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MUSKRAT-RIVER OTTER INTERACTIONS IN AND ADJACENT TO MAMMOTH CAVE NATIONAL PARK, KENTUCKY

A Thesis Presented for
the Master of Science
Degree
The University of Tennessee, Knoxville

Ryan Williamson
August 2009

DEDICATION

A man once told me that there are ‘marked’ individuals in one’s life that leave an imprint. This imprint affects how you carry yourself, live your life, and how you treat others. A ‘role model’ describes these people poorly, because these men don’t want you to be like them, they strive to make you better. They seek no praise or blessing because they get an untold amount of gratification just to see the person that you have let yourself become, knowing that they had a hand in it. I have been blessed to have known many people in my life who seek to make others more apt to conquer the world’s challenges; it is to those individuals that I dedicate this work. The endeavors that I have faced brought forth these individuals at random times and in difficult situations and affected the choices I made in life, quantify who I am, the things I have done, and the places I will go in the future. It is these choices that will make me that ‘marked’ individual in others’ lives. I have learned that life is more about helping others than it is about helping yourself and through that help, you share a part of yourself that many will benefit from. Therefore in closing, never pass on an opportunity to learn, no matter how minuscule it may be, and take a moment from your life to pass on what you know. So I say to those ‘marked’ individuals in my life; thank you for making me the man I am today.

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Without the support and blessings of my friends and family, I could not have succeeded this far in life. I am forever indebted to my mother, father, and grandparents for instilling in me the values, morals, and the love for the outdoors that I have found so valuable. My choices in life were made easier by you and I will try my best to continue to make you proud.

ABSTRACT

Anecdotal observations have suggested that muskrat (*Ondatra zibethicus*) populations were dramatically reduced in streams where the North American river otters (*Lontra canadensis)* were reintroduced. Muskrats predate upon freshwater mussels and it was speculated that river otter reintroduction could result in increased mussel numbers. My objectives were to evaluate the ecological relationship between otter, muskrat, and mussels on the Green and Nolin rivers in Mammoth Cave National Park (MCNP). Seventeen river otters were captured in or relocated to MCNP from January to May 2007. The augmentation was only marginally successful with 3 male river otters establishing home ranges within the park; of the remaining 13 animals, 10 individuals dispersed >35 km outside of the study area and 3 died shortly after release. Despite the relatively low success of the augmentation, scent-station surveys, trap-site visitation, and scat collection indicated that otter numbers had significantly increased on the Green River since Asmus' (2004) study, probably as a result of natural immigration and range expansion. Although spotlight surveys indicated that there was a concomitant decline in the muskrat population along the Green River from 2002 to 2008 ($F_{1, 73} = 36.56$, $P < 0.0001$), muskrat hair was only found in 1 of 48 (2%) river otter scats examined. That evidence, coupled with a relatively high number of both otters and muskrats on the Nolin River, did not indicate that the relationship between muskrats and otters in MCNP was causal.

On a more extensive scale, I collected data on muskrat and otter presence at 95 randomly selected bridge crossings across Kentucky but centered on MCNP. I used a 2-species co-occurrence model in Program PRESENCE to determine if the presence of river otters was related to the presence of muskrats. This occupancy model indicated that muskrats occurred independently of river otters ($\varphi = 1.02$). Observer, water level, and substrate were important

determinants of otter detection, whereas straight-line distance from original river otter release sites was an important occupancy covariate for river otters. Therefore, both my intensive and extensive data analyses do not support the notion of a negative interaction occurs between river otters and muskrats.

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INTRODUCTION

Background

Freshwater mussels are among the most threatened faunal groups in the world. Sixty-one of the nearly 300 recognized North American species and subspecies are listed as endangered and in need of immediate conservation (U.S. Fish and Wildlife Service 1999). The Tennessee, Kentucky, and Alabama river systems are home to the greatest diversity of mussels in the United States with 35% of North America's freshwater mussel fauna occurring in Kentucky alone (Cicerello and Schuster 2003). The imperiled status of mussels has led to large-scale conservation efforts, such as watershed protection (Cicerello and Abernathy 2006). Fourteen of the known 53 species of mussels that occur in the Green River are threatened or endangered (Cicerello 1999).

The muskrat (*Ondatra zibethicus*) is a semi-aquatic mammal associated with riverine habitats, and muskrat densities are known to increase when competition for food or space decreases (Evans 1970, Lowery 1974). Muskrats are primarily herbivorous but have been known to consume animal matter when vegetation is scarce (Sather 1958). Diet analyses of adult muskrats captured along the Green River revealed that freshwater mussels are an important dietary resource and are essential to sustain muskrat populations (Asmus 2004); muskrats have been known to destroy entire freshwater mussel beds (Van Cleave 1940, Zahner-Meike and Hanson 2001). Furthermore, muskrats have been known to alter species composition in some areas by practicing size- and species-selective predation, which may contribute to greater extinction risks for mussel species that are already threatened or endangered (Convey et al. 1989, Hanson et al. 1989, Neves and Odom 1989, Jokela and Mutikainen 1995, Tyrrell and Hornbach 1998, Zahner-Meike and Hanson 2001).

Although the North American river otter (*Lontra canadensis*) was historically found in most major waterways in the U.S. and Canada, many populations declined or disappeared within the last century. Early extirpations likely were related to unregulated harvest, habitat destruction, human encroachment, and water pollution (Deems 1978, Lauhachinda 1978). In 1979, river otters (subfamily Lutrinae) were placed on Appendix II of the Convention on International Trade in Endangered Species (CITES) due to overharvest. Appendixes II is reserved for species that may become threatened, endangered, or are in need of monitoring. To ensure the sustainability of trade and the survival of the species, international regulations were established only allowing export permits for wild populations that are harvested in a sustainable manner (Polechla 1988). During the 1970s, the Clean Water Act, the Clean Air Act, and the National Environmental Policy Act led to reductions of point- and non-point-source pollutants and habitat protection of wildlife species (e.g., refuges, management areas). With strong public support, many state wildlife agencies in the U.S. subsequently reintroduced the river otter throughout much of its historic range. Between 1976 and 1998, 21 states including Kentucky, implemented river otter reintroduction programs with the goal of establishing self-sustaining populations (Raesly 2001).

River otters mostly consume fish, but the diet also includes crustaceans, insects, birds, amphibians, and mammals. Otters mainly prey on slower-swimming fish species such as suckers (*Catostomus* spp.), catfish (*Ameriurus* spp., *Ictalurus* spp.), redhorses (*Moxostoma* spp.), and common carp (*Cyprinus carpio*), because these species are easier to capture. However, otters also opportunistically feed on other prey species (Towelli and Tabor 1982). Leirs (1951) documented that captive otters responded poorly to a fish-only diet, suggesting that other prey types are important. Griess and Anderson (1987) showed that crayfish were the second most common food item of river otters in central Tennessee.

The Kentucky Department of Fish and Wildlife Resources (KDFWR) initiated river otter reintroduction in 1991 with the release of 75 animals. To date, 355 animals were reintroduced in 16 counties (Cramer 1995). The Green and Nolin rivers, located in Hart and Adair counties, comprise the 2 main rivers within MCNP and received 50 reintroduced individuals between 1991 and 1994. However, Asmus (2004) speculated that the otter population within Mammoth Cave National Park (MCNP) was only small or transient in 2002.

Anecdotal observations suggest that muskrat densities drastically declined after the reintroduction of river otters into the Obed River, the Big South Fork of the Cumberland River, and the Hiwassee River all of which are located within Tennessee (Anderson 1998). Thus, river otter reintroduction may be an effective management tool for mussel conservation if otters can control muskrat populations. Predation, interspecific competition, or other factors are possible mechanisms for reductions in muskrat densities as a result of river otter reintroduction. Based on scat and digestive tract analysis, otters are known to prey on muskrats and have been reported to be the principal mammal species preyed upon by otters (Wilson 1954, Melquist and Hornocker 1983, Findlay 1992). However, the documented proportion of mammalian prey in otter diets is relatively low: 6.1% (Greer 1955), 4.3% (Hamilton 1961), and 0.9% (Lauhachinda 1978). Competition occurs when the introduction of one species results in population or distributional changes in another (Dalén et al. 2004). River otters and muskrats have different food habits, so the probability of food competition may be limited. However, the 2 species occupy the same riverine areas and may compete for particular habitat features, such as den sites.

Justification

In 2002, Asmus (2004) initiated a study to determine muskrat predation rates on mussels, establish monitoring methods, and estimate abundance of mussel, muskrat, and river otter

populations in the Green and Nolin rivers in MCNP. One of the objectives of that study was to gather baseline information prior to a river otter reintroduction. Asmus (2004) conducted spotlight surveys along the 2 rivers to assess muskrat densities and observed 358 muskrats over 48 nights resulting in a population index ranging from 0.083 to 1.33 muskrats/km. Using midden surveys, Asmus (2004) found mussels at 47 locations. Asmus (2004) used scent-station surveys to estimate river otter abundance for the Nolin River and the impounded section of the Green River within the national park. Based on a visitation rate of 2.1%, she speculated that the otter population probably was small or transient. Therefore, if river otters can be successfully reestablished at MCNP, an opportunity exists to compare relative muskrat density and mussel predation before and after the presence of river otters.

New methods have been developed to explore species interaction on a landscape scale. If a series of sites are sampled multiple times, it is possible to estimate the probability of species presence when the species is not detected at a particular site (MacKenzie et al. 2004). Covariates can be used to help explain the probability of occupancy and detection at a site. Thus, if the probability of presence of a potential competitor species is used as a covariate, species interactions can be quantified.

Objectives

The goal of my study was to determine if river otters have a negative impact on muskrat populations and to document the causal mechanism for such a relationship. To do so, I evaluated population trends and spatial interactions on a study area within MCNP before and after river otter augmentation. I also estimated occupancy by otters and muskrats at bridge crossings in a 35-county region centered on MCNP to perform a 2-species interaction analysis. My specific objectives were to:

1) estimate survival, reproduction, movements, and home ranges of translocated river otters to determine the success of the river otter augmentation;

2) determine if the muskrat population declines after the river otter augmentation;

3) determine if river otters predate upon muskrats in MCNP; and

4) determine whether a negative interaction occurs between river otters and muskrats based on field sign observed at bridge crossings.

Hypotheses

H_1: The increase in the river otter population will cause in a decrease in muskrats and a decrease in muskrat predation on mussels in MCNP.

H_2: The occupancy of bridge crossing sites in a 35-county region centered on MCNP by river otters will be negatively related to occupancy by muskrats.

STUDY AREA

General

My intensive study area consisted of the Green and Nolin rivers within MCNP (approximately 52 km) in Barren, Edmonson, and Hart counties in Kentucky (Fig. 1). MCNP was established in 1941 and named for the world's longest known cave system, which is located within the Park. MCNP has a particularly diverse aquatic ecosystem that consists of an aquatic cave environment along with impounded and free-flowing waterways. In addition to the cave systems and waterways, the national park also contained 21,450 ha of contiguous upland forest. Because of its floral and faunal diversity, MCNP was named a World Heritage Site in 1981 and an International Biosphere Reserve in 1990. MCNP received approximately 1.8 million visitors per year that participated in outdoor activities such as hiking, canoeing, camping, fishing, and caving (Kleber et al 1992).

My extensive study area included a 35-county area centered on MCNP. Kentucky is known for its karst topography, rolling hills, horse farms, coal mining, and bourbon distilleries with several metropolitan areas including Bowling Green, Elizabethtown, Frankfort, and Lexington. Kentucky contains numerous large waterways and several large reservoirs offer abundant fishing opportunities. The state provided abundant opportunities for hunting species such elk (*Cervus elaphus*), black bear (*Ursus americanus*), and wild turkey (*Meleagris gallopavo*).

Rivers

The Green River and Nolin River systems each lie within the Interior Highland and Interior River Valley and Hills Level III Ecoregions (Omernik 1987). The Green River and its tributaries drain 3,500 km^2 of land from west-central Kentucky and north-central Tennessee.

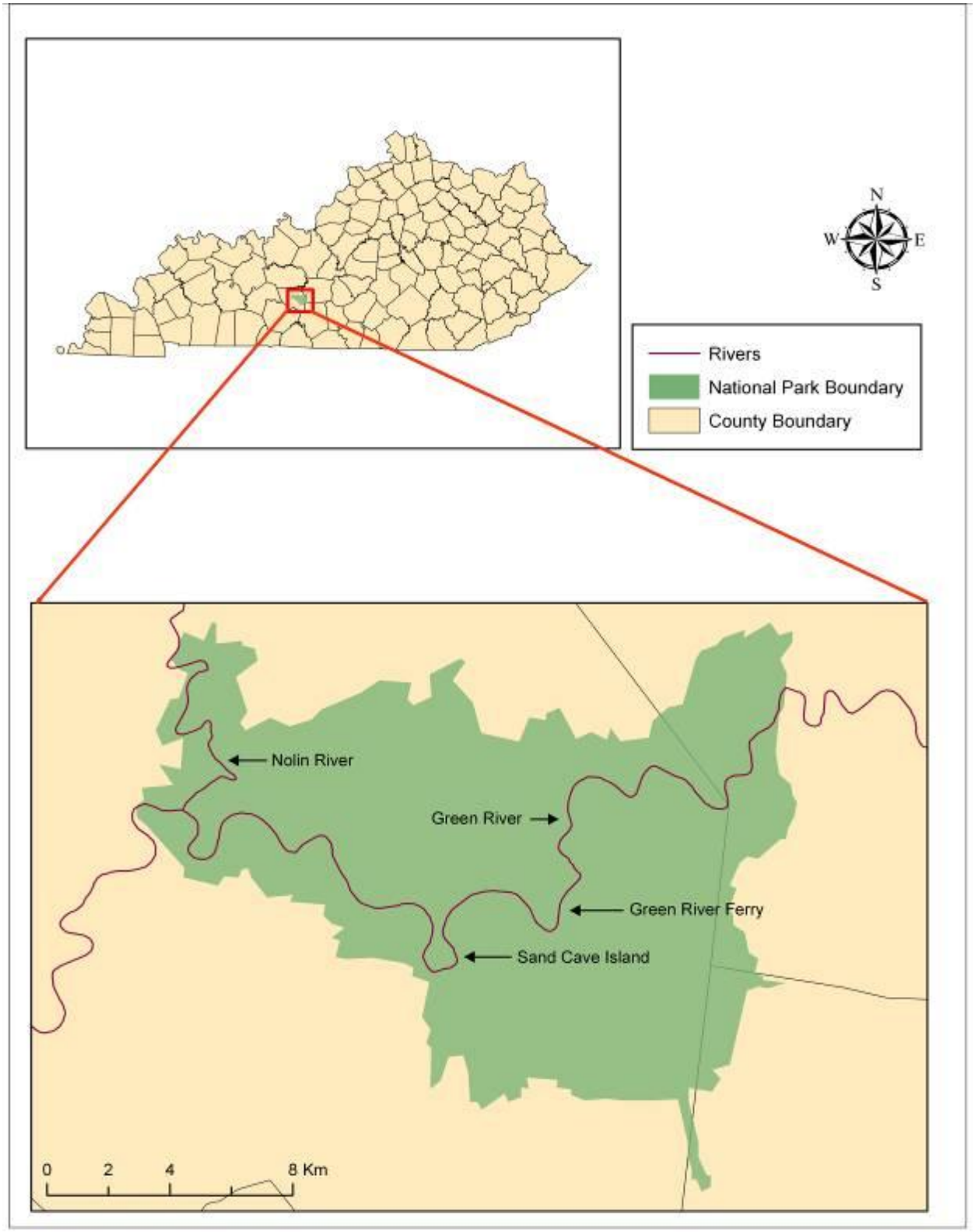


Fig. 1. Study area on the Green and Nolin rivers in Mammoth Cave National Park, Kentucky, 2007–2008.

