resident and translocated Copperheads did not demonstrate any significant differences in habitat preference (χ^2 = 3.339, df = 2, $P = 0.188$; Fig. 16). All snakes were significantly more likely to be found under near total to total (76-100%) immediate cover (χ^2 = 179.440, df = 3, $P < 0.001$; Fig. 17). Resident and translocated Copperheads did not differ in the amount of immediate cover utilized (χ^2 = 3.038, df = 3, $P = 0.386$; Fig. 18). Both groups of snakes were found under near total to total (76-100%) canopy cover significantly more often than other canopy cover categories (χ^2 = 39.148, df = 3, $P < 0.001$; Fig. 19). The amount of canopy cover was significantly different between resident and translocated snakes (χ^2 = 11.634, df = 3, $P = 0.009$; Fig. 20). Resident Copperheads were more often found with no to little (0-25%) canopy cover while translocated Copperheads were more often found under near total to total (76-100%) canopy cover.

Sex

Five males and 7 females were originally included in the study. One female was predated after just one month in the study and data from this snake were excluded from

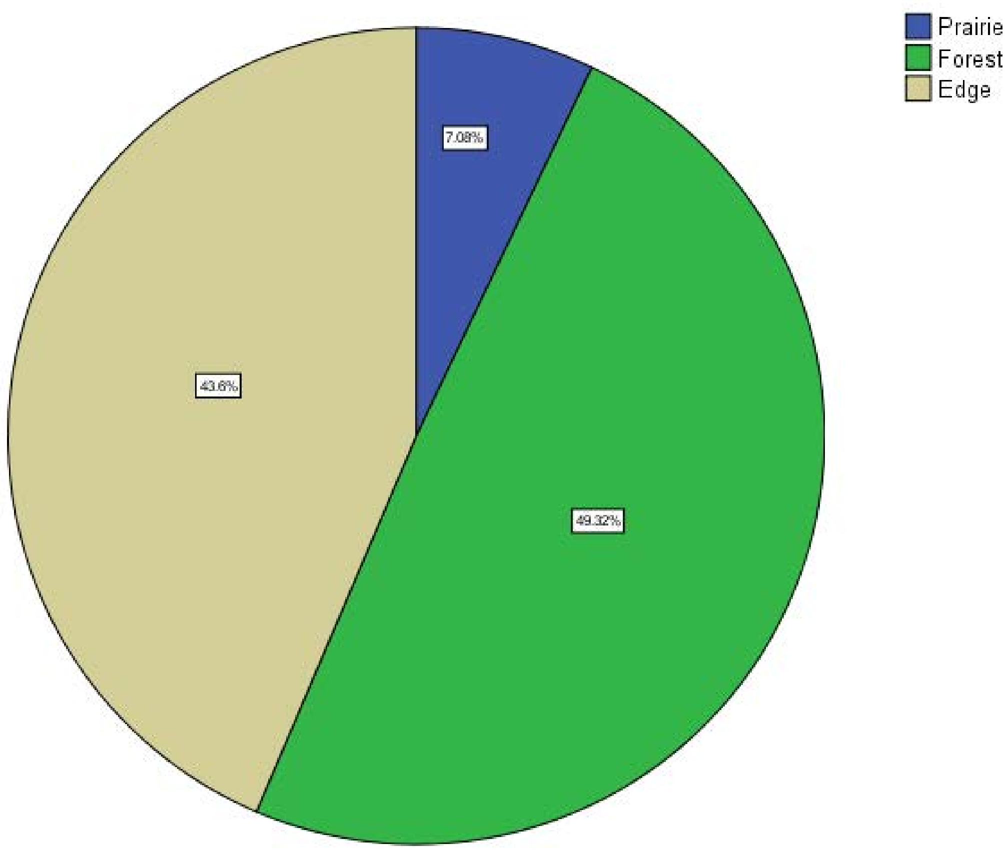


Figure 15. Habitat usage by all Copperheads. Copperheads spent significantly less time in prairie habitat.

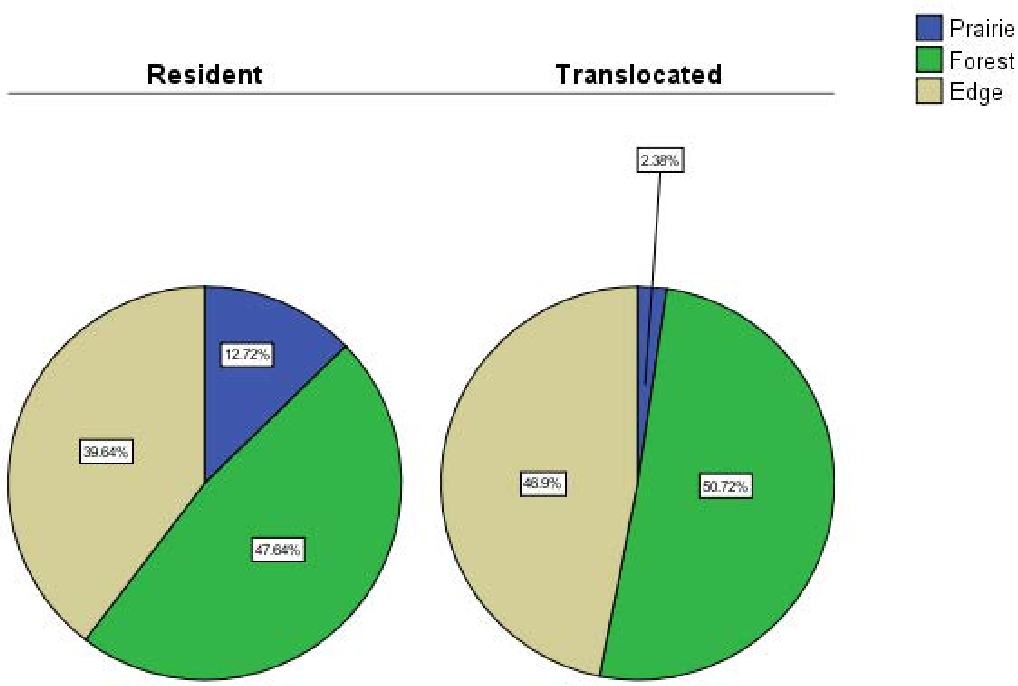


Figure 16. Comparison of habitat usage between resident and translocated Copperheads. There was no significant difference in habitat usage between resident and translocated Copperheads.

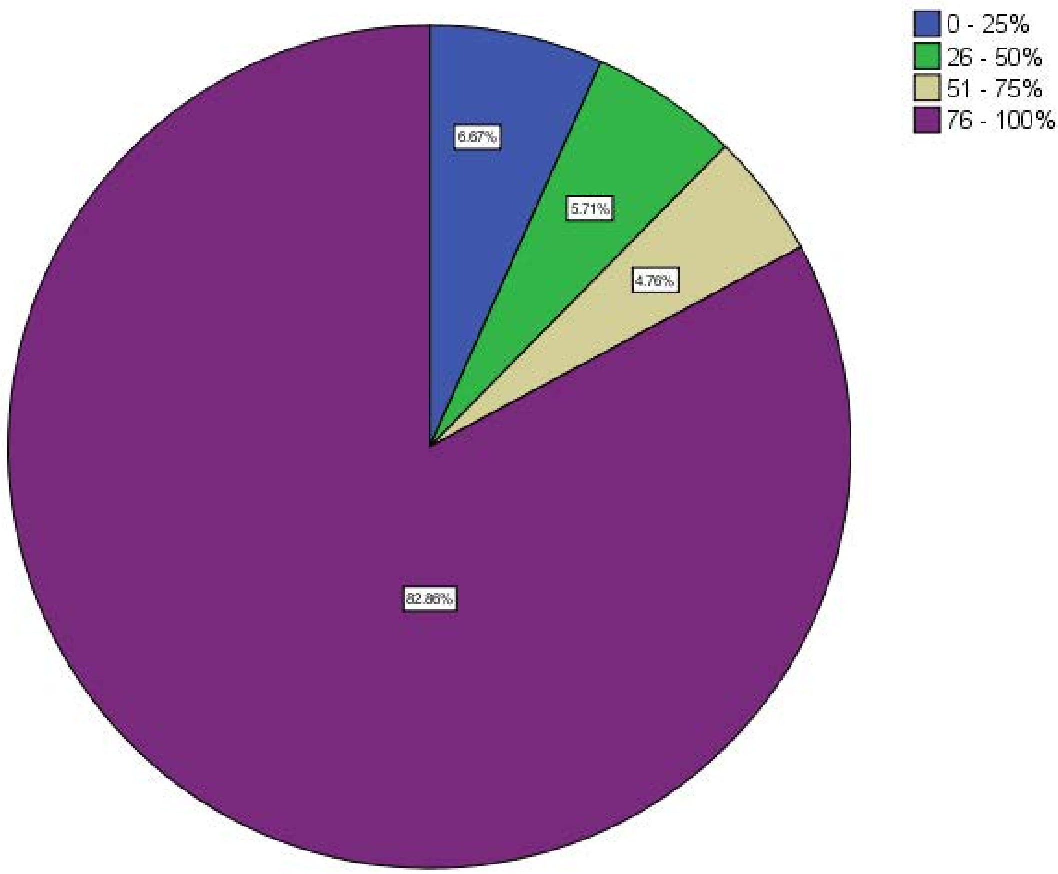


Figure 17. Immediate cover used by all Copperheads. Copperheads utilized near total to total (76-100%) immediate cover significantly more often than other immediate cover categories.

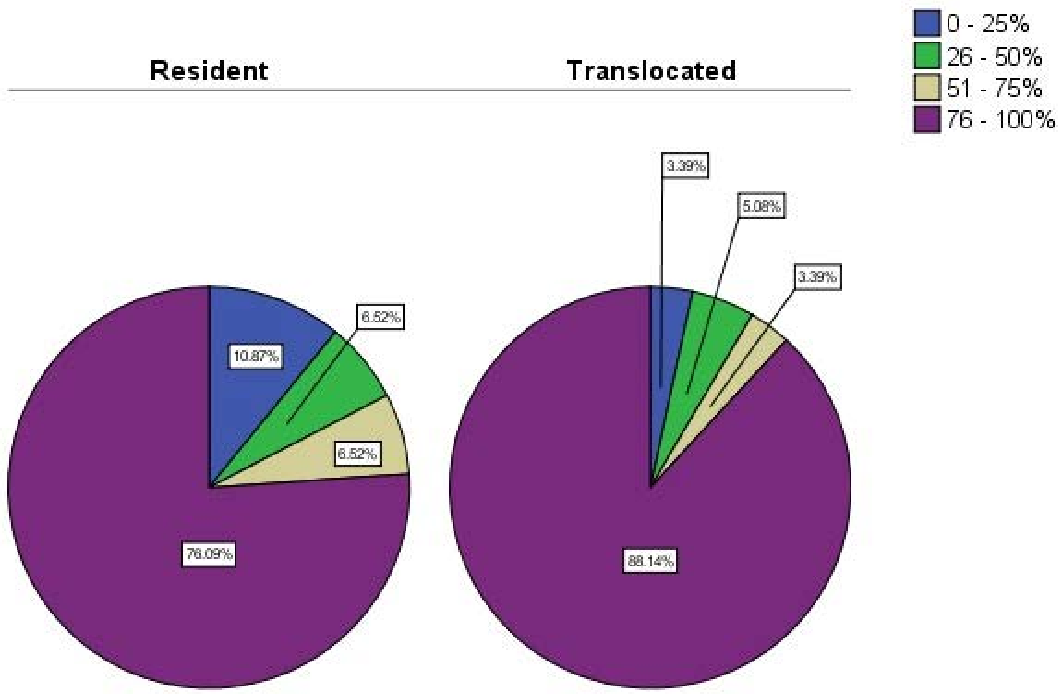


Figure 18. Immediate cover usage between resident and translocated Copperheads. Resident and translocated Copperheads did not significantly differ in immediate cover usage.

