

SURVIVAL AND SPACE USE OF RIPARIAN MUSKRATS (*ONDATRA  
ZIBETHICUS*) WITHIN AN AGROECOSYSTEM

BY

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THESIS

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## ABSTRACT

Increased agricultural production within the Grand Prairie region U.S.A. has resulted in drainage of most natural wetlands within the landscape. Semi-aquatic species that are associated with these habitats have shifted much of their distribution to riparian habitats that have unstable flow regimes and inundation times that could be related to position within watersheds. Muskrats (*Ondatra zibethicus*) are an economically important furbearer species in this region and occur in small streams and agricultural ditches throughout the Midwest. However, information regarding space use and survival of muskrats in these highly altered habitats is lacking. I examined predation risk, survival, home ranges, and space use of muskrats within small streams and agricultural ditches in a human-dominated agricultural landscape in east-central Illinois from 2007-2009. To evaluate predation risk of riparian muskrats, I monitored displacement times of radiomarked individuals during flooding events in relation to landscape position. I used known-fate models and an information-theoretic approach to examine effects of age, season, hydrology, and riparian width on weekly survival rates. As expected, muskrats positioned farther from headwaters were displaced longer, and exposed to predation from terrestrial predators longer, than those positioned closer to headwaters during flooding events. Contrary to my prediction, increased exposure during floods did not translate into lower survival because most mortalities were due to mink (*Neovison vison*) predation along stream edges during non-flooding periods. Muskrat weekly survival was lower in winter (0.9377, SE = 0.1793) than in non-winter (0.9770, SE = 0.0116) and positively related to riparian width. Larger riparian buffers were associated with greater muskrat

survival in small streams and agricultural ditches within highly altered, human-dominated agroecosystems. To evaluate home ranges and space use of riparian muskrats, I monitored movements of radiomarked individuals occurring in small streams and agricultural ditches. I used an information-theoretic approach to determine the effects of age, hydrology, burrows, local vegetation and stream morphology on home-range size. Muskrat home ranges were highly linear and restricted to stream bank edges. Home-range size was influenced by age class and positively related to number of burrows used per individual. Adults had longer home ranges ( $\bar{x} = 804$  m, SE = 171) than did juveniles ( $\bar{x} = 529$  m, SE = 53), and home ranges of combined age classes averaged 582 m (SE = 56). Muskrats used an average of  $\sim 7$  bank burrows (range = 3 – 13). An analysis of space use confirmed my hypothesis that muskrats are multiple central-place foragers that used space non-randomly within their home range. My study provides a rare example of linking riparian buffers to fitness for a stream-associated organism while also providing insights on how muskrats use space within restricted linear habitats.

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## CHAPTER 1

# EFFECTS OF FLOODING AND RIPARIAN BUFFERS ON SURVIVAL OF MUSKRATS ACROSS A FLASHINESS GRADIENT

### 1.1 Introduction

Knowledge of survival rates for species is crucial for understanding habitat quality and for promoting effective conservation (Van Horne 1983; Todd and Rothermel 2006). However, survival can vary spatially and temporally (Korslund and Steen 2005; Stephens et al. 2005; Baker and Thompson 2007) and be affected by environmental factors at multiple scales (Labbe and Fausch 2000; Ruiz-Gutiérrez et al. 2008). Thus, it is important to investigate how local habitat gradients and landscape context impact survival rates of wildlife, especially species adjusting to human-dominated landscapes.

Conversion of land for agricultural production within the midwestern United States has resulted in the drainage of most wetlands in the region (Prince 1997). For instance, 90% of the historical wetlands in Illinois have been drained, resulting in an estimated loss of 3.1 million ha of wetland area (Suloway and Hubell 1994). Furthermore, 30% of the cropland (~4 million ha) in Illinois has been tile-drained to facilitate transport of excess water from fields into adjacent streams and agricultural ditches (Zucher and Brown 1998). These dramatic landscape alterations have affected the distribution of muskrats (*Ondatra zibethicus* L., 1766) and other wetland-associated species by limiting most of their suitable habitat to small streams and agricultural ditches. These stream habitats have unstable flow regimes (King et al. 2009). Hydrological variability can decrease

survival of muskrats in wetlands (Errington 1937; Bellrose and Low 1943; Kinler et al. 1990), but patterns for riparian habitat have not been evaluated.