Two hydrologic transition zones exist on the Green River within the study area: the lower is an impounded mesotrophic section (26.4 km) that lacks shallow runs and riffles, and the upper free-flowing oligotrophic section (15.3 km) exists as a series of pool-riffle-run zones. This system covers one-third of the state, making it Kentucky's largest (Fig. 2). The Green River originates south of Danville, Kentucky then proceeds 580 km to become a major tributary of the Ohio River near Evansville, Indiana. The Nolin River originates in Larue County, Kentucky and flows southwest for 119 km before it flows into the Green River within the bounds of MCNP. The natural flow regime of the Green River was disrupted during the 1830s by the construction of 6 low-head dams along its middle section to aid in transportation of steamboats (Crocker 1976). Of these, Lock and Dam No. 6 affects the water flow regimes on the Nolin and Green rivers in the park and is located directly downstream of the study area. Additionally, the Green River was dammed approximately 160 km upstream of MCNP in 1969 by the U.S. Army Corps of Engineers to create Green River Lake. This dam provided Greensburg, Kentucky with approximately 12,950 ha of impounded water for recreation, flood control, and water supply. These structures have modified the natural hydrology of the river by producing lower peak discharges and prolonging periods of high discharges that naturally occur from fall to late spring (Hardison and Layzer 2001).

MCNP encompasses approximately 40 km of the Green River and 10 km of the Nolin River. Within the national park, the Green River averaged 60 m wide and 3 m deep with steep banks and narrow alluvial floodplains, whereas the Nolin River averaged 5 m wide and 3 m deep with sloping banks. The entire 10 km of the Nolin River is retarded downstream by Lock and Dam #6.

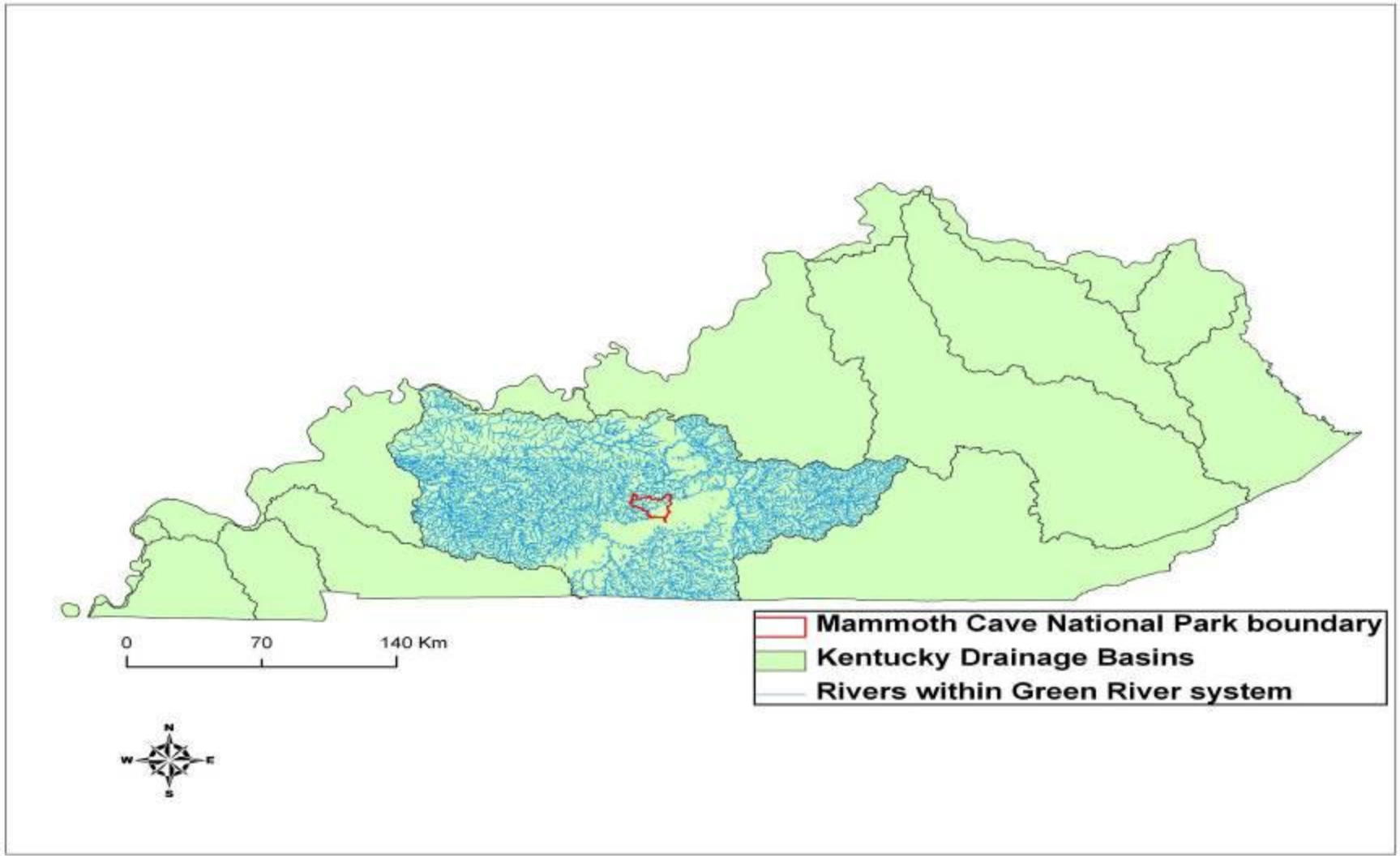


Fig. 2. Extent of the drainage network of the Green River system, Kentucky.

The extensive study area encompassed many of Kentucky's waterways throughout the state. The state is bordered on 3 sides by the Ohio, Mississippi, and the Big Sandy river systems. Most data were collected within the Green River Drainage Basin but I also sampled the Salt, Kentucky, and Licking River Drainage Basins. The waterways I sampled were primarily the 1st-, 2nd-, and 3rd-order streams that comprised the tributary mass of these larger drainage systems. These rivers and streams were surrounded by riparian vegetation except in areas of high urban development and agricultural zones. Degradation of these areas mostly consisted of the removal of vegetation but, in some cases, stream channelization had occurred. Many of these waterways are regulated by the Tennessee Valley Authority (TVA) to produce power, for flood control, and to provide recreational opportunities. These impoundments have lead to the creation of 2 of the largest man-made reservoirs east of the Mississippi River: Kentucky Lake and Lake Cumberland (Gille and Channing 1997).

Geology

Mammoth Cave National Park lies within the karst region of central Kentucky. Typical karst topography features rolling hills and valleys of limestone rock that deteriorate throughout time, resulting in a lack of surface streams, numerous sinkholes, and a vast subterranean cave system (Woodman and Thomas 2003). This karst geographic landscape stretches north to Indiana, east to the Cumberland Plateau, south to Georgia, and west to the Ozark Mountains. Mammoth Cave was formed by the Green River and its tributaries that deteriorated the limestone rock as it flowed through the Green River Valley. The rise and fall of the river levels through time have resulted in the longest, multiple-layer cave system in the world (579 km). The cave system is preserved by an insoluble layer of sandstone caprock that protects the cave from rainwater and eventual collapse, making it one of only a few dry caves in the world.

The geography of the extensive study area primarily consists of the Pennyroyal Plateau region, which is also known as the Mississippi Plateau or, locally, as the 'Pennyrile Region.' Although my focus was on the 'Pennyrile Region', the Western coal fields to the north and the Bluegrass region of horse farms to the northeast also contained sampling sites. These areas are known for their flat lands and rolling hills in which farming communities and underground cave systems are prevalent (Kleber et al. 1992).

Climate

The climate of the national park and surrounding area is typical for south-central Kentucky, which consists of mild winters and humid, hot summers with abundant rainfall. Average high temperatures in January and July were 5.0°C and 31.1°C, respectively, and the average low temperatures were -3.8°C and 20.0°C, respectively. The average annual precipitation was 110.5 cm; 45.7 cm of that was snowfall. The largest amount of precipitation occurred in March. Snowfall was recorded from November to March (National Park Service 2007). During summer 2007 and 2008, the eastern portion of the U.S. was impacted by drought conditions that affected water temperature and level.

Flora

Prior to the park's establishment, an estimated 45% of the land was old field habitat pastured by cattle with occasional eastern red cedar (*Juniperus virginiana*) and Virginia pine (*Pinus virginiana*). Therefore, the study area was mostly comprised of second-growth forest with a few small areas of old-growth timber. The drier, upland areas of MCNP were comprised mostly of an oak-hickory (*Quercus-Carya* spp.*)* forest that was typical of the transition area between the east and west. Common trees along the Green and Nolin river floodplain included box elder (*Acer negundo*), silver maple (*Acer sacharinum*), American elm (*Ulmus americana*),

sycamore (*Platanus occidentalis),* and black walnut (*Juglans nigra*). The surrounding area had similar floral diversity with the majority of timber occurring in riparian areas due to extensive farming practices. The state was 47% forested and had a diverse hardwood species mix.

Fauna

The Green River had approximately 151 species of fish and 71 species of freshwater mussels, making it the fourth most diverse river in North America (Olson 2005). The park harbored a typical suite of animals common to eastern deciduous forests and aquatic ecosystems. White-tailed deer (*Odocoileus virginianus*), beaver (*Castor canadensis*), bobcat (*Lynx rufus),* coyote (*Canis latrans*), mink (*Mustela vison*), opossum (*Didelphis virginiana),* muskrat, and raccoon (*Procyon lotor*) were common mammals found within the national park. Several federal and threatened species occur in the park including the Indiana bat (*Myotis sodalis*), gray bat (*Myotis grisescens*), and Kentucky cave shrimp (*Palaemonias ganteri*). The Green River was home to 6 endangered mussels *(Obovaria retusa, Pleurobema plenem, Epioblasma torulosa biloba, Cryprogenia stegaria,* and *Hemistena lata)* and to *Crystallaria asprella,* an endangered fish species. The cave system of MCNP had the most diverse cave biota in the world with an estimated 130 species (Culver et al. 2000). This study area was chosen due the high diversity of mussel species, high muskrat densities, and excellent water quality, which is necessary to support a river otter population.

METHODS

Trapping

I trapped within MCNP to capture resident otters for monitoring and then trapped nuisance otters reported to KDFWR from around the state and relocated them to MCNP. Blundell et al. (1999) found that the foothold traps were strong enough to hold otters by the foot without the trap damaging long bones. Therefore, I used modified #11 double long-spring foothold traps (Sleepy Creek Manufacturing, Berkeley Springs, West Virginia, USA; Shirley et al. 1983, Erickson and McCullough 1987, Serfass et al. 1996, Blundell et al. 1999). Foothold traps were equipped with multiple inline swivels and springs to minimize capture-related injuries. To prevent rust and to mask foreign odors, traps were dipped in KBL Quick Dye (Kaatz Brothers Lures, Oak Forest, Illinois, USA). Berkshire disposable stakes (Berkshire Products, Inc., Sheffield, Massachusetts, USA) were used as anchoring devices so that traps could be placed in various terrain conditions. Capture sites were chosen to avoid hazardous obstructions and human disturbance. Before establishing a capture location, I assessed the area for the appropriate amount of shade to prevent heat stress to the captured animal. I placed 2 to 4 traps at each site based on the frequency of river otter sign (e.g., "pull-outs", latrine sites, den sites). I checked traps once daily to minimize exposure time and stress to the animal.

Handling

I placed captured river otters in transport barrels and removed the trap following procedures developed by the Missouri Department of Conservation (Mike Fischer, Missouri Department of Conservation, personal communication). River otters considered to be juvenile animals (<22 kg) were immediately released. Otherwise, otters were then placed into portable

kennels and transported to the Animal Clinic of Glasgow (Glasgow, Kentucky), where they underwent surgery.

At the veterinary clinic, otters were restrained in specially designed cages to minimize stress and injury during injection (Serfass et al. 1996). Otters were immobilized with ketamine hydrochloride (Ketaset, Bristol Laboratories, Syracuse, New York, USA; 22 mg/kg, Ramsden et al. 1976, Melquist and Hornocker 1983, Serfass et al.1996) and diazepam (0.4 mg/kg, Elmore et al. 1985, Erickson and McCullough 1987, Spelman 1999). A radio transmitter (IMP/400/LNH®, Telonics, Inc., Mesa, Arizona, USA) was inserted into the intraperitoneal cavity through a small para-lumbar incision (5.0-6.5 cm; Hernandez-Divers et al. 2001, Hoover 1984, Melquist and Hornocker 1979, Serfass et al. 1993). The transmitter was housed in a high-impact plastic shell, which was covered in a physiological wax coating for waterproofing and durability. The incision site was aseptically prepared with a povidone-iodine scrub (Betadine Surgical Scrub®, Purdue Frederick Co., Norwalk, Connecticut, USA). The unique cuticular structure of under-hairs and guard hairs combined with a hydrophobic oil coating is the only mechanism for thermal insulation used by otters (Weisel et al. 2005). Therefore, the incision site was not clipped of hair due to the risk of hypothermia. This incision was closed using 3-0 absorbable, monofilament-synthetic sutures (Coated Vicryl®, Ethicon, Somersville, New Jersey, USA), and surgical glue was applied over the incision site to provide a waterproof seal (VetBond, 3M Animal Care Products, St. Paul, Minnesota, USA).

Throughout the handling procedure, I assessed respiration, temperature, and pulse to determine the condition of the animal. During anesthesia, sex, tag number, and body measurements were recorded for each river otter. Although multiple methods exist for aging otters, the most reliable involves the counting of annuli in tooth cementum (Tabor 1974,

Stephenson 1977, Matson 1981). I removed the first upper premolar for aging using cementum annuli (Garshelis 1984) and teeth were sent to a private laboratory for age assignment (Matson Laboratories, Milltown, Montana, USA). Buprenorphine (0.02 mg/kg) and meloxican (0.2 mg/kg) was subcutaneously injected with a 22-gauge needle to reduce pain and inflammation because of tooth extraction and surgical procedures. I sexed the animals by determining the distance from the anus to the urogenital openings, which is greater for males than females (Thompson 1958). Each otter received 2 Monel ear tags (size 1; National Band and Tag Co., Newport, Kentucky, USA) with a unique identification number along with interdigital tags (size 3) on the hind feet. I subcutaneously injected a passive integrated transponder (PIT) tag between the shoulder blades for permanent identification (Biomark®, Boise, Idaho, USA). Body measurements consisted of head length and width, tail length, total length, ear length, and hind foot length. Pelage color, scars, old injuries, and abnormalities also were recorded. The animals also received an injection of penicillin (1 ml/9.1 kg) to help prevent infection and eye ointment was applied to prevent eye desiccation. I held animals for approximately 8 hours to ensure complete recovery from the anesthesia and to reduce stress. I then transported and released the otters in the study area or at the original site of capture after complete recovery from anesthesia. All captured animals were handled according to protocols approved by the University of Tennessee Office of Laboratory Animal Care (IACUC #1596).