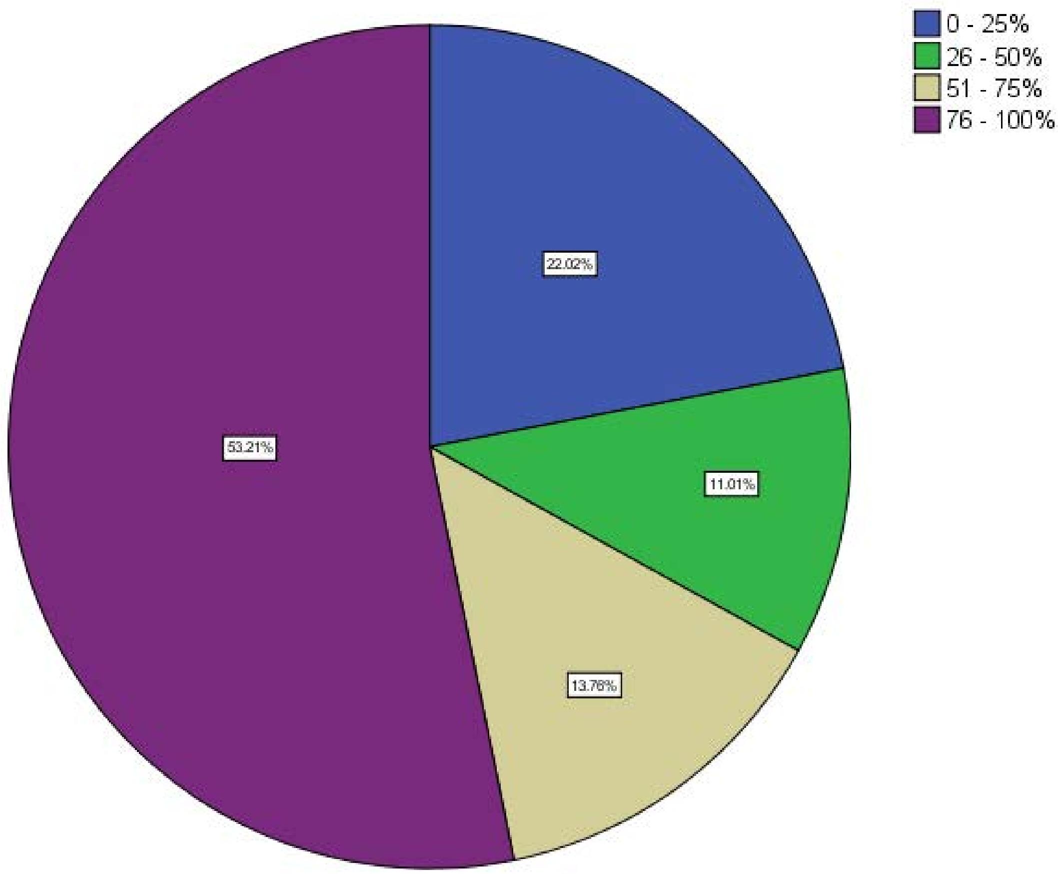


Figure 19. Canopy cover used by all Copperheads. Both resident and translocated Copperheads used near total to total (76-100%) canopy cover significantly more often than other canopy cover categories.

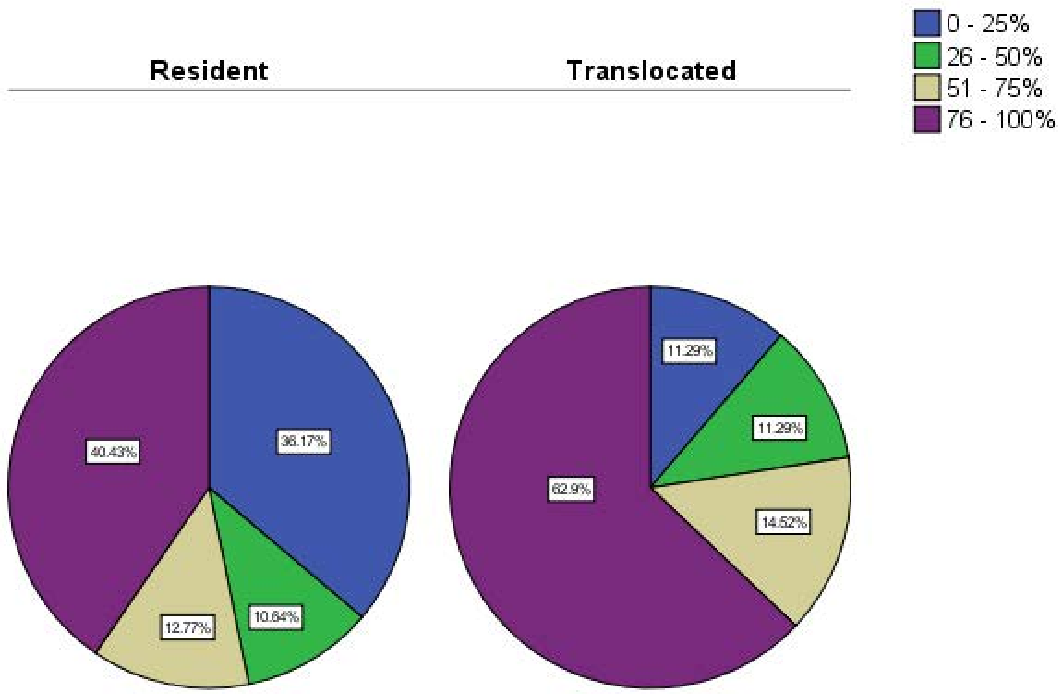


Figure 20. Comparison of canopy cover usage between resident and translocated Copperheads. Resident Copperheads were found in areas with little to no (0-25%) canopy cover significantly more often than translocated Copperheads. Translocated Copperheads were found in near total to total (76-100%) canopy cover significantly more often than resident Copperheads.

some analyses. Males had significantly longer SVL, tail lengths, and TL than females although there was no significant difference in starting weights (Table 4). Males were tracked for an average of 135 days ± 18.24 days and females were tracked for an average of 124.33 days ± 30.40 days. These means were not significantly different ($t_9 = 0.685$, $P = 0.511$) and there was no significant difference between the number of observations made for males and females ($\bar{x} = 12.20$ and $\bar{x} = 12.50$, respectively). Males had significantly larger activity ranges as measured by the MCP, 95% home range, 50% core range and range width (Table 5). Males also had significantly greater total movement, average movement, and average daily movement (Table 6). Males and females demonstrated significant differences in habitat usage ($\chi^2 = 10.07$, df = 2, $P = 0.007$). Females were found in prairie and forest habitats more often than males while males were found in edge habitat more often than females (Fig. 21). Males and females did not significantly differ between immediate cover usage ($\chi^2 = 2.52$, df = 3, $P = 0.47$; Fig. 22) or canopy cover ($\chi^2 = 6.04$, df = 3, $P = 0.11$; Fig. 23).

Table 4. Comparison of Copperhead demographics by sex.

Snake	Sex	Origin	SVL (mm)*	Tail length (mm)*	TL (mm)*	Weight (g)
C020	Male	Translocated	800	115	915	192
C158	Male	Resident	831	112	943	281
C219	Male	Translocated	556	94	650	104
C279	Male	Translocated	639	106	745	184
C321	Male	Resident	702	108	810	No data
Mean			705.60	107.00	812.60	190.25
(SD)			*(113.43)*	*(8.06)*	*(120.94)*	*(72.38)*
C043	Female	Resident	572	87	659	152
C071	Female	Translocated	588	82	670	218
C140	Female	Translocated	540	86	626	104
C180	Female	Translocated	596	84	680	168
C249	Female	Resident	476	71	547	116
C272	Female	Resident	600	91	691	162
C340	Female	Resident	483	72	555	102
Mean			550.71	81.86	632.57	146.00
(SD)			*(52.61)*	*(7.60)*	*(59.37)*	*(15.86)*
			$t = 0.724$	$t = 5.512$	$t = 3.45$	$t = 1.307$
			df = 10	df = 10	df = 10	df = 9
			$P = 0.009$	$P < 0.001$	$P = 0.006$	$P = 0.224$

Table 5. Comparison of male and female Copperhead MCPs, home ranges (HR), and core ranges (CR).

						Fixed Kernel Density (ha)		
Snake	Sex	Origin	Days	Observations	MCP (ha)*	95% HR*	50% CR*	Range Width (m)*
C020	M	T	144	14	8.84	34.87	5.11	1012.75
C158	M	R	133	10	9.04	46.43	14.72	900.73
C219	M	T	137	11	14.87	44.51	9.07	879.75
C279	M	T	155	13	6.75	36.60	7.41	1119.56
C321	M	R	106	13	7.19	16.48	2.25	657.23
Mean			135.00	12.20	9.34	35.78	7.71	913.97
(SD)			*(18.24)*	*(1.64)*	*(3.25)*	*(11.87)*	*(4.69)*	*(172.66)*
C043	F	R	91	9	3.77	10.23	1.79	700.50
C071	F	T	155	17	4.54	11.74	3.21	514.57
C140	F	T	155	16	3.35	5.98	1.04	305.50
C180	F	T	127	14	3.28	14.45	2.79	572.01
C249	F	R	133	13	0.84	2.59	0.50	378.18
C272	F	R	--	--	--	--	--	--
C340	F	R	85	9	0.39	0.90	0.17	130.58
Mean			124.33	12.50	2.70	7.65	1.58	433.56
(SD)			*(30.40)*	*(3.33)*	*(1.68)*	*(5.36)*	*(1.23)*	*(204.08)*
			$t = 0.685$	$t = -0.18$	$t = 4.38$	$t = 5.24$	$t = 3.11$	$t = 4.16$
			df = 9	df = 9	df = 9	df = 9	df = 9	df = 9
			$P = 0.511$	$P = 0.859$	$P = 0.002$	$P = 0.001$	$P = 0.013$	$P = 0.002$

M=male; F=female; T=translocated; R=resident

Table 6. Comparison between male and female Copperhead movements.