Stream segments experience varying inundation times and flow magnitudes depending upon their positions within watersheds (Junk and Piedade 1997; Gergel et al. 2002). Stream segments located in larger drainage basins, or farther from headwaters, experience longer inundation times during flooding events than those located in smaller drainage basins or closer to headwaters. The direct effect of inundation times on plant and invertebrate species has been well documented (Meintjes 1996; Ballinger et al. 2007; Nakai and Kisanuki 2007; Stokes 2008). However, how duration of inundation affects mammals occurring in riparian areas, or how landscape context (e.g., terrestrial buffers) might ameliorate predation risk associated with being displaced during these stochastic events, has received minimal attention. Madsen and Shine (1999) determined that differences in inundation times across the Adelaide River floodplain indirectly affected growth rates, reproductive activity, and survival rates of dusky rats (*Rattus colletti*). Anderson et al. (2000) reported that small mammals unable to seek arboreal refuge during flooding events died, moved to higher elevations, or abandoned their original home ranges.

The riparian zone is an ecologically important interface between the stream edge and the human-dominated landscape (Naiman and Décamps 1997). A wider riparian zone can reduce the impacts of clearcutting on small mammal communities (Cockle and Richardson 2003), increase larval salamander abundance in areas that are timber harvested (Peterman and Semlitsch 2009), and provide breeding habitat for birds in agricultural landscapes (Peak and Thompson 2006). These examples demonstrate the

potential of riparian buffers to mitigate habitat loss for terrestrial animals. However, no studies have examined how riparian width affects predation risk and survival rates for semi-aquatic species displaced from stream habitat during flooding events.

In my study region, muskrats construct burrows within stream banks and must move to alternate upland habitat (i.e., riparian buffers or agricultural fields) when forced from their burrows during flooding events, leaving them more exposed to terrestrial predators. I predicted that muskrats positioned farther from headwaters (in larger drainage areas) would be displaced longer during flooding events and thus have a greater risk of predation and lower survival rates compared to muskrats positioned closer to headwaters (in smaller drainage areas). I also tested the hypothesis that muskrats occurring in stream segments with wider riparian buffers should have temporary refugia from predators during displacement periods and thus lower risk and increased survival. I addressed these questions by monitoring radio-marked muskrats across a hydrological gradient with variable riparian buffers in a highly altered agroecosystem.

## **1.2 Materials and methods**

### *Study area*

My study area (~71 715 ha) was focused in Champaign County, which is located in the Grand Prairie region of east-central Illinois, USA (40°12'N, 88°26'W). Average temperatures range from 30° C in summer to -8.5°C in winter, with an average annual rainfall of 104 cm and snowfall of 67 cm. This region is flat (total elevation relief ~70 m) and characterized by row-crop agriculture, with most of the landscape (85%) dominated by soybean (40%) and corn (45%) production. Historically, wetlands occupied an

estimated 40-61% of the total county area (McCauley and Jenkins 2005). However, 98% of these wetlands have been lost due to extensive drainage projects and now only 0.9% of the county is covered by wetlands (Suloway and Hubbell 1994; McCauley and Jenkins 2005). Consequently, small streams and agricultural ditches provide most of the habitat for muskrats in the region.