Telemetry

I used radio telemetry to monitor survival, movements, and to estimate home-range size for river otters. Released otters were monitored daily for the first 2 weeks and 3 times/week thereafter. Monitoring consisted of locating the animals by boat using a 2-element H-antenna and a portable receiver (TR-4, Telonics Inc., Mesa, Arizona, USA). I used a global positioning

system (GPS) receiver to record x, y coordinates along the waterway. Otters that dispersed outside the study area were located with aerial telemetry monthly. Aerial telemetry was conducted from a Cessna 172 airplane equipped with a set of 2-element Yagi antennas.

I estimated home ranges for all river otters that were located ≥10 times during a 2-year period, although ≥30 is preferred (Aebischer et al. 1993). I used a univariate kernel density estimator to determine linear home ranges (Vokoun 2003). I first plotted locations on topographic maps (1:24,000) using ArcView® GIS (ESRI, Inc., Redlands, California, USA). Using the distances along the watercourses where otters were located, I created a univariate frequency distribution. I then calculated the distance from each location to a standard reference position. I used PROC KDE (SAS Version 9.1, SAS Institute, Cary, North Carolina, USA) to compute 50%- and 95%-linear kernel home ranges (Van Winkle 1975), using the Sheather–Jones plug-in method to choose the bandwidth (Silverman 1986, Marron 1989, Jones et al. 1996, Loader 1999). Additionally, I used fixed kernel analyses with references to smoothing parameters for bandwidth selection to obtain 2-dimensional estimates of 50% (core home range) and 95% home ranges (Blundell et al. 2001). I used the fixed kernel method for comparison because Vokoun's (2003) method has not been used to estimate linear home ranges for mammals. Dispersal distance was defined as the farthest known distance traveled from the release site.

The transmitters were equipped with mortality sensors that enabled me to determine the survival status of released otters. Survival was estimated using the Kaplain-Meier staggered entry procedure (Pollock et al. 1989). I documented otter reproduction by tracking females that exhibited prolonged denning behavior or by visual observation.

Scent Stations

Scent-station techniques have long been used to estimate the relative abundance of river otters (Jenkins and Burrows 1980, Johnson and Pelton 1981, Robson 1982, Clark et al. 1987). I used scent stations to determine the presence and relative abundance of river otters within the intensive study area. To provide appropriate comparisons, I used the same methods described by Asmus (2004). Scent stations consisted of a 1-m^2 area of mud or sand on alternating sides of the riverbank and spaced at 0.8-km intervals. The mud and sand was smoothed to facilitate track identification. Because of possible habituation to scent during the first phase of this project, I alternated lures after each successive station-night (Caven's Otter Lure Supreme, Minnesota Trap Line, Pennock, Minnesota, USA; Hawbaker's Otter Lure, Hawbaker and Sons, Fort Loudon, Pennsylvania, USA; Torpedo, Fox Hollow Magnum Animal Lures, Marble Hill, Georgia).

Scent-station surveys were conducted monthly. The study area was divided into 3 sections: the free-flowing Green River from Turnhole Bend to the upstream park boundary, the impounded Green River from the Turnhole Bend to the downstream park boundary, and the Nolin River from the Nolin River Dam to the confluence with the Green River (Fig. 3). I checked scent stations after a 24-hour period. I first assessed the ability of the substrate to reveal a track by pressing my thumb into the substrate. Stations that did not produce a distinct thumbprint were counted as inoperable. At visited stations I measured the length, width, and stride of tracks to aid in identification of partial or obscured tracks. In addition to scent stations, I recorded trap-site visitation by otters and scat locations to document use by river otters. I calculated a relative index (ratio of visited trap sites or scent stations to total operable trap sites or scent stations multiplied by 100) for trap-site and scent-station visitation by otters for each

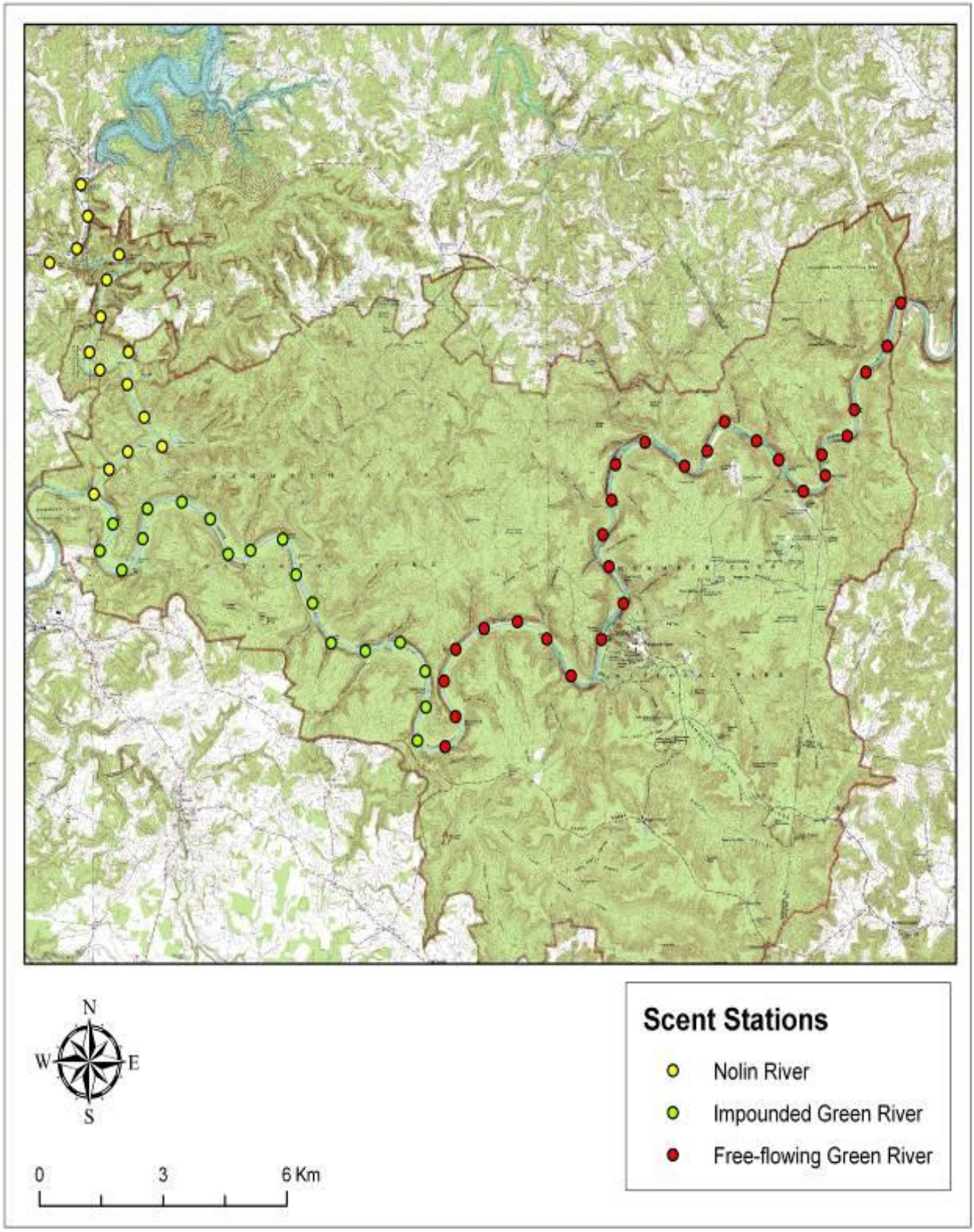


Fig. 3. Locations of scent stations to determine relative abundance of river otters on the Green and Nolin rivers, Mammoth Cave National Park, Kentucky, 2007–2008.

river section. I used analysis of variance (ANOVA) to determine if pre- and post-otter augmentation scent-station indices differed. I compared all river otter visitation indices with nonparametric methods (rank transformation) to address unequal variances and non-normality.

Spotlight Surveys

Several techniques have been used to monitor muskrat density including house counts (Dozier 1948), sign surveys (Nadeau et al. 1995), and mark-recapture analyses (Clay and Clark 1985, Clark and Kroeker 1993). Most studies have been performed in marshy areas where lodges were visible above ground and muskrat densities were high. Unfortunately, muskrat densities are lower in riverine habitats and their lodges consist of bank burrows with underwater entrances. These factors made traditional techniques such as house counts inadequate for detecting population changes on my study area.

Spotlight surveys have been used to assess populations of land and aquatic mammals, including raccoons (Gert 2002), swift foxes (*Vulpes velox*; Schauster et al. 2002, Ralls and Eberhardt 1997), white-tailed deer (Fafarman and DeYoung 1986, Cypher 1991), jackrabbits (*Lepus* spp., Smith and Nydegger 1985), muskrats (Gray and Arner 1977), beavers (*Castor canadensis*, Swafford 2002), and wood ducks (*Aix sponsa*, Minser and Cole 1991). Asmus (2004) estimated muskrat density per km using spotlight surveys at MCNP. Therefore, I used this same survey technique to provide a direct comparison of muskrat densities before and after river otter augmentation. Spotlight surveys have been criticized because of high variation caused by weather, habitat structure, and animal behavior (Stewart and Bider 1977, Wilson and Delahay 2001). Therefore, Asmus (2004) accounted for weather conditions and other abiotic environmental variables that may impact muskrat movements with 3 covariates (water level, water temperature, days^2). Days was the number of days elapsed since the first survey, which

was squared to account for the curvilinear relationship between time and muskrats/km (Asmus 2004). I also collected data on those same covariates to allow comparison with the previous survey results.

I conducted spotlight surveys weekly from January to August 2007 and from June to August 2008 on the Green River from the upstream park boundary to Sand Cave Island (22.6 km). Due to unseasonably low water levels in July and August during 2007 and 2008, the Green River spotlight surveys were only conducted bi-monthly. I used biweekly spotlight surveys on the Nolin River (Nolin boat ramp to the Green River confluence [12.2 km]) as a control dataset. Another observer and I surveyed these river sections after dusk in a motorboat traveling at approximately 8 km/hr. We used a 1-million candle-power spotlight to identify muskrats. We recorded their activity, time, and location with a GPS (Garmin eTrex Venture®) receiver. Surveys were not conducted in rain, fog, or during flood stages. I calculated an index of muskrat abundance for each night by dividing the number of muskrats seen by the number of km traveled (muskrats/km).

Muskrat sightability fluctuates during the year due to the emergence of offspring in May and reduced activity of adult females during maternity. I used PROC REG (SAS Version 9.1) to perform backward and stepwise selection with a *P*-value of 0.10 as the criterion to enter or remove variables from the model. I used analysis of covariance (ANCOVA) to determine if the muskrat density index changed between 2004 and 2007 and between summer 2007 and summer 2008. I tested model assumptions for normality of residuals and equal variance using Levene's test (Ott and Longnecker 2001).

Scat Analysis

I used scat analysis to estimate the frequency of muskrat predation by otters. Otter scat can easily be identified by size, shape, and general appearance. Most scat is 40–80 mm long, often in 2–4 segments with a diameter of approximately 20 mm (Greer 1955). Fresh scat usually appears greenish because of a mucous coating that prevents sharp bone fragments and scales from damaging intestines (Lagler and Ostenson 1942). I collected scats along the Green and Nolin rivers every 3 weeks or as I conducted other field work. I collected, bagged, and labeled fresh scat with the appropriate date and location. I washed these samples with warm water and alcohol and allowed them to air dry. Afterwards, I separated the large fragments and pulverized the sample to locate hair. Using a mammal hair identification key (Moore et al. 1974), I examined hair under dissecting and compound microscopes to identify prey species. Mussel shell fragments were also removed from scat and identified to determine if otters were consuming mussels.

Midden Surveys

Mussel predation rates have been estimated using periodic sampling and removal of mussel shells from middens (Convey et al. 1989, Hanson et al. 1989, Neves and Odom 1989, Jokela and Mutikainen 1995, Tyrell and Hornbach 1998, Zahner-Meike and Hanson 2001). During the first phase of this project, surveys were conducted by Asmus (2004) to determine the amount of mussel predation by muskrats and to document the importance of mussels as a food source for muskrats on the Green River. During the second phase of this project, I continued to document midden locations to determine if muskrat population reductions were correlated with increased mussel numbers.

Mussel surveys were conducted in cooperation with the Tennessee Cooperative Fisheries Research Unit (TCFRU) from summer 2002 through summer 2008. The TCFRU surveys consisted of annual mussel counts and identification by 30–40 quadrat samples in 0.25-m^2 plots at up to 9 sites in the Green River. Within each quadrant a subsample was taken by excavating the bottom substrate to approximately 10 cm, bagging the material and sorting it streamside (Hardison and Layzer 2001). These surveys were used to determine species present within the study area and to monitor survival and reproduction. In addition to these surveys, muskrat midden locations were recorded and the associated shells were sent to the TCFRU for further examination.

Interaction Analysis

The goal of my interaction analysis was to gain insight on the spatial use of the landscape by these 2 aquatic mammals in a riverine setting. In that context, spatial interaction that takes place when 2 species share similar habitat and have to interact on some level. There are 3 possible levels of spatial interaction: a negative interaction (i.e., avoidance), a positive interaction (i.e., attraction), or neutrality between the species.

In recent years, techniques have been developed to estimate the probability of site occupancy by organisms (Dorazio and Royle 2005, MacKenzie and Royle 2005). Past research techniques could not account for imperfect detection probabilities typical of wildlife surveys which can lead to incorrect presence statistics (Anderson 2003, Dunham and Rieman 1999, MacKenzie et al. 2006). Occupancy modeling accounts for this imperfect detection by estimating the probability of false presences at sample sites based on repeated surveys. Assumptions of occupancy modeling are that the system is demographically closed, species are not falsely detected, and detection at a site is independent of detection at other sites (MacKenzie

et al. 2002, MacKenzie et al. 2004). These techniques are useful to evaluate the effects of model covariates (e.g., habitat variables) on species presence. Furthermore, the effect of potential competitors can be modeled as a covariate. In doing so, a test can be performed to determine whether occupancy by one species affects occupancy by another and the strength of that interaction (MacKenzie et al. 2004). To perform the interaction analysis, I first developed single-species models for river otters and muskrats using a number of detection and occupancy covariates. I then used the 2 best individual models in a 2-species interaction occupancy analysis to determine if presence of one species was a significant predictor of presence of the other (Donovan and Hines 2007).

Sign surveys have been found to be efficient and accurate for assessing river otter presence (Gallant et al. 2008). Although the original study area for the project was the Green River within Mammoth Cave National Park, that area was too small to provide enough variation in muskrat and otter abundances and the number of bridge crossings was too small for valid inferences. Therefore, I sampled watersheds within a larger region centered on MCNP to ensure sufficient sample sizes and incorporate more landscape variation. I conducted 94 surveys at randomly selected bridges throughout Kentucky during summer 2008. At each site, 4 transect surveys, 2 upstream and 2 downstream, were conducted. Within each 0.54-km transect survey I recorded the presence or absence of muskrat and river otter field sign (e.g., tracks, scats). Low detection probabilities and high levels of variation among sites or surveys can potentially bias occupancy estimates (Royle and Nichols 2003). Therefore, I estimated the optimal transect length and number for analysis by conducting a pilot study using methods described by MacKenzie and Royle (2005).