Snake	Sex	Origin	Total Distance (m)*	Average per Movement (m)*	Average Daily Movement (m)*
C020	M	T	2,666.06	190.43	18.51
C158	M	R	2,110.27	211.03	15.87
C219	M	T	1,770.82	160.98	12.93
C279	M	T	2,495.26	191.94	16.10
C321	M	R	1,635.77	125.83	15.43
Mean			2135.64	176.04	15.77
(SD)			*(445.61)*	*(33.29)*	*(1.99)*
C043	F	R	1,067.84	118.65	11.74
C071	F	T	1,324.16	77.89	8.54
C140	F	T	1,079.72	67.48	6.97
C180	F	T	1,540.26	110.02	12.13
C249	F	R	1117.74	93.15	8.40
C272	F	R	--	46.73	10.01
C340	F	R	247.92	27.55	2.91
Mean			1062.94	82.46	8.45
(SD)			*(439.01)*	*(33.00)*	*(3.38)*
			t = 4.01 df = 9 P = 0.003	t = 4.67 df = 9 P = 0.001	t = 4.24 df = 9 P = 0.002

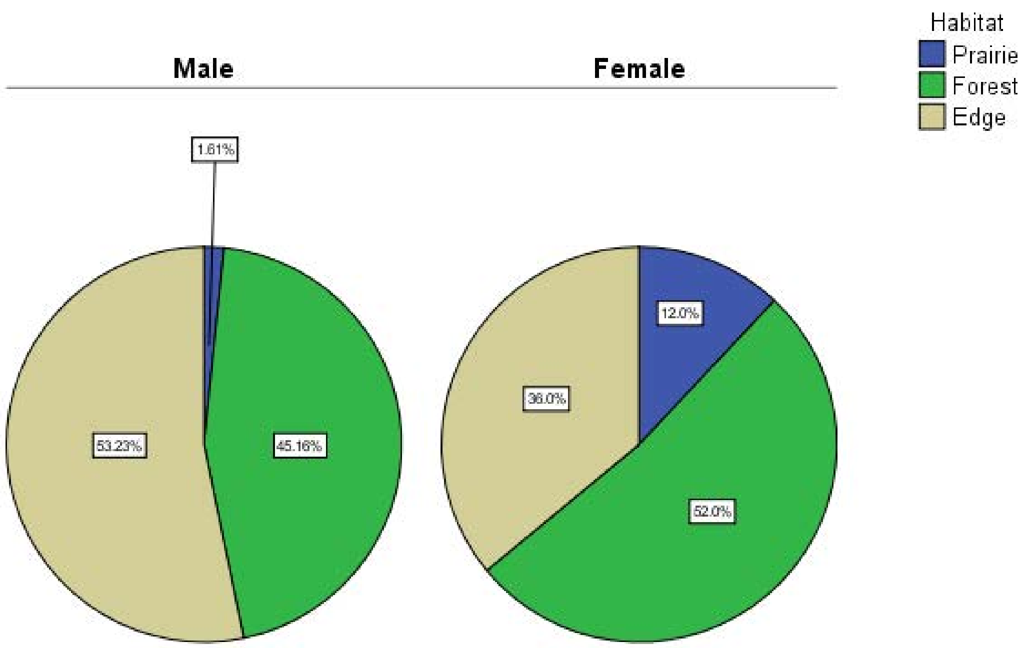


Figure 21. Comparison of habitat usage between male and female Copperheads. Males were found significantly more often in edge habitat than females. Females were found significantly more often in forest and prairie habitats than males.

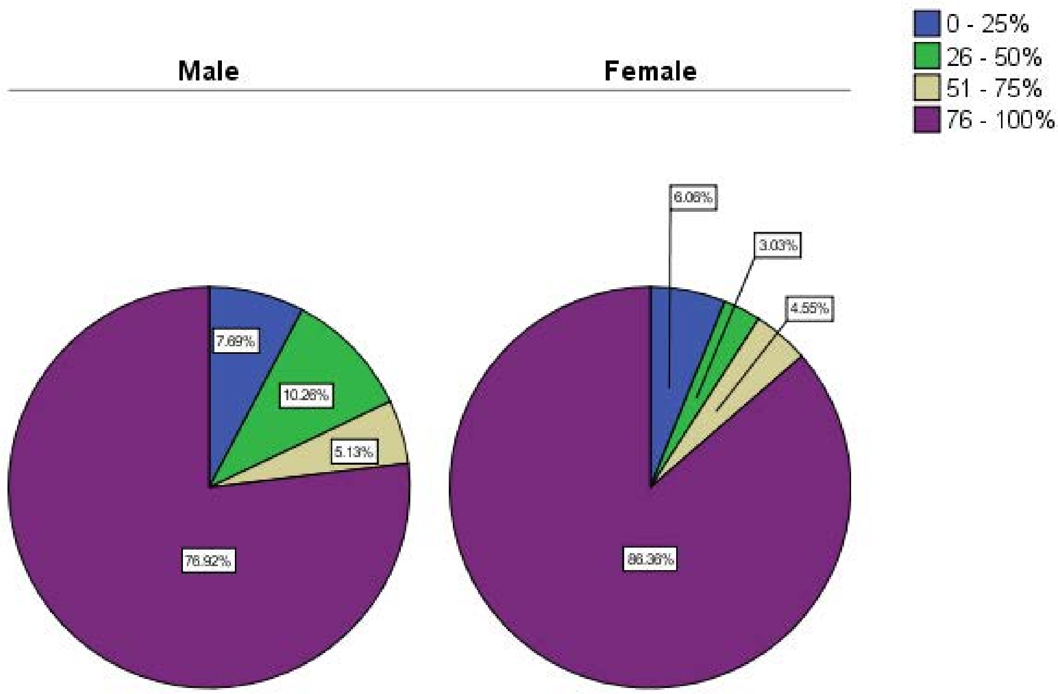


Figure 22. Comparison of immediate cover usage between male and female Copperheads. There was no difference in the immediate cover usage between male and female Copperheads.

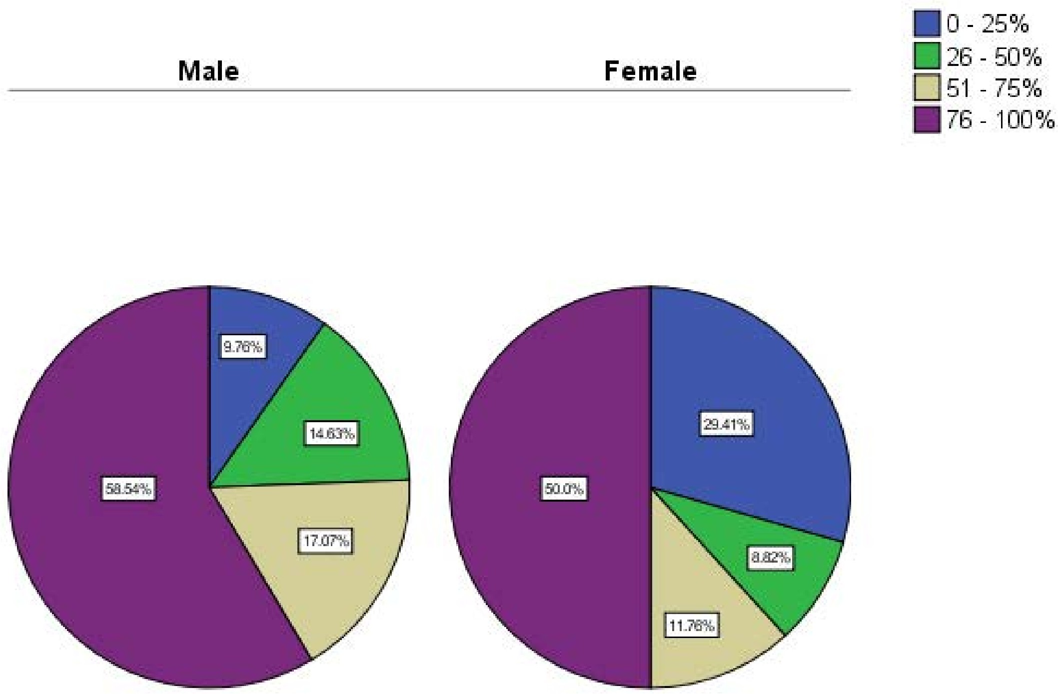


Figure 23. Comparison of canopy cover usage between male and female Copperheads. There was no significant difference in canopy cover usage between male and female Copperheads.

DISCUSSION

Demographics

The resident and translocated Copperheads did not differ on initial demographics. Thus, it was likely that both samples were comparable in terms of health and home site resources. On a larger scale, the lengths of the male Copperheads in the present study were similar to the averages described in other studies on Copperheads (Fitch, 1960; Smith, *et al*., 2009). The female Copperheads in the present study averaged approximately 110 mm smaller than the females in other studies (Fitch, 1960; Smith, *et al*., 2009). The similarities between the present sample and the peripheral northeastern population in Smith, *et al*., (2009) suggested that the two populations are similar despite being on opposite sides of the Copperhead range. However, the two populations are different subspecies (*A. c. phaeogaster* compared to *A. c. mokasen*) which may limit comparisons. The similarity between the present sample and the Kansas population studied by Fitch (1960) suggested that Nebraska Copperheads were at least as healthy as a non-peripheral population of *A. c. phaeogaster*.

Observations

Despite searching for snakes with radio-transmitters, the snakes proved challenging to locate. Reinert (1992) recommended tracking a minimum of every two days. The inability to follow this recommendation meant that snakes had more time to travel in unknown directions for unknown distances. This investigator spent considerable time searching for a signal in the wrong direction and backtracking to locate a snake’s transmitter signal. On numerous occasions, the search for an individual snake had to be discontinued in favor of attempting to track the remaining Copperheads. More frequent tracking opportunities would likely reduce the area required for the investigator to explore to locate the snake. At the recommended two day interval even if a Copperhead moved daily, the results from this study suggest that most Copperheads would still be within 10-30 meters of its previous location.

The microhabitats utilized by the snakes also presented difficulties in locating Copperheads. The density of the vegetation at times inhibited the ability to find the animal or reduced the likelihood of encountering it without significant warning to the snake and disturbance to its location. The snakes were generally under some form of cover, making it difficult to impossible to physically locate them without destroying the habitat. Locating C249 was particularly challenging given its utilization of grass and rodent burrows. Although attempts to measure altitude were unreliable (the GPS unit frequently gave radically different readings for the same location over different tracking dates), the topology of the study site consisted of considerably steep ledges. Both C140 and C321 used these ledges and on one occasion C020 was observed entering a rock crevice while the investigator climbed a ledge to get to its location. A final challenge related to the terrain was the frequency of radio interference with the equipment. Transmitter signals were susceptible to bounce when the snakes were located in creek beds. This bounce also required considerable backtracking and sometimes led to abandonment when multiple strong signals were encountered many meters apart with no sign of the snake. In mid-July, the signal for C249 experienced significant unknown interference that sounded like a competing radio transmission although no other snake transmitter signal was close to the same frequency. This interference persisted for nearly the entirety of the study. Thus, even when a potential location was narrowed to a few meters, locating the snake took considerable time or was not possible.

Mortality

Mortality during the study was limited to two Copperheads and both were residents of the study area. This outcome was unexpected and in contrast to the findings of several studies involving other snake species (Reinert and Rupert, 1999; Plummer and Mills, 2000; Nowak, *et al*., 2002; King, *et al*., 2004, although see Butler, *et al*., 2005). C272, the largest female in the study, was predated between July 28, and August 4. The snake appeared in good health during the study and successfully foraged at least once. C272 also used locations close to two other resident Copperheads (C043 and C158) during overlapping times. C158, a male and the largest snake in the study, was predated at the end of the active season. Given the fall timing of predation, it was possible that weather played a role in rendering C158 more vulnerable to predators. As C158 was a very large male, it may be that age played a role in predation as well. Based on the age estimates of Fitch (1960) C158 exceed the size range for 8 year old Copperheads. Fitch (1960) also noted that few Copperheads likely live more than 15 years in the wild. Thus, C158 may have reached the natural end of life age expectation for a wild Copperhead. It is possible this same explanation applies to C272, the largest female in the study, although C272 was only 5 years old based on the estimates of Fitch (1960). Additional demographic information may allow for more precise age estimations for this population of Copperheads.

Several factors did not appear to play a role in this study. No evidence of disease was noted in any snakes. All appeared to maintain an outwardly healthy appearance. Additionally, the present study site appeared well protected from human interference. Much of the site experiences limited human utilization so interactions with humans are likely rare. Despite the proximity of several Copperheads, both resident and translocated, to human activity sites (homes and dirt roads), no human caused mortality was observed. The landowners in this area reported that they generally do not kill any snakes and one landowner reported he had never seen a Copperhead or a Timber Rattlesnake prior to this investigator showing them to him. Although two translocated Copperheads were found south of a two-lane paved road, it is unclear how they crossed the road. It was possible for the snakes to follow the river and cross beneath a bridge.