I selected 10 stream segments (hereafter “sites”) located in 3 distinct watersheds (Kaskaskia River, Embarrass River, and Black Slough; Fig. 1) using ArcMap 9.2 (Environmental Systems Research Inc. 2006) and digital orthoquadrangle photos (DOQs) from 2008. Within each watershed, I stratified my sites by distance from the headwaters to ensure that sampled individuals were positioned along a drainage-area gradient (Fig. 2). All sites were located within 1<sup>st</sup>, 2<sup>nd</sup>, or 3<sup>rd</sup> order streams (Strahler 1957) that included varying stages of channelization. Average thalweg depths of sites ranged from 0.25 – 0.55 m, and average wetted width of sites ranged from 3.25 – 11.15 m. Reed canary grass (*Phalaris arundinacea*) was the dominant vegetation type along bank edges. Dominant upland riparian vegetation included broom sedge (*Andropogon* spp.), goldenrod (*Solidago* spp.), big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), eastern cottonwood (*Populus deltoides*), and willow (*Salix* spp.) Most of the surrounding agricultural landscape was managed via tile drainage to transport excess water into adjacent streams.

### *Stream hydrology*

To quantify hydrological flashiness, I collected data on water levels and duration of inundation for my 10 study sites. I define a ‘flashy’ site as one with a quick rise to a peak

water level and a quick return to baseline flow during a flooding event. In contrast, ‘non-flashy’ characterizes a stream segment that remained inundated for a relatively longer period of time after a flooding event. Water-level measuring stations were designated on bridges nearest my study sites, and were an average of 0.26 km (range = 0 – 1.18 km) from these sites. The distance from each station to the stream substrate was measured once during the study period with a measuring tape to obtain a ‘total distance’. I obtained subsequent measurements with a Sonin 45<sup>®</sup> ultra-sonic measuring device from the designated measuring point to the water surface. ‘Total distance’ minus ‘water surface distance’ determined the water depth at a site. I measured water levels  $\geq 1$  time per week or opportunistically during non-flooding periods to obtain estimates of base-line flow depth for all sites. During rain or runoff events, I measured water levels until a peak water depth was recorded. As water levels receded back to base-line flow, measurements were taken more frequently to estimate duration of inundation time for each site during a particular flooding event.

#### *Capture and radiomarking*

Muskrats were live trapped using single-door, collapsible Tomahawk live traps (Model 202) from 14 June 2008 to 29 November 2008. Each trap was placed on a platform (Schooley and Branch 2006) constructed of 2-cm thick plywood (76 × 25 cm) attached to three legs (1.5-cm PVC pipe, 91-cm long). Heights of platforms were adjustable so that traps were kept at water level. I placed platforms with traps in streams near muskrat burrows or areas with abundant muskrat sign, and baited traps with apples or carrots 1 hr before sunset. I checked traps 1-2 hrs after sunrise the following day.

Each captured individual was immediately taken to a sterile surgical lab at the Small Animal Clinic at the University of Illinois College of Veterinary Medicine where they were pre-medicated with 0.2 mg/kg atropine sulfate and 0.5 mg/kg medetomidine. Animals were anesthetized using isoflurane (5%) combined with oxygen (0.6 L/min) administered through a facemask, and marked with a 14-g radio transmitter (Advanced Telemetry Systems, Model M1215) surgically implanted into the peritoneal cavity (MacArthur 1980; Lacki et al. 1989; Zschille et al. 2008). Transmitters were <2% of the body weight of muskrats ( $\bar{x}$  = 1050 g, SE = 45.9 g) and were equipped with a mortality sensor. I also uniquely marked each animal with a passive integrated transponder (PIT) tag (Schooley et al. 1993). Post-operatively, each muskrat received 0.25 mg/kg atipamazole as a reversal agent for medetomidine, 0.2 mg/kg meloxicam as an analgesic, and 0.1 ml of penicillin to control against infection. Muskrats were held for a minimum of 2 hrs post-operatively before being released at their point of capture. All capture and handling methods were approved by the University of Illinois Institutional Animal Care and Use Committee (Protocol # 07105).