Covariate information can be incorporated to account for heterogeneity among sites (e.g., habitat variables). I selected covariates based on a priori knowledge and existing literature of the species (Table 1). I used 2 types of covariates: survey covariates may affect the detection probability of a species at a particular site, whereas site covariates may affect the probability of occupancy within a given survey (Tyre et al. 2003).

I first evaluated covariates that may be related to the detection probabilities of both muskrats and river otters. Time since last rain was evaluated as a detection covariate (National Oceanic and Atmospheric Administration 2008). My hypothesis was that recent rain events would reduce the ability to detect sign for both river otters and muskrats. I also used stream regulation as a detection covariate because the release of water from dams may reduce the detectability of sign. I determined which streams were regulated based on 1:24,000 topographic maps. I hypothesized that the presence of an island or tributary would increase the detectability of otter sign because these areas are favored for communal marking and latrine sites (Mowbay et al. 1976, Swimley et al. 1989, Newman 1990). For muskrats, I hypothesized that the presence of partially submerged woody debris would increase detection probabilities because muskrats prefer such structure for latrine sites and feeding platforms (Svihla and Svihla 1931, Smith 1938). Therefore, presence/absence of partially submerged woody debris was recorded for each site. I used percent vegetation coverage on river banks as a covariate because detection of sign likely is greater in areas with less vegetation. Similarly, substrate also affects the ability to observe tracks. I ranked the substrate of each transect on a scale of 1–5. High detection substrates were composed of sand and mud and low detection substrates were composed of large boulders and bedrock. Water substrate of each transect was ranked on a scale of 1–5. Water level was evaluated as a

Table 1. List of variables collected at each bridge survey site that could influence occupancy and detection probabilities of river otter and muskrats. Data collected throughout Kentucky during summer 2007. Abbreviations listed after variable name refer to their use in Program PRESENCE.

River otter	Muskrat
1. Crawfish (O)[a]	Aquatic vegetation (aq. veg.) (O)
2. Islands and tributaries (islands) (D)[b]	Mussels (O)
3. Beavers (O)	Partially submerged woody debris (SWD) (D)
4. Estimated depth (depth) (O)	Estimated depth (depth) (O)
5. Estimated width (width) (O)	Estimated width (width) (O)
6. Bank development (bank) (O)	Bank development (O)
7. Proportion of bank vegetated (pro) (D)	Proportion of bank vegetated (pro) (D)
8. Stream regulation (D)	Stream regulation (D)
9. Time since last rain (time) (D)	Time since last rain (time) (D)
10. Substrate (D)	Substrate (O)
11. Water level (level)(D)	Water level (level) (D)
12. Observer I or II (D)	Observer I or II (D)
13. Euclidean distance to release point (straight) (O)	
14. Actual river distance to release point (actual) (O)	

[a] (O) indicates variable was analyzed as an occupancy covariate
[b] (D) indicates variable was analyzed as an detection covariate

covariate because high water may wash away animal sign, thereby lowering detection. Finally, surveys were conducted a research technician and I, who likely had different experience identifying otter or muskrat sign, so I used observer as a survey covariate.

Covariates related to occupancy were also incorporated into the models. The shortest distance from the original KDFWR reintroduction sites was considered to impact occupancy at a given site so those distances were estimated for each bridge crossing, both via water and the over-land Euclidean distance. The distance via water was calculated using the cost distance function in ArcGIS®. The Euclidean distance was measured in ArcGIS® using the ruler function. I also included the presence or absence of crayfish and beavers for otter site occupancy. I hypothesized that occupancy of otters would be higher in areas that had a food source (crayfish) and abandoned beaver dens for refuge (Grenfall 1974, Towelli and Tabor 1982, Debuc et al. 1990, Newman 1990). Because river otters need adequate water for swimming, I estimated water depth and width. I hypothesized that otters avoid areas of high human disturbance and areas where cattle are present so I recorded an index of bank development. That index was scaled from 1 (wooded areas with no humans or cattle) to 5 (areas with presence of human activities and cattle).

To model the occupancy probability of muskrats, I used the same survey variables that I used for river otters. I also recorded the presence or absence of aquatic vegetation and the presence or absence of mussels which may affect occupancy by muskrats (Asmus 2004, Dozier 1953, O'Neil 1949). In addition, substrate type was recorded due to its potential affect on the ability of muskrats to select or create den sites.

Presence-absence data were analyzed using the computer software Program PRESENCE 2.0 (Hines 2006). This program uses a series of 0s and 1s to establish occupancy and detection

probabilities for each survey. The occupancy probability of a particular site is defined as ψ and the probability of detecting a species in the i^{th} survey is p[i]. I individually evaluated each covariate to assess performance, and then evaluated biologically logical combinations of covariates based on Akaike's Information Criterion (Burnham and Anderson 2002). Final model selection was based on the most parsimonious model incorporating detection and occupancy covariates. The data were bootstrapped 1000 times to assess goodness of fit of the model with all covariates. If overdispersion was detected, ĉ-values were adjusted.

Once each single-species model was built and significant covariates identified, the best models were then incorporated into a 2-species interaction model. This model estimates odds ratios that incorporate the imperfect detection of both species and where detection of one species depends on whether one or both species are present at a site (MacKenzie et al. 2006). The model produces interaction coefficients and a species interaction factor (SIF[φ]). The SIF is the ratio of how much more or less likely the species are to co-occur at a site compared with what would be expected if they occurred independently (MacKenzie et al. 2004, MacKenzie et al. 2006). If SIF < 1, this would suggest that avoidance is occurring, whereas SIF > 1 would indicate attraction and SIF = 1 suggests that the species occur independently of each other.

RESULTS

River Otter Trapping and Handling

I captured 27 river otters from February 2007 to August 2007 (Table 2, Fig. 4). Of those, 4 animals (2M; 2F) were captured within the boundary of MCNP (Fig. 5), 3 of which were anesthetized and equipped with radio-telemetry transmitters and released at the capture site. The other animal died of unknown causes during transportation to the veterinarian's office. Of the remaining 23 animals captured outside my MCNP study area, 14 (7M; 6F; 1 pup of unknown sex) were relocated to the study area. Nine animals were juveniles and, thus, not relocated. However, 1 juvenile of unknown sex was captured with its mother and was relocated with her into the study area. In total, I released 16 river otters within the national park from February 2007 to August 2007.

River Otter Movements and Survival

I collected 113 radio locations on the 16 released river otters ($\bar{x}$ = 7 locations per animal; Fig. 6). Locations were mostly collected during the day (1200–1700; 53%), with remaining locations in the morning (0600–1200; 30%) and at night (1700–0600; 17%). River otters were located in dens (47%), hiding or resting in riparian vegetation (10%), moving (25%), or inactive (18%). Nine otters (70%) left the study area and were not found during 2008. There were 3 known deaths shortly after release of animals into the study area. Of the animals that remained on the study area, annual survival was 0.333 (SE = 0.272). I observed 1 river otter pup and collected 3 scats of presumed juveniles within the park. Of the 4 remaining otters, only MT25, MR20, and MR41 established core home ranges within the national park and were found on

Table 2. River otter capture data from animals caught in or relocated to Mammoth Cave National Park, Kentucky, 2007.

River otter	Sex	Age	Capture date	County	Body mass (kg)
FT01	Female	n/a	2/24/07	Bath	8.5
FT03	Female	4	6/17/07	Harrison	7.6
MT5	Male	15	3/13/07	Rowan	10.1
MR20	Male	3	4/4/07	MCNP	8.6
MT23	Male	3	7/11/07	Harrison	8.8
MT25	Male	2	3/3/07	Rowan	7.6
FT27	Female	8	6/18/07	Harrison	7.9
FT29	Female	6	5/22/07	Grant	7.3
FR34*	Female	1	4/2/07	MCNP	7.8
MT34	Male	3	7/21/07	Grant	7.7
MT37*	Male	3	3/7/07	Rowan	7.7
MR41	Male	3	4/4/07	MCNP	7.9
MT44	Male	n/a	3/12/07	Rowan	9.0
FT49*	Female	3	5/21/07	Grant	7.3
MT55	Male	6	3/2/07	Rowan	8.4
FT57	Female	3	8/7/07	Harrison	7.4

* indicates known mortality during the study

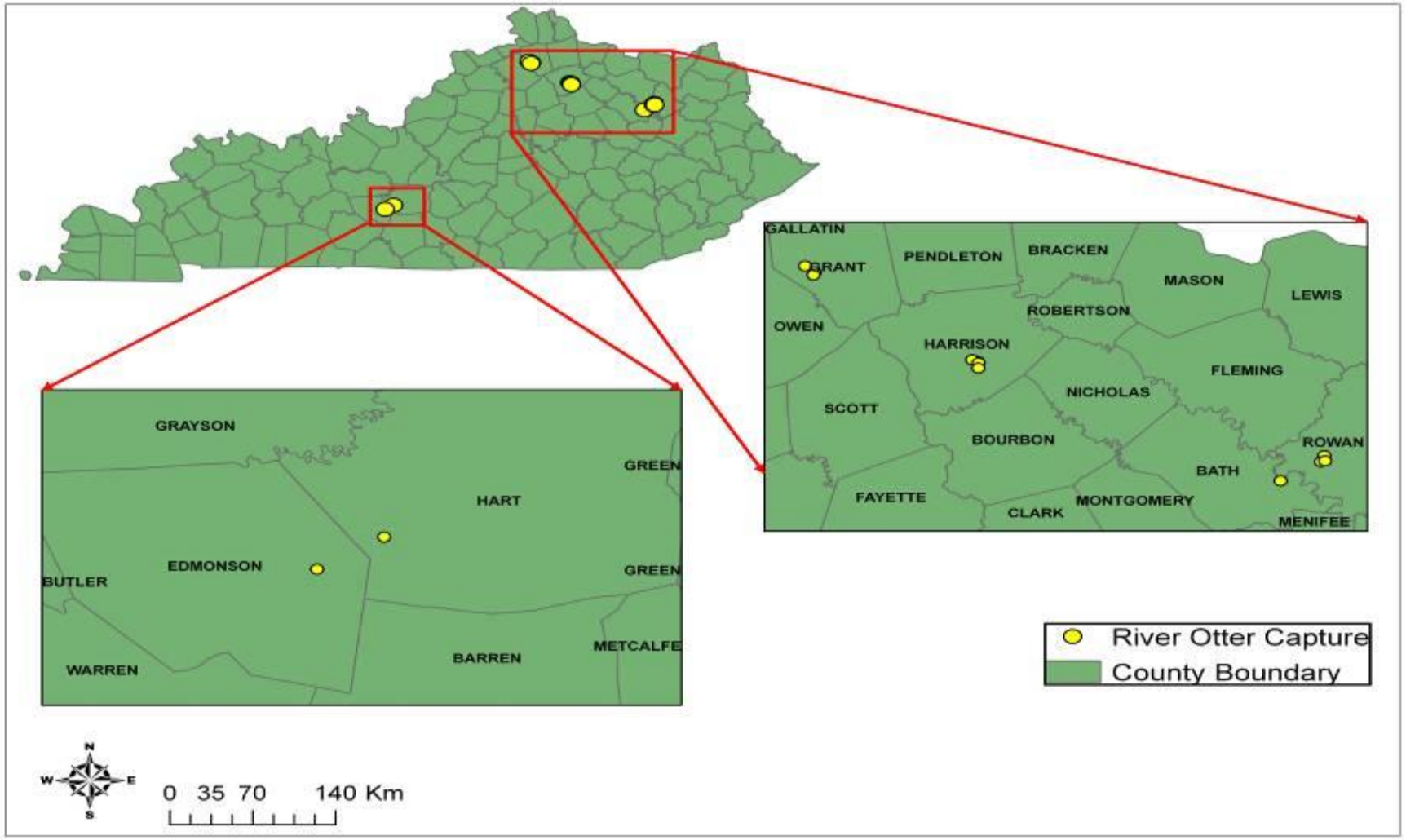


Fig. 4. Capture sites of river otters in Kentucky, spring and summer 2007.

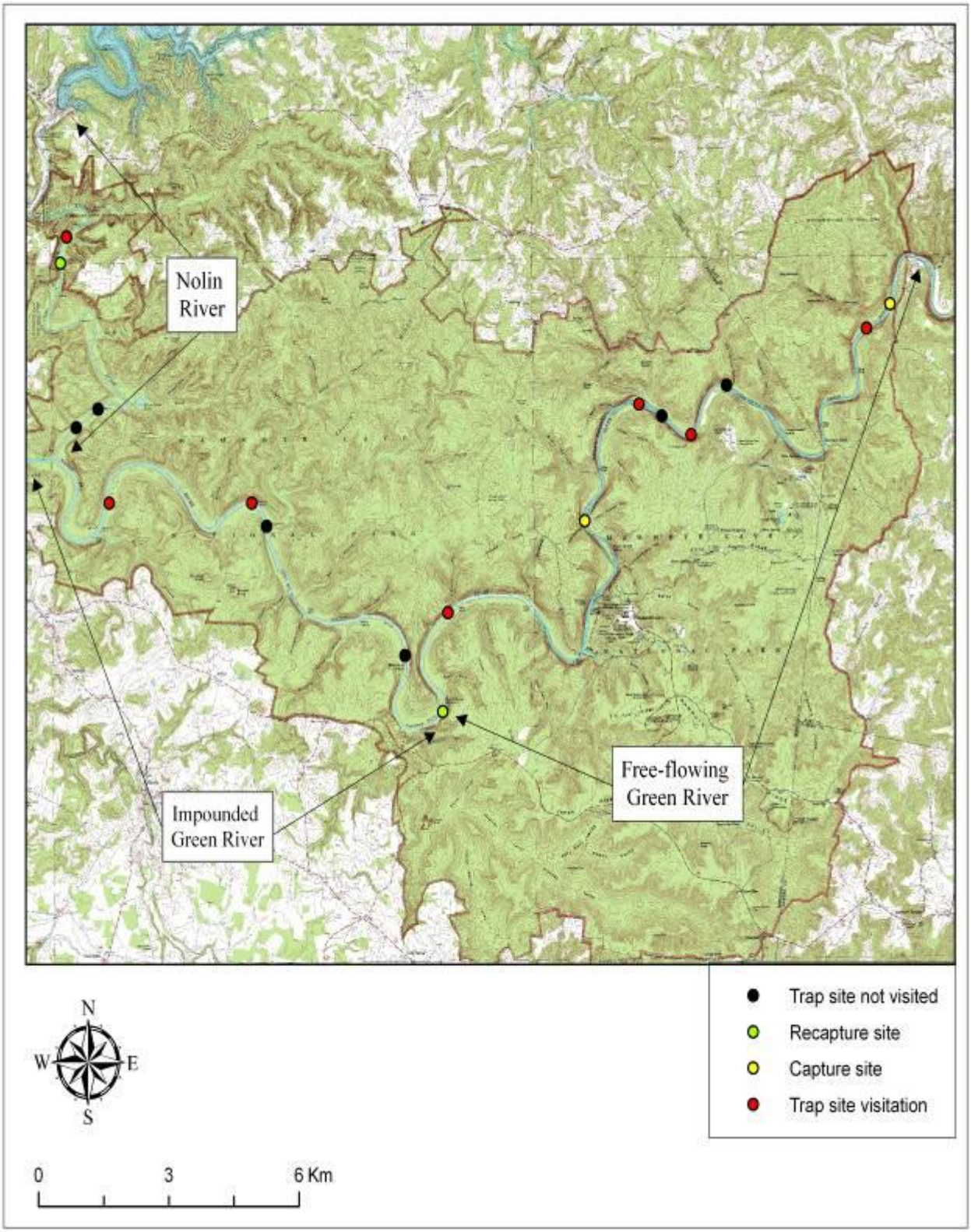


Fig. 5. Capture, recapture, trap sites visited, and unvisited by river otters on the Green and Nolin rivers, Mammoth Cave National Park, Kentucky, 2007.