Overwintering was an unknown factor in the present study. King, *et al*. (2004) reported a high rate of mortality for overwintering Massasaugas (*Sistrurus catenatus*), despite one translocated cohort experiencing no active season mortality. Although overwinter survival was not measured for all translocated snakes in the present study, at least one translocated Copperhead (C279) was recaptured the following spring in apparent good health (Fig. 24). C279 was a concern at the end of the fall season as it was not in a known hibernaculum. All other translocated snakes appeared to enter suitable hibernacula. C071 was not in a known hibernaculum but its last location appeared to have the qualities of a suitable hibernaculum (rock wall with deep fissures). Unfortunately, the transmitters in all but two translocated Copperheads failed over the winter months so no assessment of overwinter survival was possible. The transmitter for translocated C180 provided a signal the following spring but the snake could not be located. It was

Figure 24. Spring 2008 recapture of translocated Copperhead C279. The snake was located beneath the surface layers of this wood pile.

presumed C180 was still in the hibernaculum. Following the recommendations of King, *et al*. (2004) and Reinert and Rupert (1999), future translocations on this study site should assess overwinter mortality.

Ultimately, it appears the translocated Copperheads were able to successfully avoid predators despite the unfamiliar location and they were able to locate sufficient resources to survive to at least the end of the active season. The survival of at least one translocated snake to the next season provides some evidence that Copperheads can be successfully translocated.

Activity and Movement

As a whole, the Copperheads in the present study had larger daily movements ($\bar{x}$ = 11.63 meters per day) than a previous study on Copperhead movements (Fitch and Shirer, 1971). Fitch and Shirer (1971) found that Copperheads moved an average of 8 meters per day. However, the methods used by Fitch and Shirer (1971) likely altered the behavior of the snakes, which may have reduced movements. Copperheads in the present study had much smaller annual total movement distances than the Copperheads in Smith, *et al*., (2009). However, the present study included substantially fewer observations ($\bar{x}$ = 12.63 in one year vs. $\bar{x}$ = 220 over several years) than Smith, *et al*., (2009). It is likely that the total distances reported in the present study underestimate the true total movement by the snakes.

The lack of significant differences in activity patterns and movements despite large differences in those measurements between resident and translocated animals is consistent with the published literature for other translocations (Reinert and Rupert, 1999;

Plummer and Mills, 2000; Nowak, *et al*., 2002; Sullivan, *et al*., 2004; Butler, *et al*., 2005). The lack of significance may be due, in part, to the low sample sizes used. In the present study, translocated Copperheads averaged approximately 1.6 times the MCPs, home ranges, and core ranges as the resident Copperheads. The larger activity areas for translocated Copperheads are on the low end of published differences, which range from 3–6 times larger for translocated animals (Reinert and Rupert, 1999; Plummer and Mills, 2000; Sullivan, *et al*., 2004; Butler, *et al*., 2005) with some MCPs for translocated snakes exceeding 10 times the MCPs of resident snakes (Reinert and Rupert, 1999). Translocated snakes in the present study moved approximately 1.5 times more in total movement and moved 33% further per move, although this increase translated into only 1.8 meters of increased daily movement. This movement was less than that reported by Reinert and Rupert (1999), who found that translocated *C. horridus* had 3–5 times greater daily movement. Additionally, Sullivan, *et al*., (2004) found that translocated *Heloderma suspectum* had significantly greater daily movement than controls while Butler, *et al*., (2005) found that translocated *Notecus scutatus* had greater monthly movement than resident snakes although significance was found in only one month.

The larger activity areas and increased movement distances among translocated Copperheads were likely the result of unfamiliarity with the new site. Butler, *et al*., (2005) reported that long initial movements may have been exploration or a search for familiar territory. The present Copperheads did not consistently make long initial movements away from the release site. The short initial movements by the translocated snakes may have been attempts to become orientated with the new site. It was also possible that the short movements reflected the suitability of the habitat at the translocation site. The translocated snakes may have had their needs met with the available resources, which might have eliminated the need for long initial forays. Weather and cool temperatures may also have contributed to the snakes making short initial movements. Smith, *et al*., (2009) found that Copperheads moved very small distances in the early spring. The translocated Copperheads in the present study were released during the spring months. Movement has both energetic costs and risks for predation (Gibbons and Semlitsch, 1987). Short movements might be an adaptive feature to cooler temperatures to prevent the loss of limited energy and reduce exposure to predators while moving at suboptimal conditions.

Copperheads did not demonstrate any evidence of homing, adding to the literature that snakes lack homing abilities (Fitch and Shirer, 1971; Butler, *et al*., 2005). C279 made an initial movement of approximately 31 meters toward its home site but subsequent moves were away from the home site.

Habitat

Copperheads in the present study spent significantly less time in prairie than in locations with more trees and spent greater time under full cover than openly exposed. These findings replicated the observations of Fitch and Shirer (1971; although see Reinert, 1984), who found that Copperheads tended to avoid open areas and when found in open areas the snakes were screened by dense vegetation. This pattern was particularly apparent in C249, which spent much of its time in open areas but covered entirely by thick grasses or hiding underground. Smith, *et al*., (2009) found habitat preference changed over the season although Copperheads appeared to avoid densely forested areas and preferred areas with mixed canopy cover and open areas with dense vegetation. The similarity in habitat selection between the resident and translocated Copperheads suggested that even translocated snakes maintain some core ability to determine and locate appropriate habitats. Translocated Copperheads do not appear to settle for inferior habitat or disadvantageous cover as a result of unfamiliarity with the area. Rather, it may be that translocated snakes move greater distances before finding the preferred habitat while resident snakes already know the locations of these sites. If this is the case, translocated snakes should be able to reduce their movements in subsequent years due to increasing familiarity of the location.

The findings for canopy cover were not as clear as habitat selection or immediate cover. As a group, Copperheads utilized locations with full or nearly complete canopy cover. However, the finding that translocated snakes preferred locations with full canopy cover more than resident snakes was unexpected. It may be that translocated snakes chose locations that afforded increased safety given their unfamiliarity with the overall site. This explanation seems unlikely as it would not explain why residents would prefer sites that afforded less protection. Differences in foraging success, which might account for a preference of a less secure location, were not observed in the present study. Another explanation might be related to the source of the resident snakes. Resident snakes originated from several different hibernacula. Based on the home ranges of the resident snakes, half the resident Copperheads (C041, C158, and C272), utilized an area with little available canopy cover. The lack of canopy cover was likely not a significant problem as the vegetation in the home ranges of these snakes was particularly tall. Additionally, there was an abundance of man-made debris in these home ranges, which allowed for lengthy movements under complete immediate cover. None of the translocated snakes were released anywhere near the home ranges of these three resident snakes and were never found close enough to this area to conclude they knew it was there. C249 utilized locations without canopy cover but also likely benefited from familiarity with the location and the likely connectedness of the underground mammal burrows. Thus, the benefits of canopy cover were achieved through the unique habitat features available. Future studies should explore whether translocated Copperheads demonstrate a preference for full canopy cover more than resident Copperheads by collecting all resident snakes from a single hibernaculum and releasing all translocated snakes at that same hibernaculum.

Sex

The differences in home range size and movements between males and females supported the findings of other studies (Fitch and Shrirer, 1971; Gibbons and Semlitsch, 1987; Gregory, *et al*., 1987; Reinert and Rupert, 1999; Nowak, *et al*., 2002; Sealy, 2002; Smith, *et al*., 2009). The larger home ranges and core ranges of males likely represented different needs between the sexes. The larger home ranges and longer movements for males would lead to more reproductive encounters with females. Conversely, females can maximize their safety and conserve their energy by maintaining smaller home ranges and allowing males to find them. The conserved energy can be directed toward reproductive success. The difference in habitat selection between males and females may also represent behaviors that maximize reproductive success. Males found in edge habitat may have been migrating between females in forested and prairie habitat. Alternatively, these males may prefer edge habitat as a way to increase detection of a potential mate in either prairie or forest habitat without committing to searching for females in only one habitat type. These explanations are consistent with the conclusion of Smith, *et al*., (2009) that male Copperheads engage in mate searching while females do not actively search for mates. Although none of the differences in home range or movements between the sexes was unexpected, these findings further increase the understanding of habitat selection and movement between the sexes.

Conservation

A primary objective of the present study was to determine if the Copperhead was a suitable candidate for conservation. Although success, defined as the establishment of a reproductive population, was not measured, it appears the Copperhead made a good translocation subject. Translocated Copperheads foraged successfully and found suitable hibernacula. At least one translocated Copperhead emerged the following year and appeared in good health. The utilization of similar habitats between resident and translocated snakes suggested that the process of translocation did not change the internal cues for identifying adaptive locations. The increased movement of translocated snakes did not result in increased predation and did not appear to have a significant impact on survival. Snakes were moved during the breeding season so no reproductive events were expected. No evidence was observed that suggested breeding would not occur the following season in the new site or that such breeding would be unsuccessful. Additionally, one resident Copperhead (C043) mated in spring 2008 with a transmitter still implanted (Fig. 25). This observation combined with the multiple mating and

Figure 25. Spring 2008 mating of resident Copperhead C043 with a previously unmarked resident male. The head of C043 is in the forefront while the male's head is slightly behind the head of C043.

parturition events in Smith, *et al*., (2009) suggest it is possible to measure mating success in translocated snakes while they are being actively studied.

These results allow for the formulation of a comprehensive conservation plan. Such a plan should seek to maintain existing Copperhead populations while expanding populations to suitable locations within their historic range. A basic conservation plan should include the following:

1. Identification of existing Copperhead populations
2. Identification of potential translocation sites within the Copperhead's historical range
3. Education for the public regarding the benefits and relevant cautions necessary for successful co-existence with Copperheads
4. Identify landowners willing to increase or establish Copperhead populations on their land
5. Long-term monitoring of existing or established Copperhead populations

A potential site for translocation should include the following:

1. Proximity to a river or stream
2. Rocky ledges that provide suitable hibernacula sites
3. Sufficient established riparian areas to provide for adequate movement with limited overlap in Copperhead home ranges
4. Canopy cover in the riparian areas should be full or nearly full in multiple locations
5. Some prairie bordering the riparian forest areas
6. At least some edge habitat between the prairie and forest

CONCLUSIONS

The Copperhead is one of four venomous snakes in Nebraska where it exists in only a few locations. Although venomous to humans, Copperheads serve a valuable function in the management of rodent populations while providing a food source to other predators. It is recognized as needing conservation in Nebraska and it appears that the Copperhead may be a suitable candidate for translocation as part of an effort to increase the number of Nebraska Copperhead populations. Through the long-term management of existing populations and the establishment of new populations, the Copperhead should be a successful conservation candidate.