#### *Displacement during flooding*

I determined locations of muskrats and their burrows by homing with ground-based telemetry using a 3-element Yagi antenna and receiver (Advanced Telemetry Systems, Model R410). Locations were recorded with a hand-held GPS unit. Muskrats were located at least 1-2 times per week during non-flooding periods. During flooding events, muskrats were located as soon as possible to determine when each individual was displaced from its burrow. A muskrat was considered as displaced during a flooding

event if it was outside of its burrows, located in upland terrestrial habitat (riparian buffer or agriculture), and not actively foraging. Locations were recorded periodically throughout the flooding event until the animal was located back in its burrow (i.e., end of displacement event). I compared individual displacement times for muskrats positioned along the flashiness gradient during discrete flooding events.

### *Mortality causes*

Common predators of muskrats within my study area included American mink (*Neovison vison*), coyotes (*Canis latrans*), red foxes (*Vulpes vulpes*), domestic dogs (*Canis familiaris*), and red-tailed hawks (*Buteo jamaicensis*). When I obtained a transmitter signal in mortality mode, I immediately retrieved the carcass. All mortalities that could be determined to be predation related were classified as either mink predation or canid predation (coyote or red fox). A muskrat was assumed killed by a mink if the remains were found in a burrow, or if remains were characteristic of mink predation as described by Errington (1943). Predation was classified as canid-caused if the transmitter had evidence of deep tooth marks, or if remains were located >50 m from the stream edge. Furthermore, all mink predation events were in areas with confirmed mink sign, whereas all canid predations occurred near active coyote or red fox burrows. If cause of mortality could not be determined in the field, remains were delivered to the College of Veterinary Medicine at the University of Illinois where a full necropsy was performed.

### *Survival analysis*

I constructed a set of models *a priori* to explain survival of muskrats that included age (juvenile or adult), season (winter or non-winter), two hydrological variables (drainage area and stream sinuosity), and riparian buffer width. Muskrat age was determined by weight at capture. This technique for estimating age of muskrats was effective during my summer-fall live-trapping period (Errington 1939) when weights of juveniles ( $\bar{x} = 986$  g, SE = 38.5) were substantially smaller than weights of adults weights ( $\bar{x} = 1430$  g, SE = 91.8). I classified my 2 seasons based upon minimum and maximum daily temperatures reported by the National Climatic Data Center for Champaign County (National Climatic Data Center 2009). Winter started when minimum daily temperatures fell below 0° C and ended when maximum daily temperatures exceeded 0° C, spanning 27 October 2008 – 4 March 2009. Non-winter included 14 June 2008 – 26 October 2008 and 5 March 2009 – 3 July 2009. Total drainage area for each individual's site was remotely delineated using watershed and sub-watershed layers (United States Geological Survey 2005), raster elevation layers (Illinois State Geological Survey 2003), and area measuring tools in ArcMap 9.2 (Environmental Systems Research Inc. 2006). Channelization of streams can negatively impact natural habitat and biomass and increase variability of the hydrologic regime (Zimmer and Bachmann 1978; Davis et al. 2003; King et al. 2009). Moreover, the degree of channelization is correlated with sinuosity of the stream channel; natural streams have longer stream channels than channelized streams within similar-sized drainage areas (Zimmer and Bachmann 1978; King et al. 2009). To investigate how stream channelization might affect muskrat survival, I measured 'sinuosity' of a stream segment

as the ratio of total meandering stream channel length divided by the Euclidian distance from the start of the headwaters to the downstream extent of an individual's known movements. Characterization of the riparian zone differs among researchers (Naimon and Décamps 1997). I defined riparian zone as the area of natural vegetation between the wetted edge of the stream and the adjacent human-modified landscape (i.e., agriculture, urban areas, and highways). The riparian-zone width was measured every 50 m within the extent of an individual's known movements and then averaged.