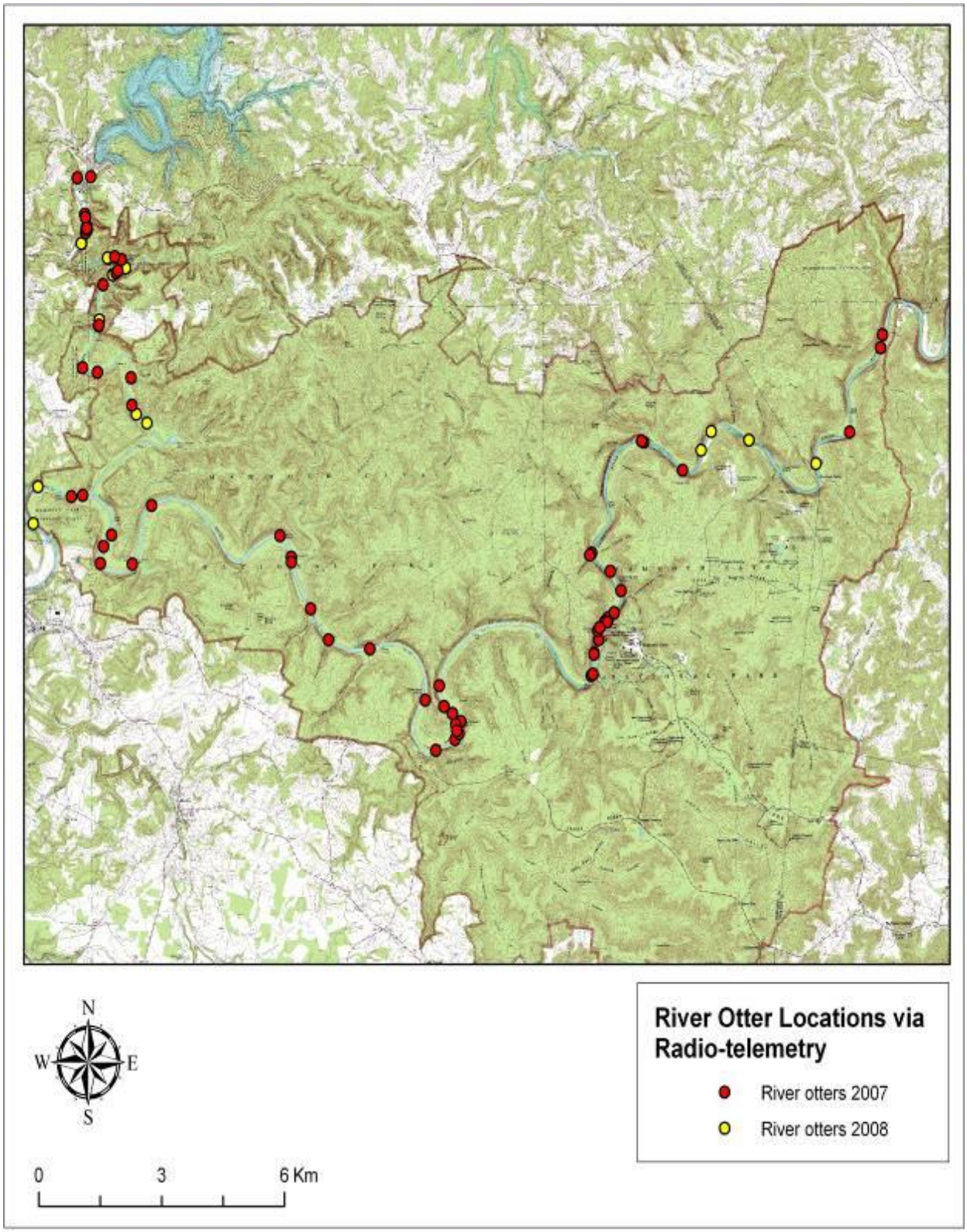


Fig. 6. Telemetry locations of river otters collected along the Green and Nolin rivers, Mammoth Cave National Park, 2007−2008.

a daily basis (Fig. 7, 8, 9). Otters MR20 and MR41 were captured within the park and often were found together. They were observed with 2 other otters on several occasions, possibly the remainder of the family unit. Based on several locations within the national park, river otter MT23 likely had a portion of its home range within MCNP.

Sample sizes were sufficient to determine home ranges for 3 otters (MT25, MR20, MR41; Table 3). The mean 50% and 95% linear home-range estimates were 6.8 (SE = 2.5) and 26.9 (SE = 4.4) km, respectively. Because the home ranges were projected linearly, the estimates were projected equally upstream and downstream in the case of branches or confluences. The fixed kernel estimates with least squares cost validation for the 50% core home averaged 8.1 (SE = 3.0) km^2 and the fixed kernel with ad hoc smoothing parameters for 95% home ranges averaged 55.8 (SE = 18.9) km^2. .

Scent-station Indices

Scent-station surveys were conducted on the Green and Nolin rivers in January 2007 and from May 2008 to August 2008. A total of 61 scent stations were established, with 28 being located along the free-flowing Green River, 18 along the impounded section of the Green River, and 15 along the Nolin River (Fig. 10). Overall, there were 274 station-nights producing 232 animal visits. Fifteen species were identified from tracks. Based on the scent stations, I documented the presence of otters on the free-flowing section of the Green River and the Nolin River, but no activity was recorded along the impounded section. However, visitation at trap sites indicated that otters were using all 3 sections of river within the study area.

Scent-station indices for river otters ranged from 0 to 8.3% with presence only being documented on the free-flowing portions of the Green River and the Nolin River sections (Table

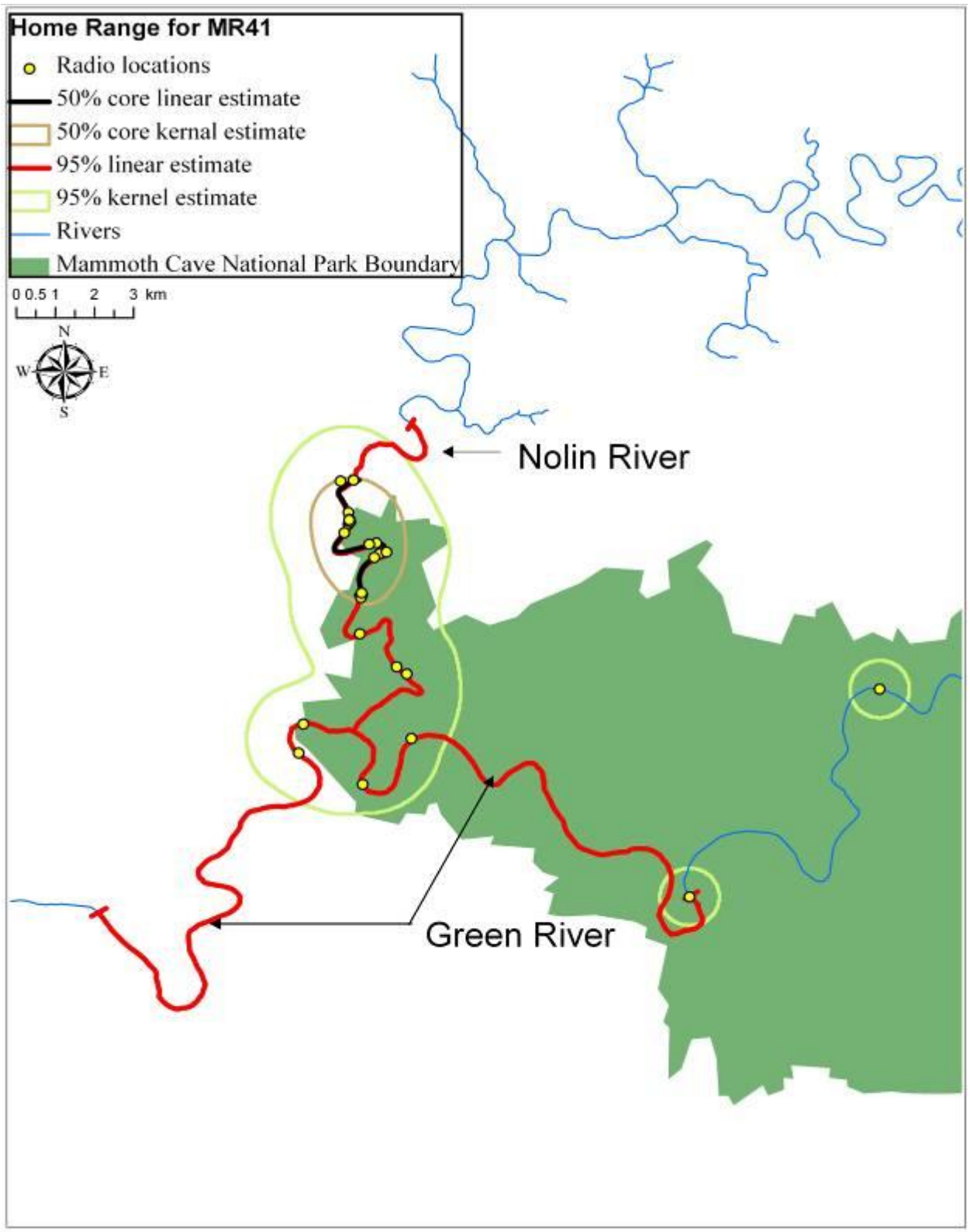


Fig. 7. Linear home ranges (95% and 50%) of river otter MR41 on the Green and Nolin rivers, Kentucky, 2007−2008.

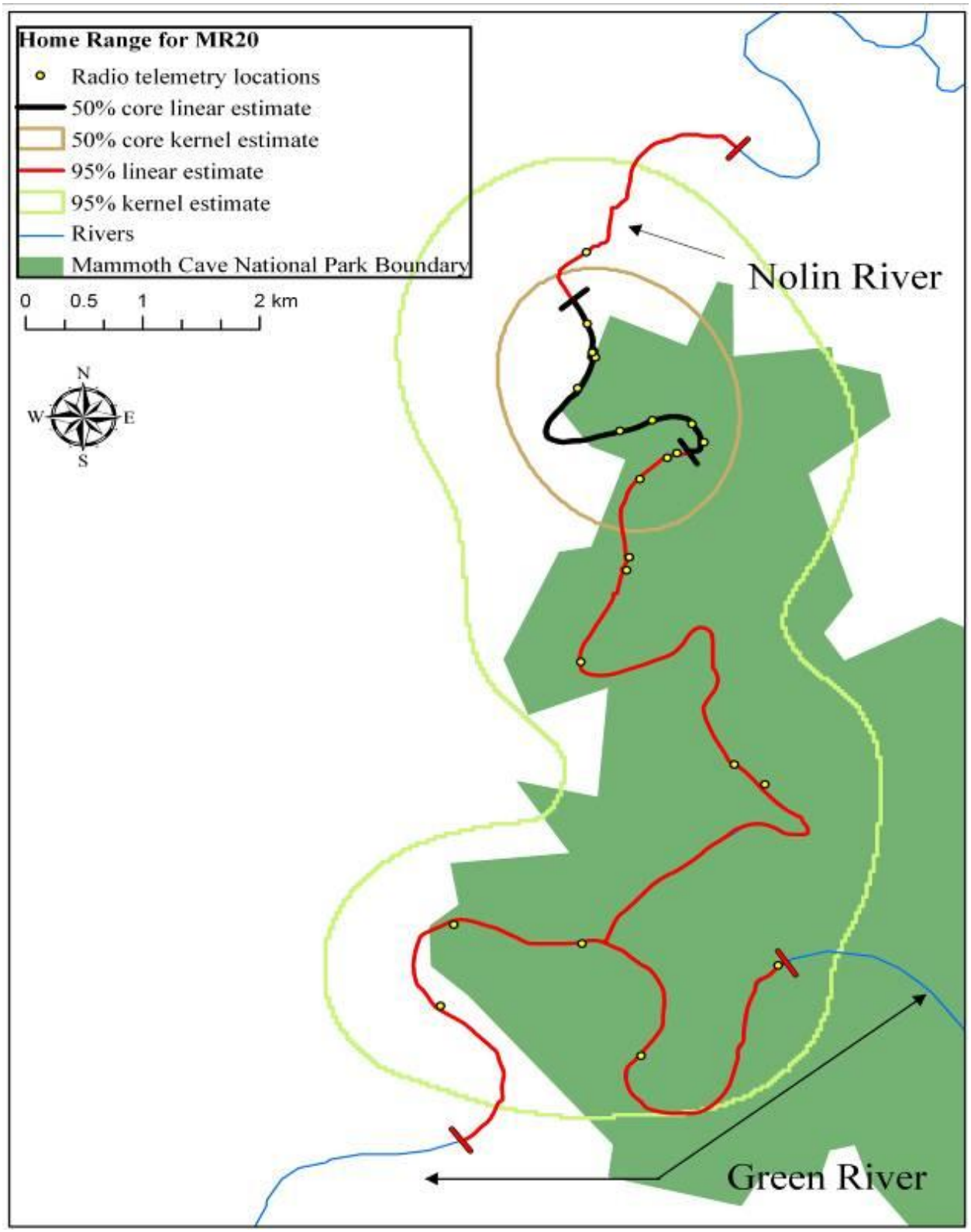


Fig. 8. Linear home ranges (95% and 50%) of river otter MR20 on the Green and Nolin rivers, Kentucky, 2007−2008.