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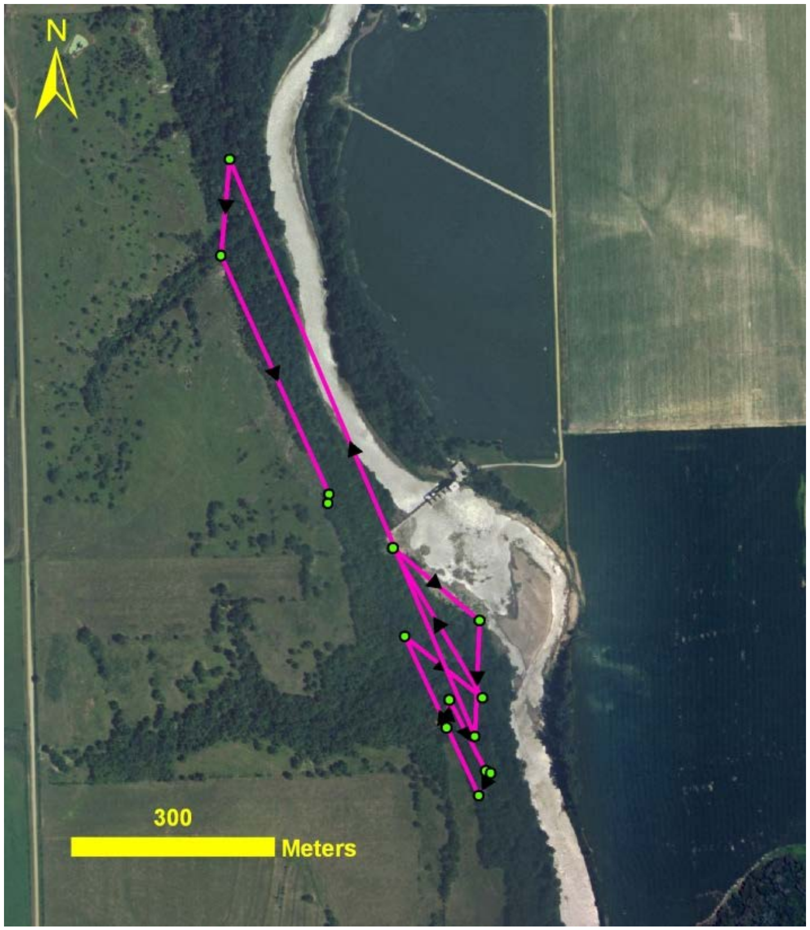
APPENDIX A

A. 

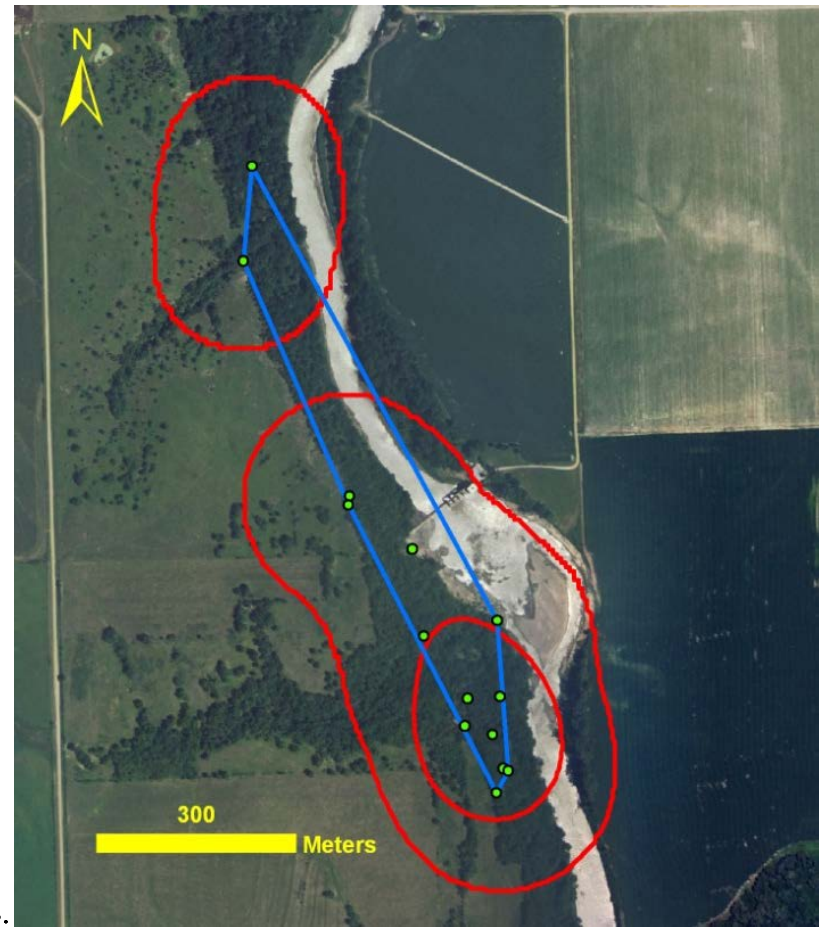
B. 

Figure 26. (A) Translocated male C020. Direction and total distance moved = 2666.06 meters; (B) MCP (blue line) = 8.84 ha, 95% home range (outer red lines) = 34.87 ha, 50% core range (inner red circle) = 5.11 ha.

A. B.

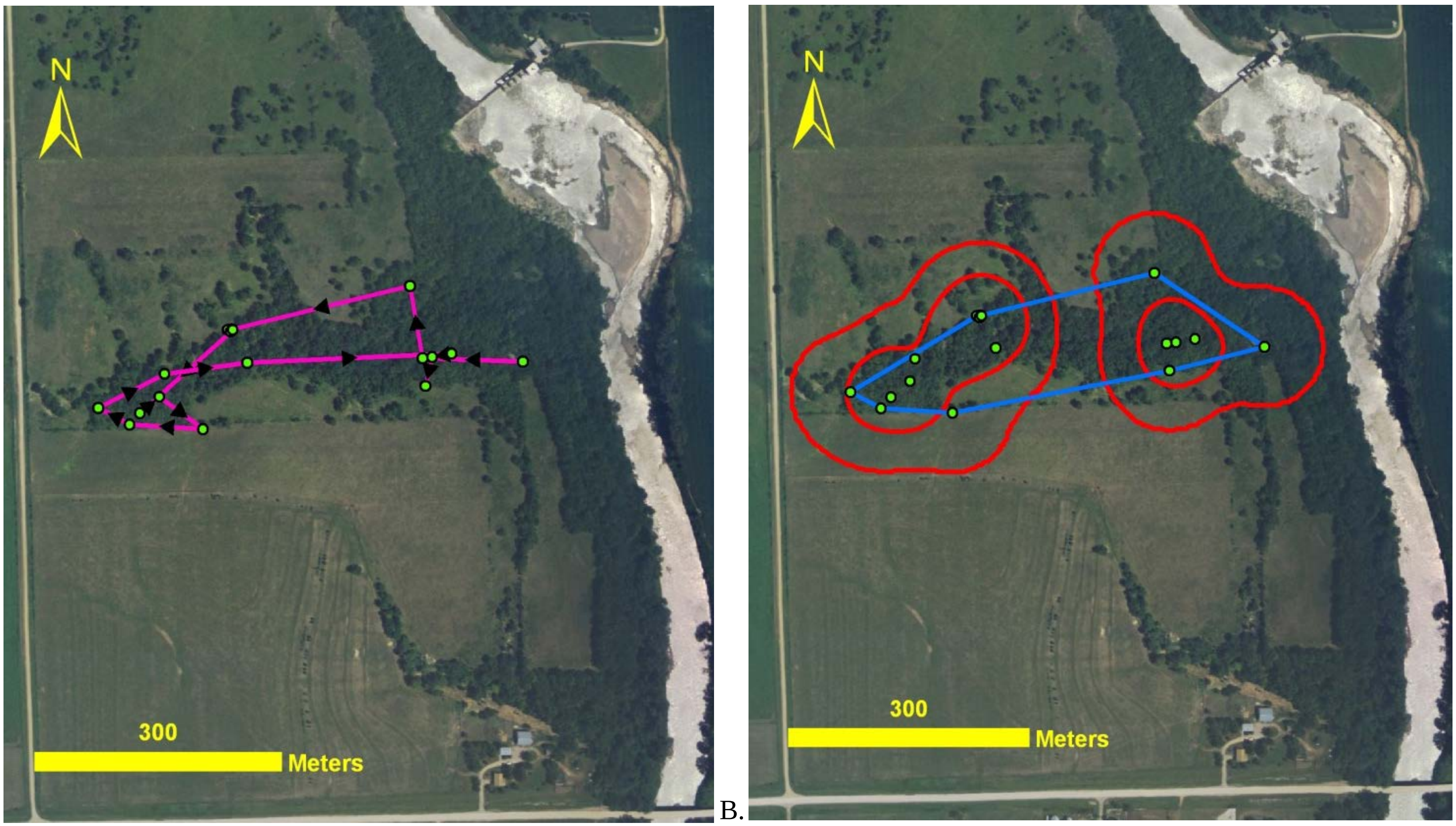


Figure 27. Translocated female C071. (A) Direction and total distance moved = 1324.16 meters; (B) MCP (blue line) = 4.54 ha, 95% home range (outer red lines) = 11.74 ha, 50% core range (inner red lines) = 3.21 ha.

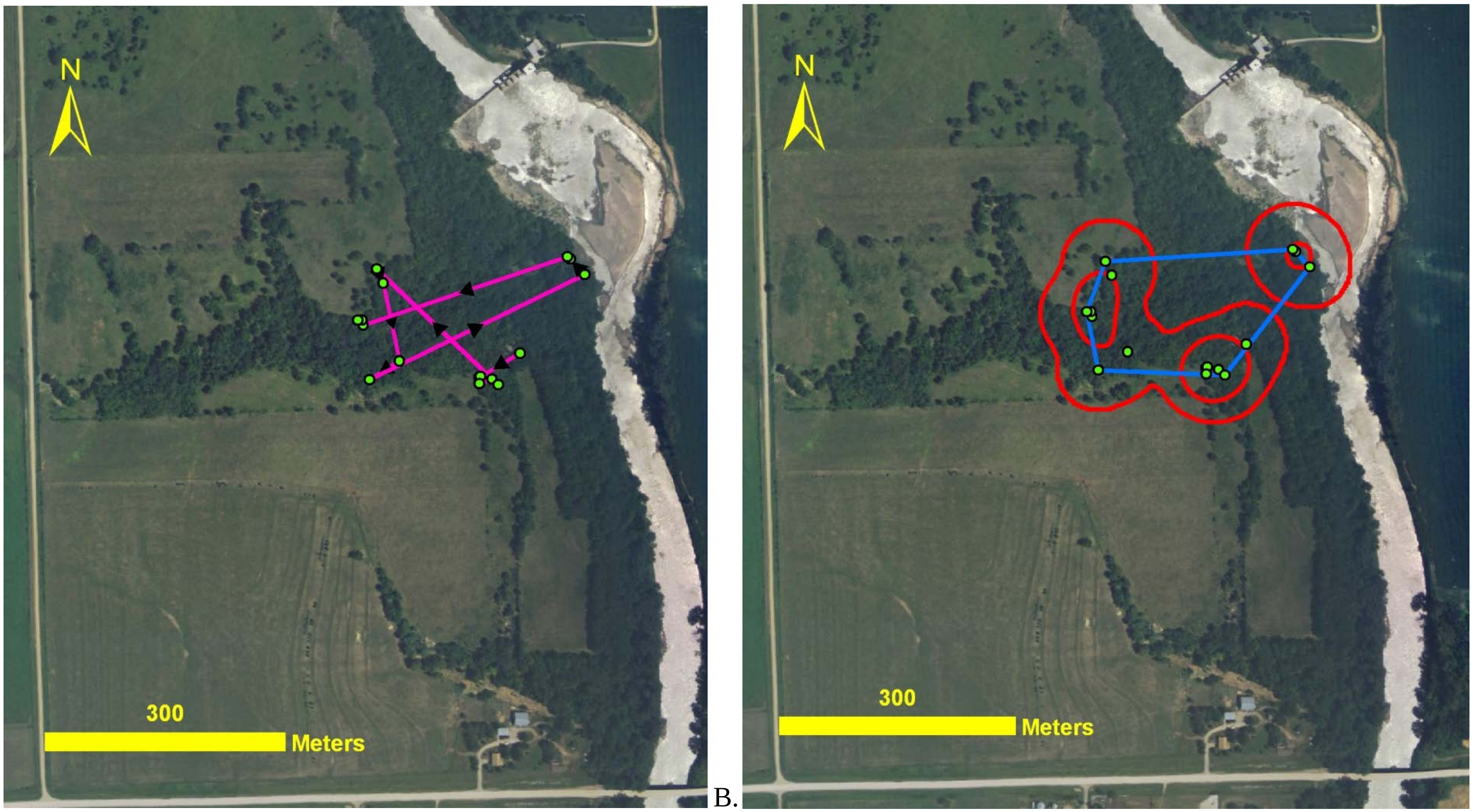


Figure 28. Translocated female C140. (A) Direction and total distance moved = 1079.72 meters; (B) MCP (blue line) = 3.35 ha, 95% home range (outer red lines) = 5.98 ha, 50% core range (inner red lines) = 1.04 ha.