I used known-fate models in program MARK (White and Burnham 1999) to estimate weekly survival, and an information-theoretic approach (Burnham and Anderson 2002) to evaluate support for my competing models. All models included an intercept term and up to 2 predictor variables. The number of estimable parameters for each model never exceeded 3, allowing us to optimize the model likelihood without sacrificing the precision of my individual covariate estimates by over-parameterizing my data (Burnham and Anderson 2002). Muskrat survival was estimated over a 392-day period from 14 June 2008 to 3 July 2009. I used 56 discrete encounter intervals of 7 days each to estimate weekly survival. If an individual's fate was unknown (e.g., movement out of study area or transmitter failure) for a given interval, it was censored from the analysis (Cooch and White 2008). I chose the logit link function for all models to transform the probability of my binary response variable, survival, from  $[0, 1]$  to  $[-\infty, +\infty]$  to express the probability of weekly survival as a linear function of my covariates (Cooch and White 2008). Models were ranked using Akaike's Information Criterion ( $AIC_c$ ), which includes a correction for small sample sizes, and models with a  $\Delta AIC_c \leq 2$  were considered to have substantial support (Burnham and Anderson 2002).

### 1.3 Results

I radio-marked 31 muskrats (5 adults and 26 juveniles). I removed 4 individuals from my analysis: 3 mortalities probably related to surgeries and 1 individual that was never relocated after radio-marking. Hence, survival analysis was based on 27 muskrats. Eight individuals apparently outlasted the battery life of their transmitters ( $\bar{x} = 205$  days,  $SD = 16$ ), and the fates of 3 additional muskrats were unknown.

Study sites located farther from headwaters of a watershed remained inundated longer during flooding events than sites positioned closer to headwaters (general pattern is exemplified in Fig. 3). This result was consistent for all measured flooding events; however, the magnitude of difference in inundation times between sites depended on the amount of precipitation or snow melt associated with the individual flooding event. I obtained 107 radiolocations for 16 individuals during 9 flooding events. However, during 4 of the 9 flooding events, I was unable to track multiple muskrats and could not compare displacement times. Thus, I compared displacement times of muskrats along the flashiness gradient for 5 separate flooding events (Fig. 4). Graphical representation of displacement times during floods as a function of drainage area demonstrates that muskrats positioned farther down the flashiness gradient generally were displaced for longer periods of time than those positioned closer to headwaters (Fig. 4).

Of 15 known predation mortalities, 80% were from mink ( $n = 12$ ) and 20% were from a canid ( $n = 3$ ). Sixty-seven percent ( $n = 10$ ) of known predation mortalities occurred in winter, and 33% ( $n = 5$ ) occurred in non-winter. Only 1 of 15 known predation

mortalities (canid caused) occurred while individuals were displaced during flooding events.

My best approximating model indicated that muskrat survival differed between seasons and was influenced by width of the riparian zone (Table 1). No other models with substantial support included variables other than season and riparian width (Table 1). Estimated weekly survival probability for muskrats was higher in non-winter (0.9770, SE = 0.0116) than in winter (0.9377, SE = 0.1793). The probability of surviving the duration of the study (56 weeks) was 0.1199 (SE = 0.0703). Riparian-zone width ( $\bar{x}$  = 25.5 m, range = 6.1 - 74.5 m) was related positively to survival ( $\hat{\beta}$  = 0.0370, SE = 0.0198); muskrats positioned within a wider riparian zone had a higher survival probability. This effect of landscape context was particularly important for muskrats in winter (Fig. 5).

#### **1.4 Discussion**

My results demonstrated that inundation times during flooding events can be ordered along a flashiness gradient: stream segments positioned closer to headwaters are flashier and have shorter inundation times than stream segments positioned farther from headwaters. Displacement times of muskrats during flooding events also varied along the flashiness gradient with individuals positioned in larger drainage basins displaced longer, and exposed to an increased risk of terrestrial predation, than those positioned closer to the headwaters. However, I did not detect an effect of landscape position and associated displacement time during flooding on muskrat survival. Because I recorded only 1 predation event while muskrats were displaced during flooding, my data also did not

support the hypothesis that wider riparian zones ameliorate predation risk and increase survival while animals are displaced from their burrows during flooding events.