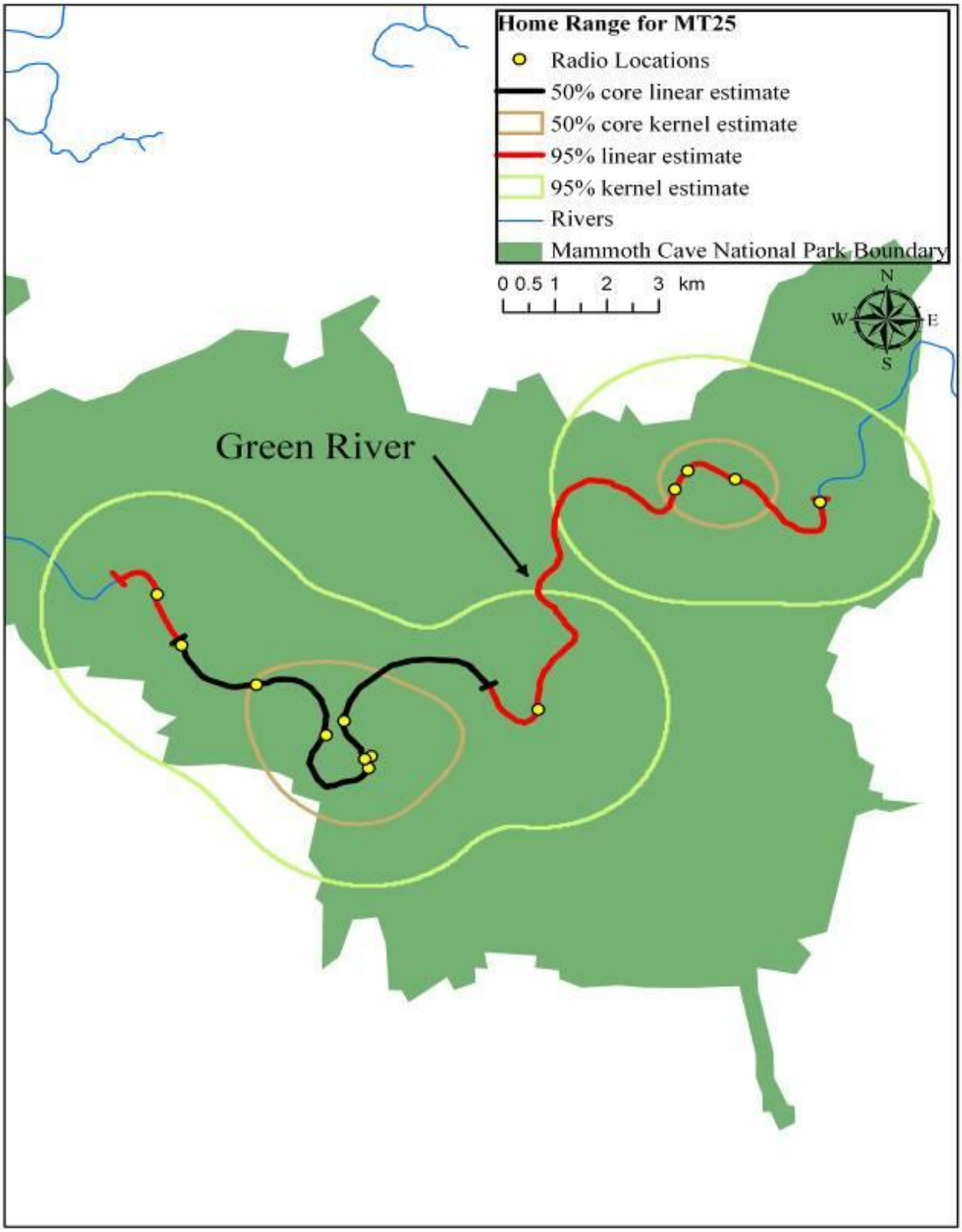


Fig. 9. Linear home ranges (95% and 50%) of river otter MT25 on the Green and Nolin rivers, Kentucky, 2007−2008.

Table 3. Home range estimates for river otters radio-tracked on the Green and Nolin rivers, Mammoth Cave National Park, Kentucky, summer 2007–summer 2008. Linear home range is the distance between the most upstream and downstream relocations. Univariate linear kernel estimates of 95 and 50% delineated the percentage of time the otter was estimated to have been within this range. Fixed kernel home ranges were estimated using least squares cost validation for 50% core home ranges and ad hoc smoothing parameters for 95% home ranges.

				Home Range			
River Otter ID	Number of relocations	Maximum dispersal distance from release site	Linear (km)	95% linear kernel (km)	95% fixed kernel (km^2)	50% linear kernel (km)	50% fixed kernel (km^2)
MT25	14.0	39.0	27.2	28.3	92.7	11.7	14.0
MR20	30.0	39.0	42.1	18.7	30.2	3.3	4.0
MR41	28.0	20.0	42.2	33.7	44.5	5.5	6.3
Mean	24.0	32.7	37.2	26.9	55.8	6.8	8.1
Std. Error	5.0	6.3	5.0	4.4	18.9	2.5	3.0

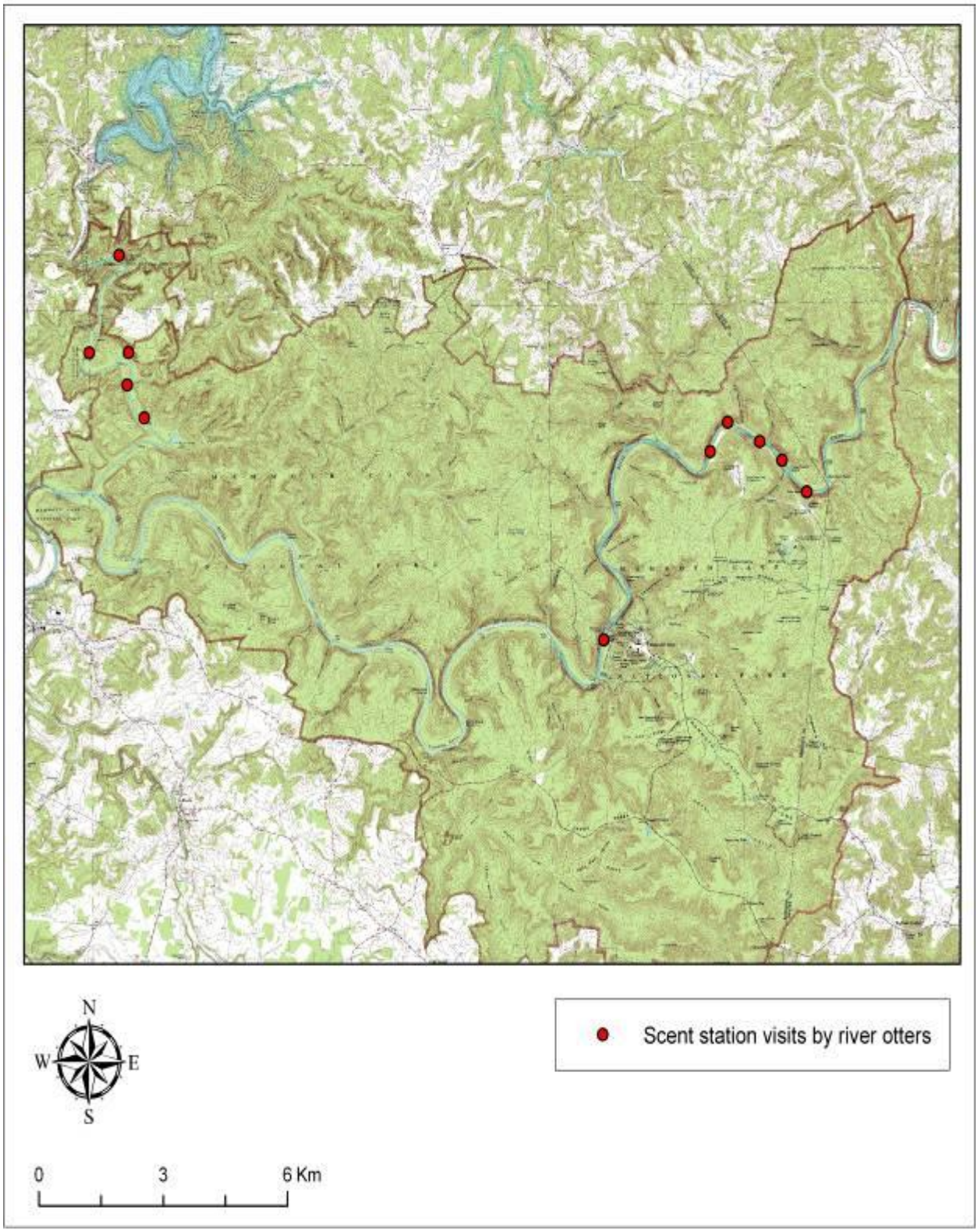


Fig. 10. Locations of scent-station visits by river otters on the Green and Nolin rivers, Mammoth Cave National Park, Kentucky 2007−2008.

4). Visitation indices were greater on the free-flowing Green River compared with the impounded portion ($F_{1, 44} = 4.70$, $P = 0.036$), and were greater on the Nolin river than the impounded portion of the Green River ($F_{1, 31} = 8.45$, $P = 0.007$). However, visitation rates between the free-flowing sections of the Green and Nolin rivers did not differ ($F_{1, 41} = 1.81$, $P = 0.185$) during 2007–2008.

River otter visitation rates on the free-flowing Green River were greater ($F_{1, 54} = 7.36$, $P = 0.008$) than those reported by Asmus (2004), but lower on the impounded Green River ($F_{1, 34} = 10.74$, $P = 0.002$). There was no difference in the otter visitation rate on the Nolin River ($F_{1, 29} < 0.001$, $P = 1.000$) from pre- to post-otter augmentation (Table 5), nor when I pooled otter visitation rates across the study area ($F_{1, 120} = 0.11$, $P = 0.743$). From pre- to post-augmentation, trap-site visitation rates were 4.9% $\pm$ 0.5% ($\bar{x} \pm$ SE*; n* = 570) for the total study area, 5.0% $\pm$ 0.3% (*n* = 399) for the free-flowing Green River, 8.3% $\pm$ 3.4% (*n* = 48) for the impounded Green River, and 2.4% $\pm$ 0.6% (*n* = 123) for the Nolin River. In contrast to the scent-station data, otters were detected at all trap sites on the Green and Nolin rivers. The majority of trap site visitations by river otters occurred on the free-flowing section of the Green River, where trapping efforts were concentrated.

Spotlight Surveys

I observed 382 animals during 30 spotlight survey nights. The most commonly observed animals were muskrats, beaver, and raccoons. The population index ranged from 0.0 to 0.40 muskrats/km (Fig. 11). The average number of muskrats observed declined from January through February and then slightly increased from March until May, then declined slightly through the final survey in August on the Green River (Fig. 12). The average number of muskrats/km on the Nolin River was similar to that from the Green River for the same time

Table 4. Scent-station indices for the Green and Nolin rivers, Mammoth Cave National Park, Kentucky, 2007. Numbers represent mean ± standard error.

Species	Total study area (n = 274)	Free-flowing Green River (n = 145)	Impounded Green River (n = 69)	Nolin River (n = 60)
All animals	83.9 % ± 2.1 %	69.6 % ± 3.2 %	108.6 % ± 2.8 %	90.0 % ± 3.8 %
River otter	4.0 % ± 0.4 %	4.1 % ± 0.5 %	0 % ± 0 %	8.3 % ± 1.5 %

Table 5. Scent-station indices for river otters on the Green and Nolin rivers before and after river otter augmentation. Mammoth Cave National Park, 2002−2007. Numbers represent mean ± standard error. The number of visits indicated by *n.*

River section	Pre-augmentation	Post-augmentation
Free flowing Green River	0 % ± 0 % (n = 346)	4.1 % ± 0.5 % (n =145)
Impounded Green River	3.0 % ± 0.2 % (n = 231)	0 % ± 0 % (n = 69)
Nolin River	5.6 % ± 0.4 % (n = 160)	8.3 % ± 1.5 % (n = 60)
Total study area	2.1 % + 0.1 % (n = 737)	4.0 % ± 0.4 % (n = 274)

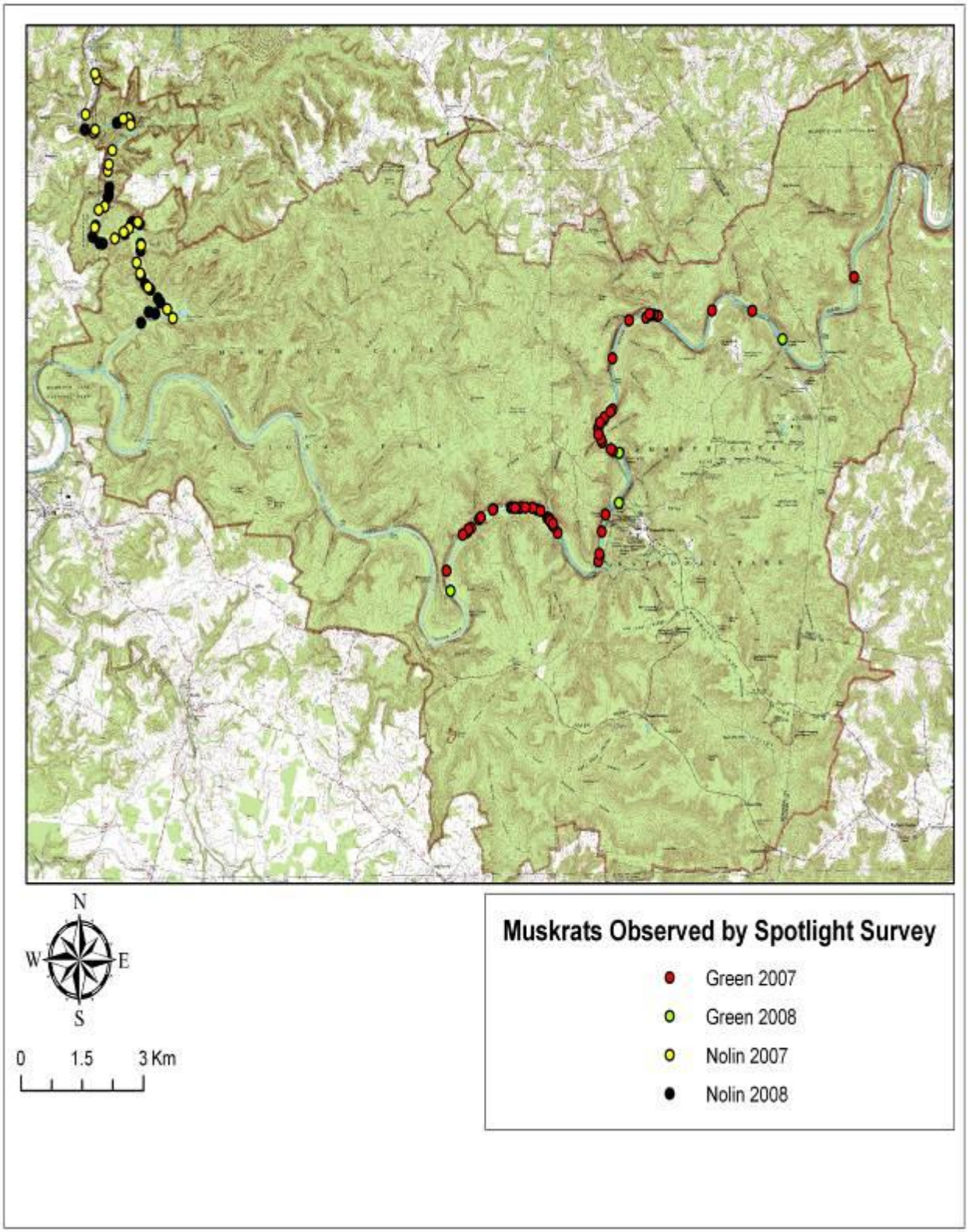


Fig. 11. Locations of muskrats observed using spotlight surveys on the Green and Nolin rivers, Mammoth Cave National Park, Kentucky, 2007−2008.