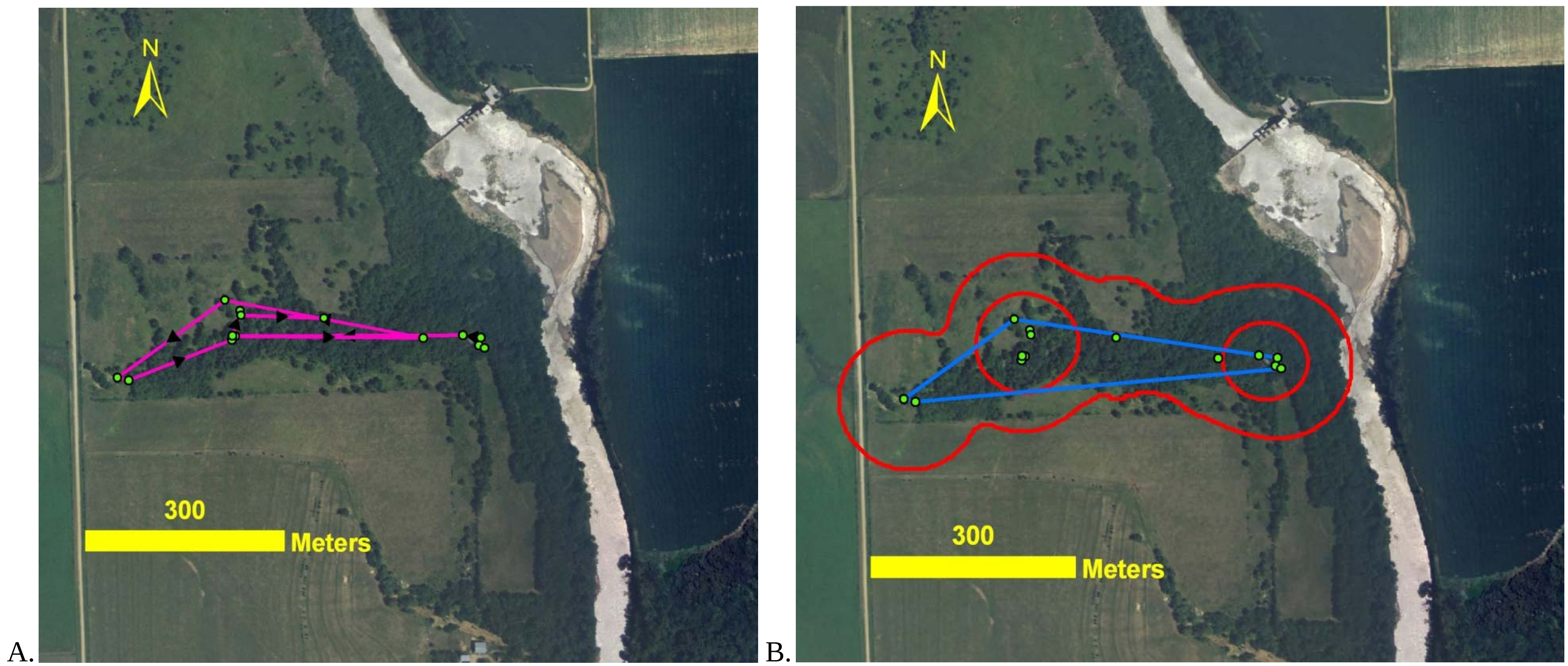
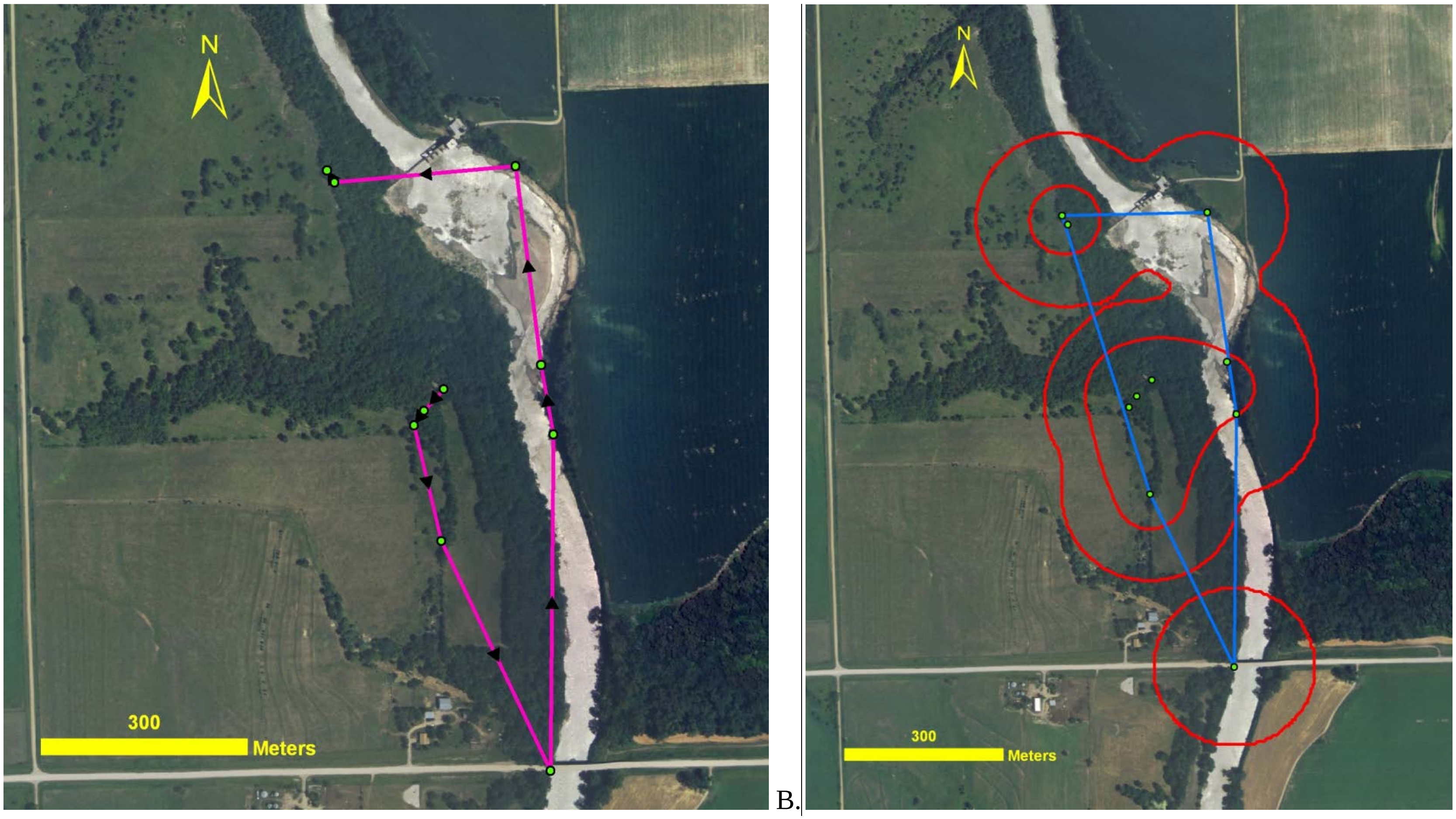


Figure 29. Translocated female C180. (A) Distance and total distance moved = 1540.26 meters; (B) MCP (blue line) = 3.28 ha, 95% home range (outer red line) = 14.45 ha, 50% core range (inner red lines) = 2.79 ha.



A. B.

Figure 30. Translocated male C219. (A) Direction and total distance moved = 1770.82 meters; (B) MCP (blue line) = 14.87 ha, 95% home range (outer red lines) = 44.51 ha, 50% core range (inner red line) = 9.07 ha.

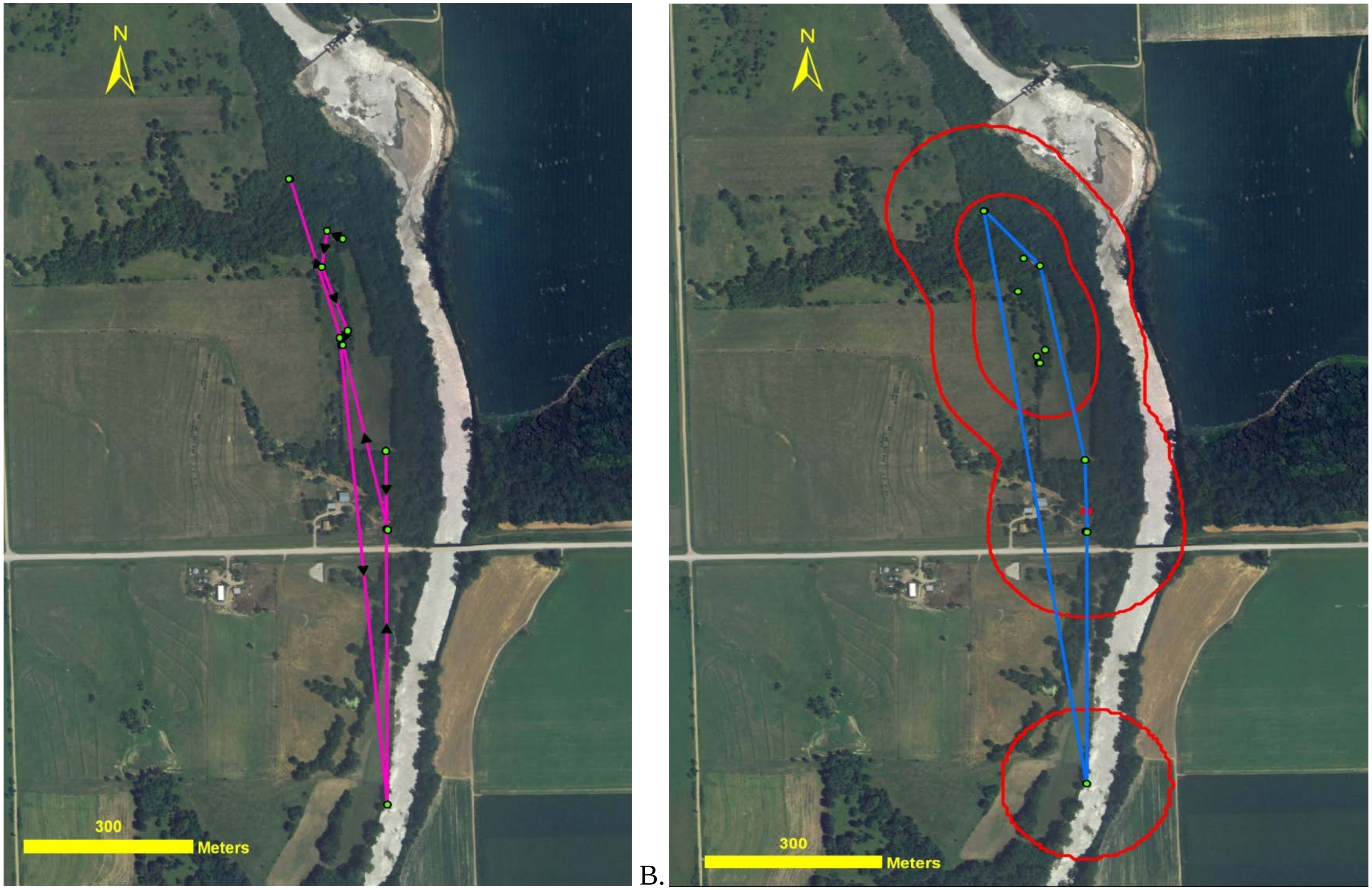


Figure 31. Translocated male C279. (A) Direction and total distance moved = 2495.26 meters; (B) MCP (blue line) = 6.75 ha, 95% home range (outer red lines) = 36.60 ha, 50% core range (inner red line) = 7.41 ha.