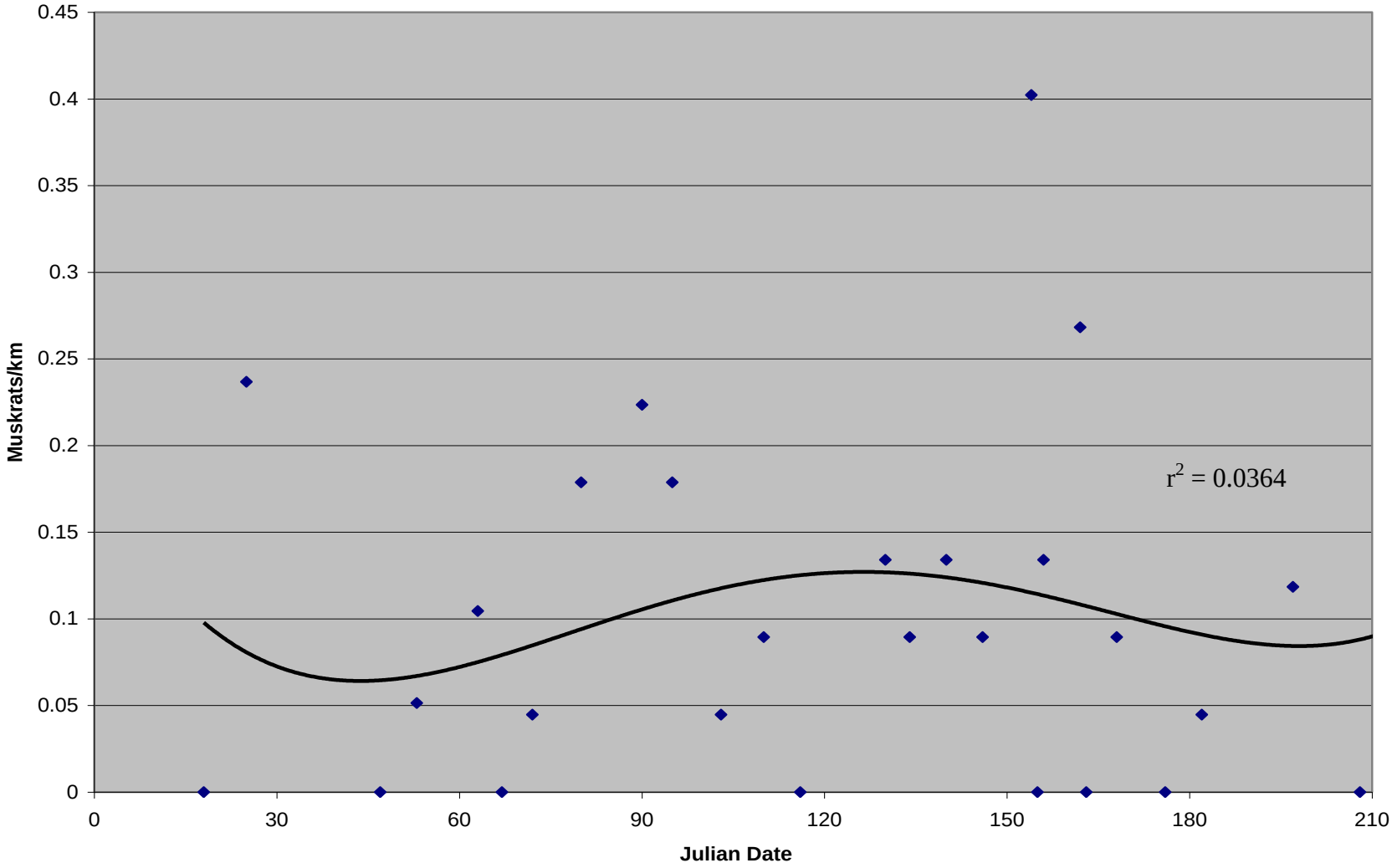


Fig. 12. Average number of muskrats/km observed using spotlight surveys on the Green River, Mammoth Cave National Park, Kentucky, 2007−2008.

period (Fig. 13).

The ANCOVA indicated that muskrat numbers during my study (0.08 $\pm$ 0.05) were lower than those observed by Asmus (2004) on the free-flowing Green River (2004; 0.49 $\pm$ 0.04; $F_{1, 73}$ = 36.56, $P < 0.001$). The number of muskrats detected on the Nolin River did not differ from 2007 to 2008 ($F_{1, 5}$ = 0.17, P = 0.698).

Scat Analysis

I collected 48 river otter scats: 30 on the free-flowing Green River, 5 on the impounded Green River, and 13 on the Nolin River (Fig. 14). Only 1 scat provided evidence of muskrat predation, yielding a predation frequency of 2.1%. That scat was collected on the Nolin River during July when preferred fish and crawfish are abundant. Wood duck remains were found in 2 (4%) of the collected scats. Forty-five (93.8%) scats contained crawfish and fish remains and 15 (31.2%) contained otter hair, likely from grooming.

Midden Surveys

Asmus (2004) found 47 muskrat middens during her May 2002 surveys. TCFRU personnel found 36 midden locations from February to August of 2002 and collected 388 specimens of 18 species (Table 6). In contrast, I was unable to locate any middens during summer 2007 and 2008. TCFRU personnel found only 10 middens during June 2007 and 1 midden during August 2008; they collected 64 specimens of 9 species and 24 specimens of 6 species, respectively. Because sampling months were not consistent, I did not make statistical comparisons. However, based on the August sampling periods, 17 middens were found in 2002 in contrast to only 1 located during 2006 and 1 during 2008.

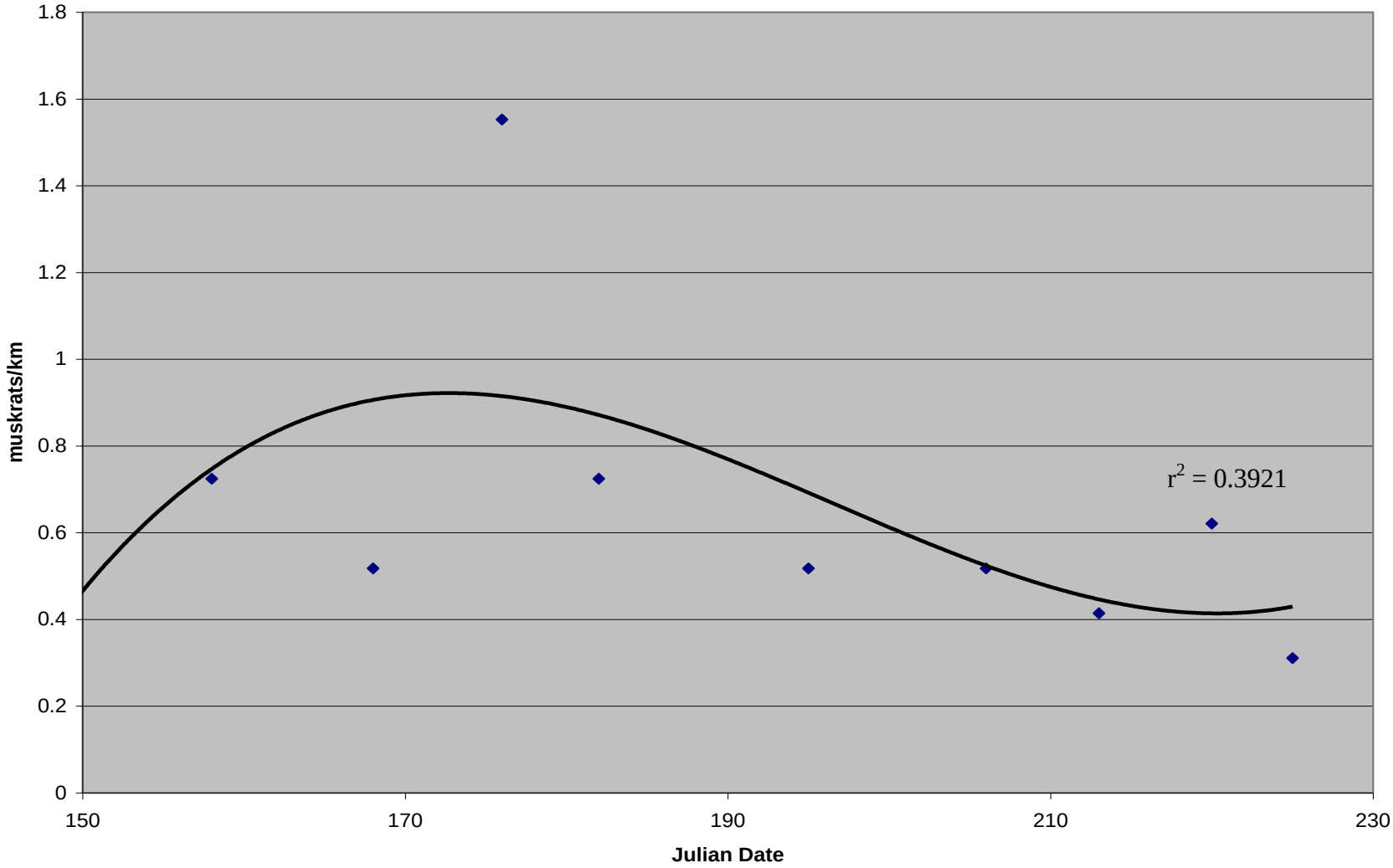


Fig. 13. Average number of muskrats/km observed using spotlight surveys on the Nolin River, Mammoth Cave National Park, Kentucky, 2007–2008.



Fig. 14. Locations of river otter scat collection sites on the Green and Nolin rivers, Mammoth Cave National Park, Kentucky, 2007−2008.

Table. 6. Tennessee Cooperative Fisheries Research Unit midden survey results for the Green River between Sand Cave Island and the north-east national park boundary, Mammoth Cave National Park, Kentucky, 2002–2008.

	2002			2003			2004	2005	2006	2007	2008
Species	Feb	Jun	Aug	Jan	Apr	Jul	Sept	Mar	Aug	Jun	Aug
Actinonaias ligamentina	--	3	10	27	2	6	3	6	3	1	--
Amblema plicata	3	7	18	61	2	14	23	11	1	2	1
Cyprogenia stegaria[1]	1	--	1	9	1	2	2	1	2	--	--
Cyclonaias tuberculata	--	1	7	14	--	12	9	6	1	--	--
Elliptio dilatata	--	1	11	41	--	17	8	8	2	--	--
Ellipsaria lineolata	--	--	3	3	--	1	2	1	6	--	--
Fusconaia subrotunda	--	--	4	17	1	5	2	2	11	2	--
Lasmigona costata	--	--	--	1	--	--	--	--	--	--	--
Lampsilis cardium	--	--	--	2	--	--	--	--	--	--	--
Leptodea fragilis	2	54	31	20	--	6	--	21	--	6	--
Obliquaria reflexa	1	8	36	30	3	6	15	2	7	10	4
Pleurobema cordatum	--	--	4	6	--	2	3	2	15	--	--
Pleurobema sintoxia	1	--	3	20	--	7	5	5	4	--	--
Plethobasus cyphyus	--	--	--	1	--	1	--	--	1	--	--
Potamilus alatus	--	5	10	2	--	1	1	1	--	5	--
Ptychobranchus fasciolaris	--	1	2	1	--	--	1	--	2	--	--
Quadrula metanevera	--	--	9	6	1	7	1	1	--	--	--
Quadrula pustulosa	6	7	36	47	5	31	11	9	16	4	3
Quadrula quadrula	4	10	35	24	2	6	19	4	--	28	12
Quadrula verrucosa	2	4	23	11	--	3	11	9	3	6	3
Strophitus undulatus	1	5	18	28	1	13	--	1	--	--	1
Truncilla truncata	--	--	--	--	--	--	4	2	--	--	--
Total number of shells	23	106	261	369	18	140	120	101	74	64	24
Number of middens	6	13	17	13	2	4	7	6	1	10	1

[1] Federally listed as endangered

Bridge Surveys

I conducted 376 transect surveys at 94 bridge crossings (Fig. 15). The global model for muskrat showed a lack of fit (Model 18, Table 7; $\chi^2 = 2.14$, $P = 0.012$; $\hat{c} = 2.086$). After adjusting $\hat{c}$, the null model with no covariates was the most parsimonious model (Model 1, Table 7; McCullagh and Nelder 1989, Burnham and Anderson 2002). In contrast, the global model for river otters fit the data well (Model 8, Table 8; $\chi^2 = 0.97$, $P = 0.48$, $\hat{c} = 0.96$); the best-fitting model contained the detection covariates for observer, water level, and substrate, whereas Euclidean distance to release sites was an important covariate for occupancy (Model 1, Table 8). The interaction model indicated that the occupancy of muskrats was independent from the occupancy of river otters (Table 9, $\varphi = 1.02$).

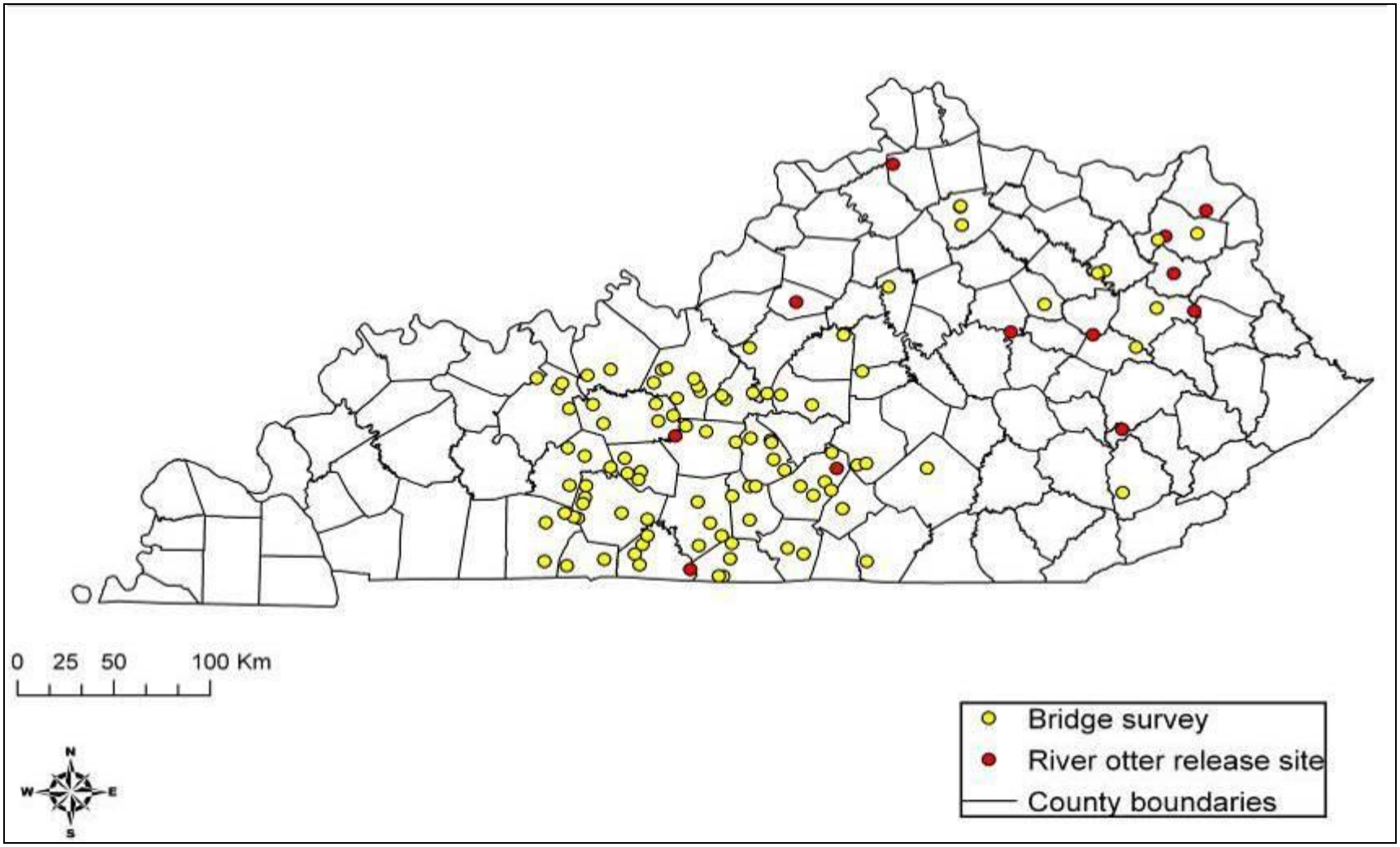


Fig. 15. Locations of bridge surveys (2008) and release sites of river otters (1991–1994), Kentucky.

Table 7. Models used to estimate muskrat occupancy (ψ) and probability of detection (p) in Kentucky, summer 2008, having being adjusted for lack of fit. Covariates are listed in parenthesis following psi and p.

Model	AIC	delta AIC	AIC weight	Model Likelihood	No. Par.	-2*Log Likehood
1. psi(.), p(.) (no covariates) [1]	213.72	0.00	0.13	1.00	2	439.99
2. psi(depth), p(.)	213.88	0.16	0.12	0.92	3	436.14
3. psi(mussels), p(.)	214.34	0.62	0.09	0.73	3	437.10
4. psi(aq. veg), p(.)	214.39	0.67	0.09	0.72	3	437.20
5. psi(.), p(level)	214.67	0.95	0.08	0.62	3	437.79
6. psi(substrate), p(.)	215.35	1.63	0.06	0.44	3	439.22
7. psi(width), p(.)	215.35	1.63	0.06	0.44	3	439.21
8. psi(.), p(time)	215.43	1.71	0.05	0.43	3	439.38
9. psi(depth, mussels, aq. veg), p(.)	215.45	1.73	0.05	0.42	5	431.03
10. psi(.), p(SWD)	215.59	1.87	0.05	0.39	3	439.71
11. psi(bank), p(.)	215.60	1.88	0.05	0.39	3	439.73
12. psi(pro), p(.)	215.66	1.94	0.05	0.38	3	439.87
13. psi(depth, mussels, aq, veg), p(level)	216.43	2.71	0.03	0.26	6	428.89
14. psi(.), p(observer)	217.52	3.80	0.02	0.15	4	439.57
15. psi(depth, mussels), p(level, SWD)	217.81	4.09	0.02	0.13	6	431.78
16. psi(aq. veg, mussels, depth), p(level, SWD)	219.22	5.50	0.01	0.06	7	430.55
17. psi(depth, pro, mussels), p(level, SWD)	219.58	5.86	0.01	0.05	7	431.31
18. psi(depth, width, pro, bank, substrate, aq. veg, mussels), p(observer, level, SWD, time)	230.43	16.71	0.00	0.00	14	424.70

[1]psi: probability that the area is occupied by muskrats; p: probability of detecting muskrats.

Table 8. Models used to estimate river otter occupancy (ψ) and probability of detection (p) in Program PRESENCE in Kentucky, summer 2008. Covariates are listed in parenthesis following psi and p.

Model	AIC	delta AIC	AIC weight	Model Likelihood	No. Par.	-2*Log Likelihood
1. psi(straight), p(observer, level, substrate) [1]	377.13	0.00	0.44	1.00	7	363.13
2.psi(straight, bank), p(observer, level, substrate)	378.8	1.67	0.19	0.43	8	362.80
3. psi(straight), p(observer, substrate)	378.95	1.82	0.18	0.40	6	366.95
4. psi(straight line, crawfish), p(observer, substrate)	380.55	3.42	0.08	0.18	7	366.55
5. psi(straight), p(observer, islands, substrate)	380.59	3.46	0.08	0.18	7	366.59
6. psi(straight, bank, crawfish), p(observer, islands, substrate)	383.99	6.86	0.01	0.03	9	365.99
7. psi(straight), p(observer)	385.32	8.19	0.01	0.02	5	375.32
8. psi(.), p(.)all covariates	388.21	11.08	0.00	0.00	17	354.21
9. psi(straight, bank, crawfish), p(observer)	388.87	11.74	0.00	0.00	7	374.87
10. psi(actual), p(observer, water level, substrate)	399.42	22.29	0.00	0.00	6	387.42
11. psi(actual), p(observer)	400.09	22.96	0.00	0.00	5	390.09
12. psi(straight, crawfish , bank), p(observer, substrate)	400.81	23.68	0.00	0.00	8	384.81
13. psi(straight, crawfish), p(observer, level, substrate)	402.2	25.07	0.00	0.00	8	386.20
14. psi(straight), p(observer, level)	404.91	27.78	0.00	0.00	6	392.91
15. psi(.), p(.)no covariates (no covariates)	410.63	33.5	0.00	0.00	2	406.63

[1]psi: probability that the area is occupied by river otters; p: probability of detecting river otters.

Table 9. Models used to determine 2-species interaction in Program PRESENCE collected in Kentucky, summer 2008. Covariates are listed in parenthesis following psi and p.

Model	AIC	delta AIC	AIC weight	Model Likelihood	No. Par.	-2*Log Likelihood
1. psiA(straight), psiB, phi(0), pA(observer ,level, substrate), pB, pA'(observer, level, substrate), pB', pAB	825.23	0.00	0.98	1.00	13	799.23
2. psiA(straight), psiB, phi(0), pA(observer), pB, pA'(observer), pB', pAB	833.62	8.39	0.01	0.02	11	811.62
3. psiA(straight), psiB, phi(0), pA(observer, level), pB, pA'(observer, level), pB', pAB	835.62	10.39	0.00	0.01	12	811.62
4. psiA(straight, time), psiB(time), phi(0), pA(observer, level, substrate), pB, pA' (observer, level, substrate), pB', pAB	838.18	12.95	0.00	0.00	14	810.18
5. psiA(straight), psiB, phi(0), pA(0), pB, pA'(0), pB', pAB	838.93	13.7	0.00	0.00	9	820.93
6. psiA, psiB, phi, pA, pB, pA', pB', pAB (no covariates)	858.85	33.62	0.00	0.00	8	842.85
7. psiA(0), psiB, phi(0), pA(observer, level, substrate), pB, pA'(observer, level, substrate), pB', pAB	859.53	34.3	0.00	0.00	13	833.53

[1]psi^A: probability that the site is occupied by river otters
psi^B: probability that the site is occupied by species muskrats
phi: probability that the site is occupies by both species
p^A: probability of detecting river otters, given muskrats are not present
p^B: probability of detecting muskrats, given river otters are not present
$p^{A'}$: probability of detecting river otters, given both are present
$p^{B'}$: probability of detecting muskrats, given both species are present
p^{AB}: probability of detecting both species, given both species are present

DISCUSSION

Three of 16 river otters died within a month of capture and release, although necropsies revealed no specific cause for these mortalities. Capture and surgery along with excessive movements while adapting to a new environment may have increased stress to these animals. High dispersal rates are common for river otters after translocations or reintroductions. In Missouri, an otter moved 320 km from its release site (Erickson et al. 1984), whereas a distance of 114 km was recorded in Illinois (Anderson and Woolf 1984) and a distance of 189 km in Tennessee (Miller 1992). Although these are maximum distances moved by individual animals, the mean distance that otters moved from release locations ranged was 25.4 $\pm$ 2.8 km (Griess 1987) in a riverine system to 2.7 $\pm$ 0.4 km (Johnson and Berkley 1999) in a palustrine wetland. Therefore, movements outside the national park boundary should not be viewed as uncommon.

The resident animals that I captured stayed within the general study area but were observed moving substantial distances (>32 km/night). Although river otters can travel great distances over land (Griess 1987), my study animals spent most of their time in or along river systems. Consequently, the fixed kernel home range likely overestimated the probability of use of land areas adjacent to the rivers. Linear home-range estimates for the 3 river otters within the national park (3–46 km) were similar to those reported by Melquist and Hornocker (1983; 8–78 km) in Idaho, Erickson et al. (1984; 11–78 km) in Missouri, and Woolington (1984; 1–23 km) in Alaska.

With only 1 translocated individual residing within the national park and another one nearby, abundance of river otters within the national park showed little benefit from augmentation efforts. It should be noted that MCNP has relatively few tributaries to the Green River as a result of underground water flow associated with the cave system (Fig. 2). This

relative scarcity of small tributaries in the park may reduce the carrying capacity of river otters compared with other similar habitats but with more typical above-ground water flows. Regardless, river otters were more abundant in the study area compared with Asmus's (2004) study, as evidenced by scent-station surveys, scat collections, and trap-site visitation data.

My scent-station results were similar to Clark's (1982) indices of 8.8 % $\pm$ 2.0 % and 6.0 % $\pm$ 0.9 % collected in Georgia during 1980-1981 and 1981-1982, respectively. Scent stations have been criticized as a method for determining population abundance because of seasonal variation in animal responses and habituation to scent (Robson and Humphrey 1985). Although scent stations were randomly placed in areas where known radio-marked animals reside, there was a lack of activity at scent stations within those areas. For example, 1 scent station was directly located across the river from a known den entrance of 2 study animals yet was never visited. By using a combination of techniques, however, I was able to identify the areas of otter use within the study area (Gallant et al 2007, Clark et al. 1987).

Muskrat abundance typically decreases in winter because accumulating mortality and a reduction in available food resources. Conversely, populations increase in spring when young of the year emerge from their dens (Errington 1941, Schacher and Pelton 1975, Perry 1982). After adjusting for these annual fluctuations, I detected a decline in the number of muskrats on the Green River after the river otter augmentation. However, I found relatively high numbers of muskrats on the Nolin River (0.59 muskrats/km compared with 0.49 muskrats/km reported by Asmus [2004] on the Green River prior to the river otter augmentation) where river otters also were present.

My scat analysis indicated a typical diet of riverine otters, with the most common food items being crayfish and fish. The scat analysis suggested that river otters only occasionally

consumed muskrats. The documented predation event occurred during July when muskrat kits leave the den (Schacher and Pelton 1975). There was no evidence of muskrat predation by river otters along the Green River, where the muskrat population declined. Mussels can be an important food source for river otters (Morejohn 1969) but I found no evidence of mussel predation by otters. However, Melquist (1981) suggested that only the mussels themselves may be consumed so shell fragments would rarely be observed in scat, possibly resulting in underestimation of mussel predation. Evidence of wood duck predation by river otters occurred during mid-March which coincides with brooding time for this species. Waterfowl is a common river otter food item (Lauhachinda 1978, Toweill 1974, Wilson 1954).

Asmus (2004) used stable isotope analysis and documented that muskrat predation on mussels is a general occurrence and that their presence may increase the carrying capacity of muskrats on the Green River. The results of the midden surveys suggest that the number of middens has substantially declined and are almost nonexistent, suggesting that the muskrat population has declined. This decline in muskrat numbers was substantiated by the results of the spotlight surveys.

The muskrat occupancy model exhibited a lack of fit suggestive of overdispersion. One explanation for lack of model fit is that the detection probabilities for the 4 transect surveys at each sample site were not independent. For example, if tracking conditions were good for 1 transect at a bridge crossing, conditions were likely good for the other 3 transects at that crossing. If another site was surveyed the following day after a flood event, tracking conditions would probably be poor at all 4 transects, resulting in overdispersion. This may be particularly evident for muskrat detection rates because only a small amount of rain could eliminate muskrat field sign. Most muskrat sign is found at or slightly above water level, whereas river otter sign is

generally found at greater distance from the water (e.g., a pull-out leading to a latrine site above the high water mark). Although I tried to account for high water levels with a water level covariate, previous high water events are difficult to determine because a watershed rain event could impact water far below the source. I speculate that this is the reason why the water level covariate was not an important covariate in the muskrat model.

Analysis of the otter data indicated that the best model was one in which detection probabilities were functions of the observer, water level, and substrate, whereas the probability of occupancy was a function of Euclidean distance to the nearest release site (Table 10). An inverse relationship existed between water level and detection probabilities, with higher water levels resulting in lower detection rates (parameter estimate = -0.537 $\pm$ 0.276). Likewise, finer substrates provided better opportunities to detect otter sign (parameter estimate = -0.451 $\pm$ 0.164). The third covariate affecting detection of otters was observer. Detection rates were higher for surveys conducted by me compared with the field technician (parameter estimates = 1.121 $\pm$ 3.843 and 0.192 $\pm$ 3.857, respectively). This finding likely reflects less experience by the technician to detect otter sign and stresses the importance of including survey covariates (Evans et al. 2009). Of all models that included occupancy covariates, the highest-ranked model was the Euclidean distance to river otter release sites. With increasing distance from an original release site, the probability of occupancy decreased (parameter estimate= -0.000059 $\pm$ 0.00001). This further suggests that the otter population in Kentucky is still expanding its range because sites far from the reintroduction sites had lower probabilities of occupancy. This would also support my contention that otters have recently expanded their range and increased their numbers in MCNP. Although my results support no spatial interaction, there could be temporal interactions (i.e., partitioning resource use by time of day or mutual avoidance within the home

range rather than exclusion from the entire home range) that would not be detected with my methods.

In summary, the relative density estimate of muskrats has declined on the free-flowing section of the Green River from pre- to post-river otter augmentation. However, both muskrats and river otters co-occurred at relatively high densities on the Nolin River. There were no data to suggest what the density of muskrats was on this section prior to river otter colonization, but the densities of muskrats on the Nolin, post-river otter augmentation, were higher than those of the Green River pre-augmentation. Although muskrat numbers declined on the Green River, their co-occurrence on the Nolin and the lack of any significant predation by otters does not suggest causality. Furthermore, the occupancy analysis suggested that river otters and muskrats occurred independently on a landscape scale. Therefore, I reject the hypothesis that the increase in the river otter population will cause in a decrease in muskrats and a decrease in muskrat predation on mussels in MCNP, and the hypothesis that occupancy at bridge crossings by river otters will be negatively related to occupancy by muskrats.

MANAGEMENT IMPLICATIONS

My study indicates that river otter reintroductions likely would not be an effective management tool to control muskrats and conserve mussels. Although muskrats consume mussels to sustain their populations on the Green River, their impact on the mussel community is probably overshadowed by the loss of habitat due to water impoundment (Asmus 2004). The impoundment of water is the result of a series of 6 locks and dams built and regulated by the Army Corp of Engineers (Crocker 1976). These dams impound sections of the river that once provided the shallow shoal habitat that mussels need for propagation and survival. If survival and reproduction of the freshwater mussels in the Green River drainage is of concern, localized trapping of muskrats may be effective but the most substantial benefit for mussels would be to increase available habitat areas by removing decommissioned dams.

Spotlight surveys are an effective means of monitoring riverine muskrat populations. Because muskrats are known to exhibit cyclical population trends within and between years, I recommend 2 surveys be conducted every season (i.e., 8/year; Errington 1951, 1954, 1963). To further increase the effectiveness of this technique I also recommend spotlight surveys be conducted later than 24:00 hrs, based on the increase in activity I observed after 20:00 hrs.

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