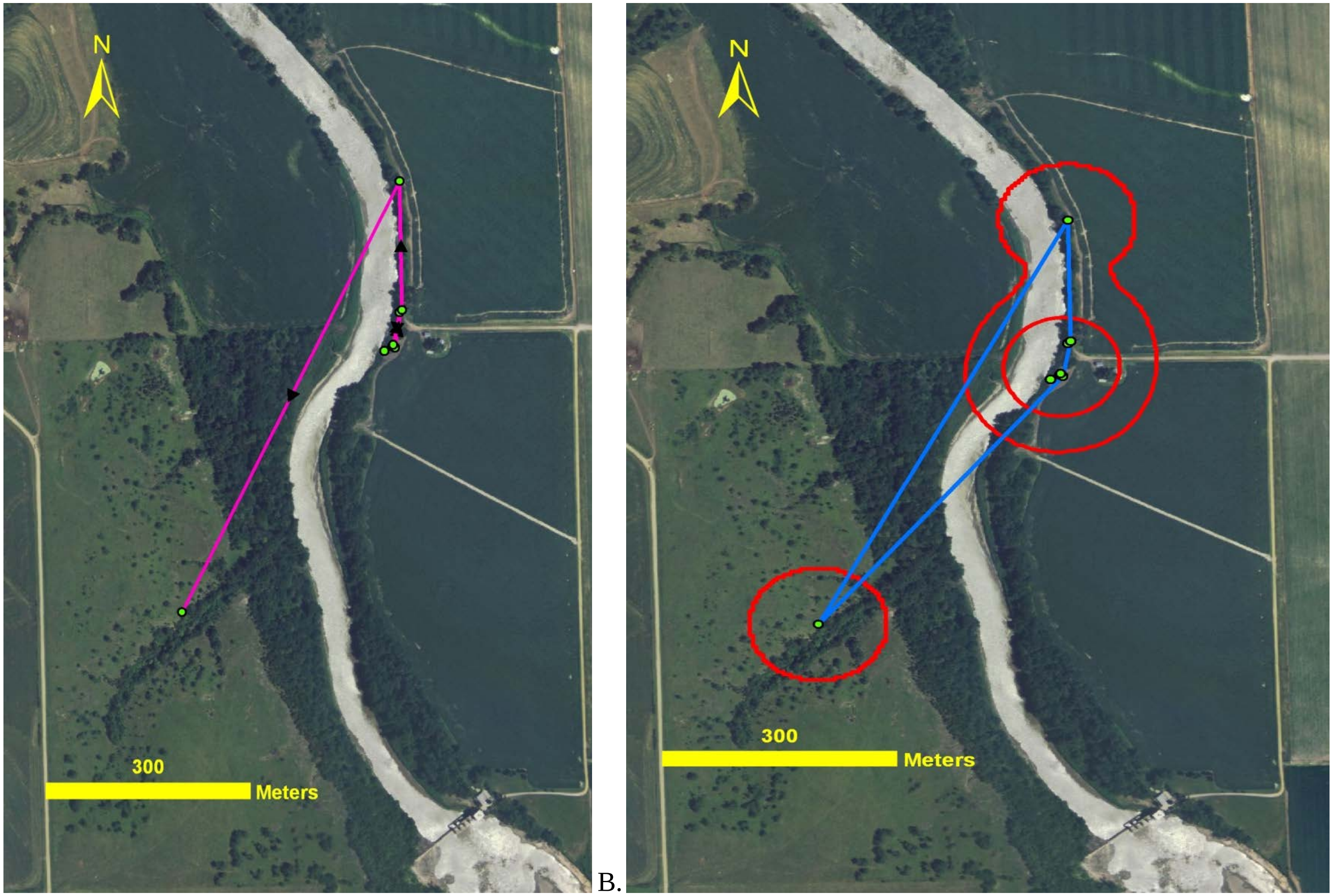


Figure 32. Resident female C043. (A) Direction and total distance moved = 1067.84 meters; (B) MCP (blue line) = 3.77 ha, 95% home range (outer red lines) = 10.23 ha, 50% core range (inner red line) = 1.79 ha.

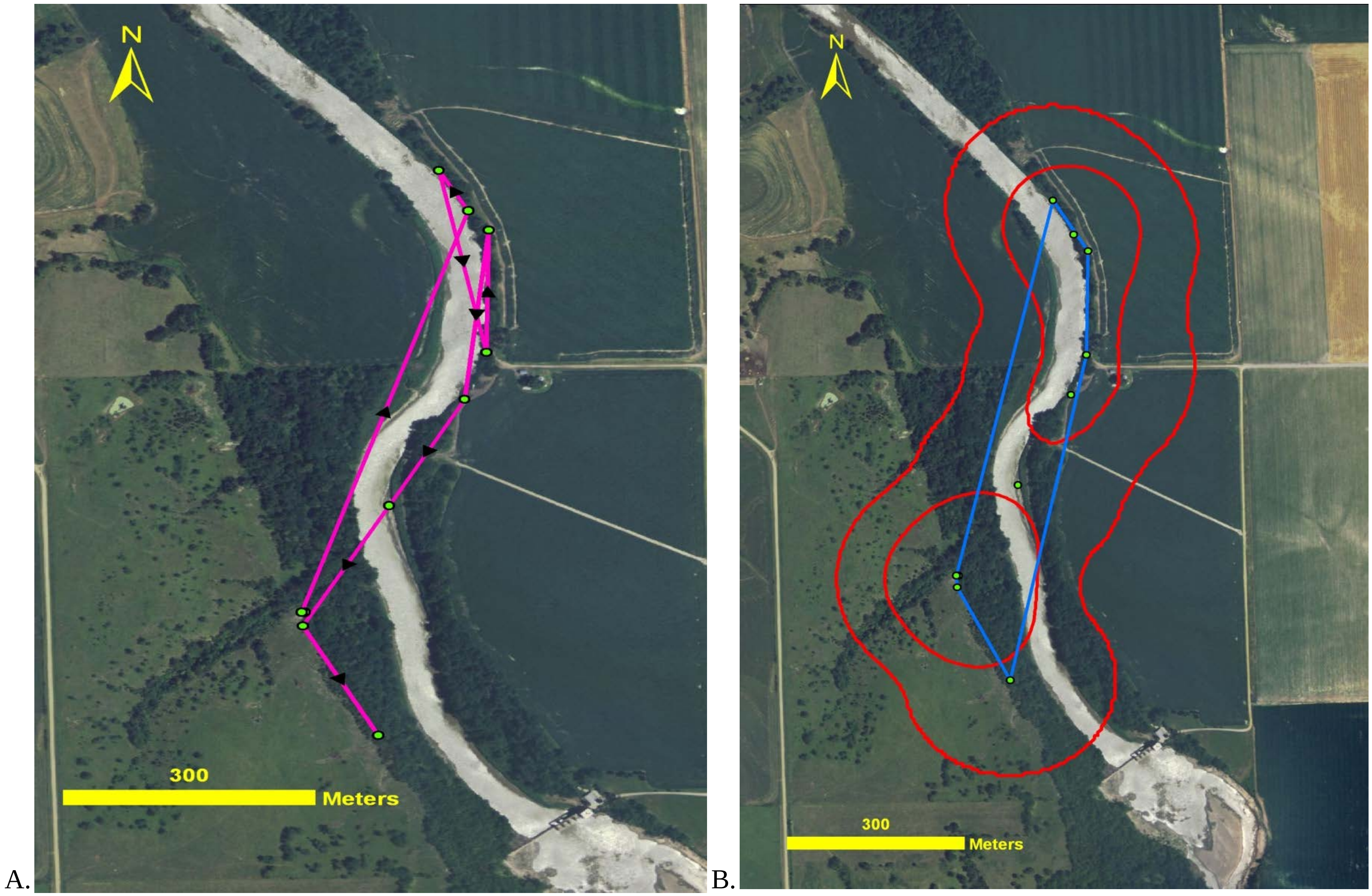


Figure 33. Resident male C158. (A) Direction and total distance moved = 2110.27 meters; (B) MCP (blue line) = 9.04 ha, 95% home range (outer red line) = 46.43 ha, 50% core range (inner red lines) = 14.72 ha.

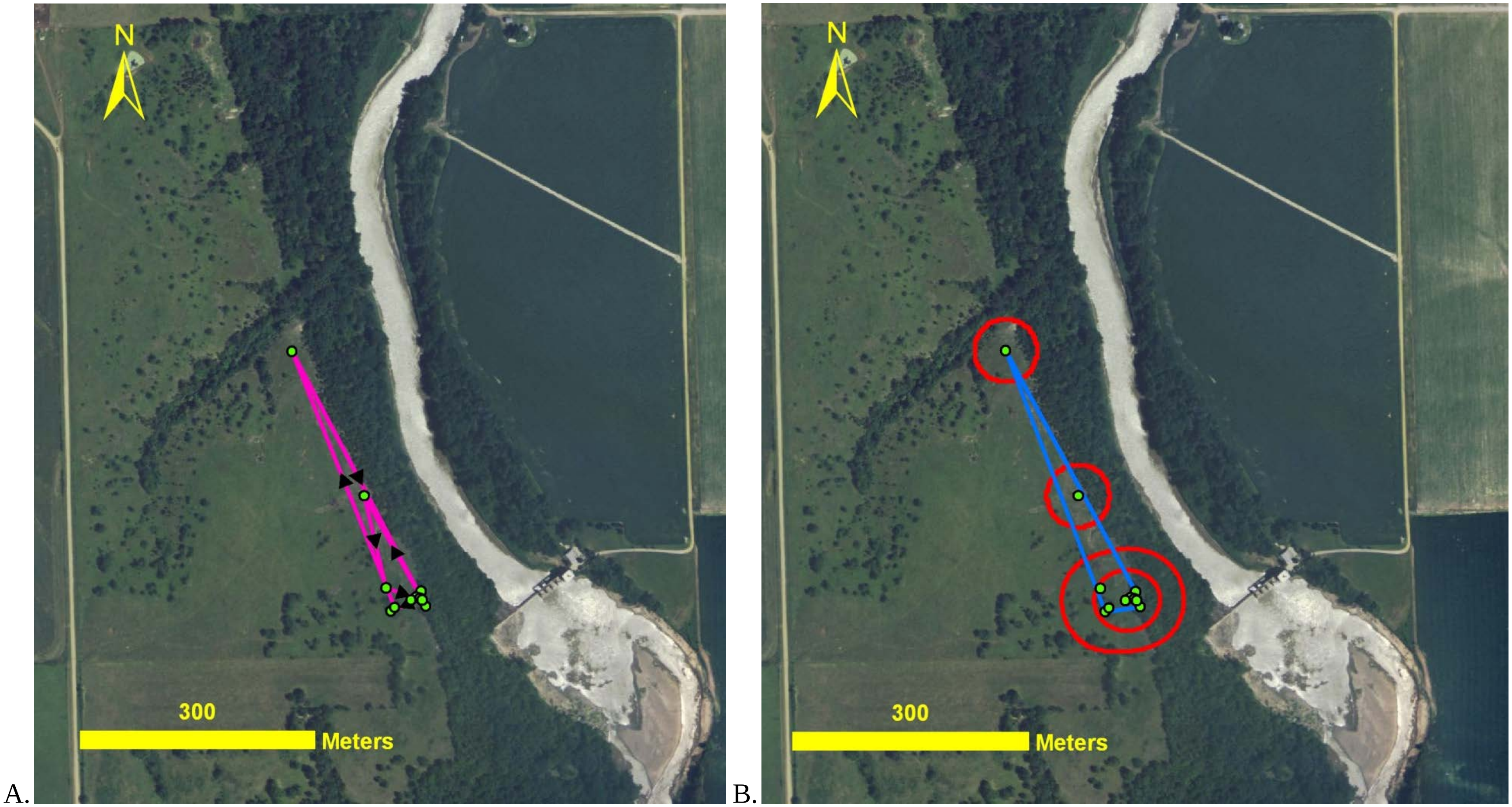


Figure 34. Resident female C249. (A) Direction and total distance moved = 1117.74 meters; (B) MCP (blue line) = 0.84 ha, 95% home range (outer red lines) = 2.59 ha, 50% core range (inner red line) = 0.50 ha.

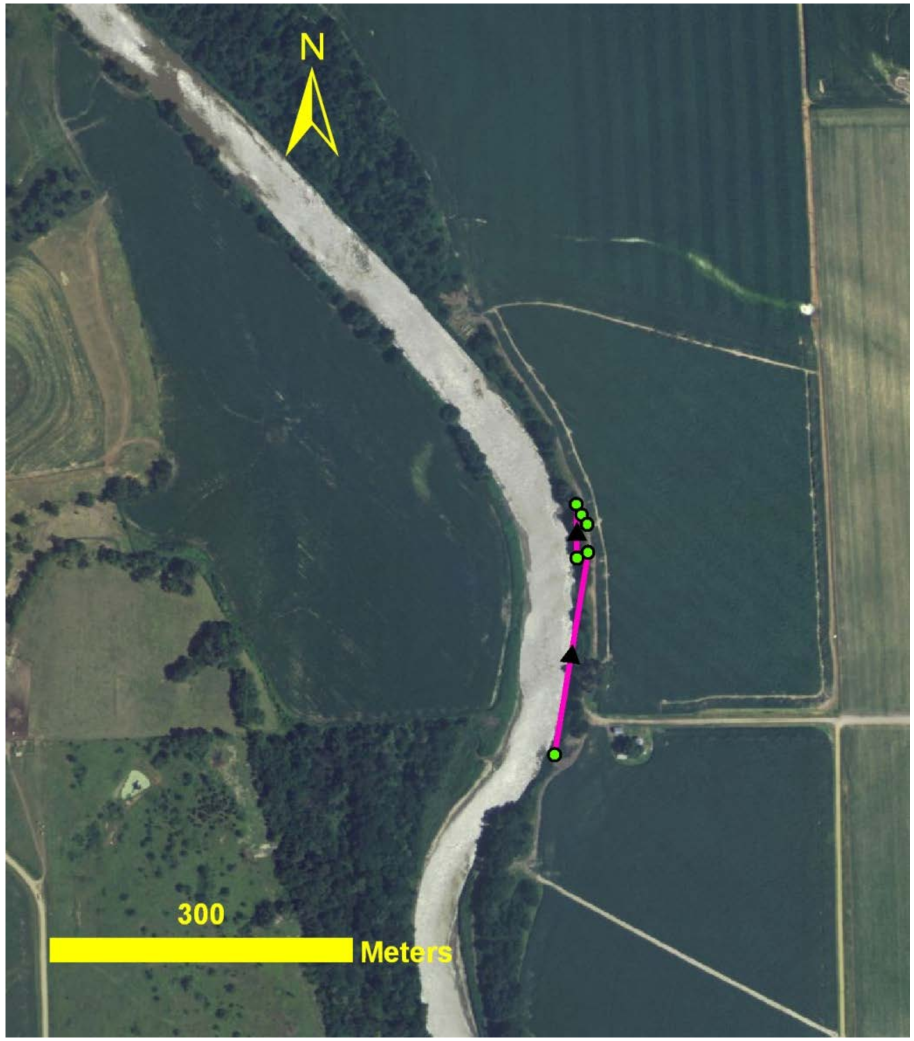


Figure 35. Resident female C272. C272 was captured at the southernmost point and moved north. Total distance, MCP, 95% home range, and 50% core range were not calculated due to predation.

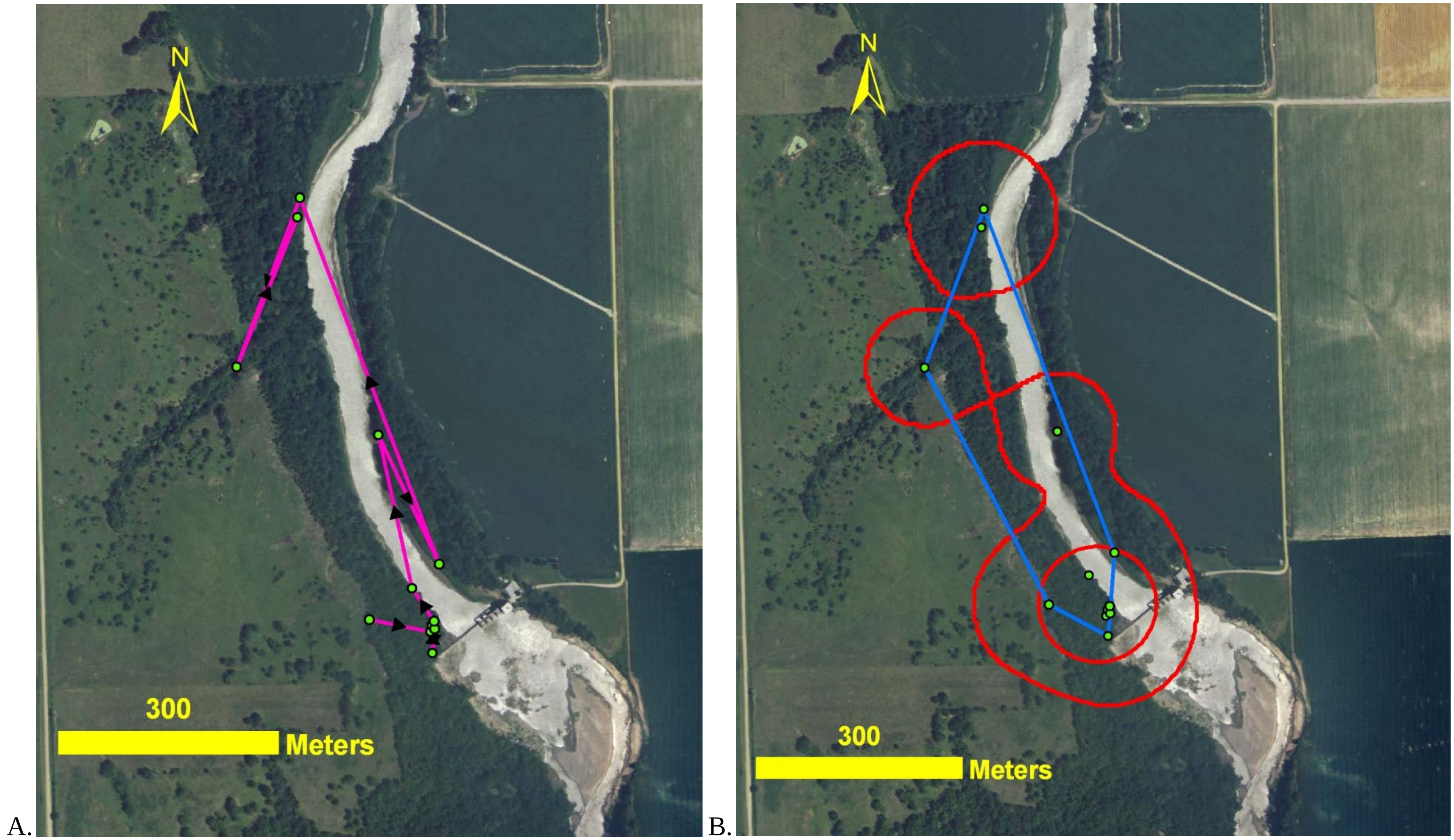


Figure 36. Resident male C321. (A) Direction and total distance moved = 1635.77 meters; (B) MCP (blue line) = 7.19 ha, 95% home range (outer red lines) = 16.48 ha, 50% core range (inner red line) = 2.25 ha.

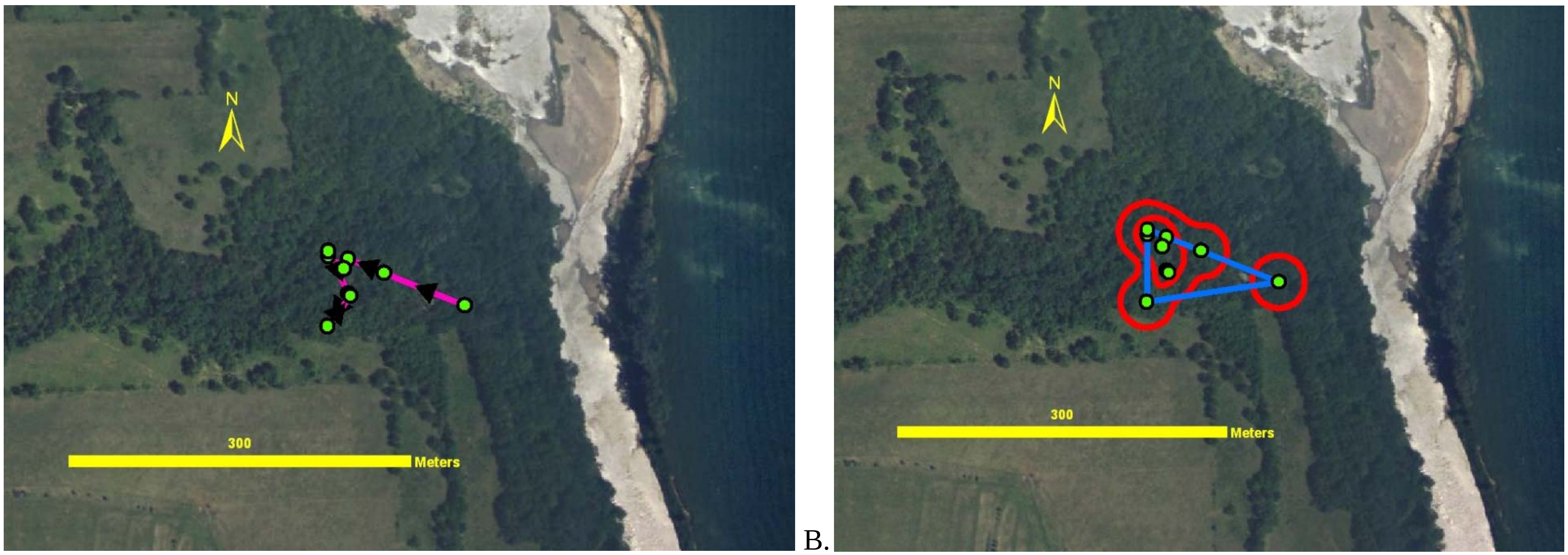


Figure 37. Resident female C340. (A) Direction and total distance moved = 247.92 meters; (B) MCP (blue line) = 0.39 ha, 95% home range (outer red lines) = 0.90 ha, 50% core range (inner red line) = 0.17 ha.