Nevertheless, my results indicate that wider riparian zones were associated with greater muskrat survival in small streams and agricultural ditches, especially during winter.

Riparian buffers, a habitat feature that varies considerably in human-dominated landscapes, can affect the fitness of semi-aquatic organisms.

Flood inundation patterns can vary depending on a stream segment's position within the watershed. During flooding events, hydrology creates inundation gradients that should be integrated with other habitat factors to discern overall habitat quality in riparian areas. Species fitness in these dynamic habitats should partially depend on an organism's ability to overcome or outlast these stochastic events. Although the patterns are clear, there are some caveats associated with my inferences regarding the correlation between landscape position and stream hydrology. First, my study sites were positioned within tile-drained and channelized 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> order streams, and all inferences are restricted to these habitat types. Second, my study area received abnormally high levels of precipitation during my investigation. Illinois received ~129 cm of precipitation in 2008, which was ~29 cm above average, and the 2<sup>nd</sup> wettest year recorded in the state since 1895 (Changnon et al. 2009).

I expected predation risk for muskrats to increase when they were displaced during flooding events. Muskrats use burrows constructed within the stream bank for refuge, and are relatively easy prey for predators in terrestrial habitat (Errington 1946), especially for coyotes and foxes that likely would have difficulty depredating muskrats in the water or in burrows. Muskrats are reluctant to swim in 'choppy' or fast-flowing water and will

remain upland, but close to the water's edge, unless forced back into the water during flooding events (Errington 1937). I observed displaced muskrats 'waiting out' high waters in terrestrial habitat directly above established bank burrows. As water levels returned to baseline flow, animals followed the receding water back to their burrows. The composition of terrestrial habitat providing cover for displaced muskrats varied temporally and depended on riparian zone width. If animals were displaced beyond the riparian zone into surrounding agricultural fields during the growing season, potential cover consisted mostly of soybeans and corn. If the same animals were displaced beyond the riparian zone post-harvest (typically from October-May), there was virtually no cover from predators.

Although predation risk should be increased for displaced muskrats, most muskrat mortalities occurred during non-flooding periods. One possible explanation is that muskrats forced from their burrows and into the terrestrial matrix recognized the increased predation risk and allocated relatively more time to antipredator vigilance instead of foraging and other activities (Lima and Dill 1990; Lima and Bednekoff 1999). Increasing vigilance could compensate for increased predation risk during displacement. Given the potential for substantial periods of displacement during floods, individuals would then need to compensate with increased foraging, and higher risk, after returning to streams.

Muskrat survival was related positively to riparian buffer width, especially during winter. However, my original hypothesis that larger riparian buffers should ameliorate predation risk associated with displacement during floods was not supported because most mortalities did not occur during flooding events. Instead, most winter mortalities

were due to predation along banks or within bank burrows, suggesting lower survival of muskrats within narrower riparian zones was caused by increased predation pressure close to the stream bank. Simberloff and Cox (1987) proposed that narrower riparian corridors could be used by predators to efficiently target prey species that occur within the corridor. Smith et al. (2008) found that larger-bodied predators concentrated their activity around a narrow (~50 m wide) transmission line right-of-way, and this could reflect the concentration of small vertebrate prey in the linear habitat. Coyotes and mink (Stevens et al. 1997; Gosselink et al. 2003) readily use riparian areas for burrow sites and foraging in landscapes dominated by agriculture. The structure and composition of riparian areas provide habitat for many prey species (e.g., *Peromyscus* spp., *Microtus* spp., and *Sylvilagus floridanus*). Narrow riparian zones should constrain available foraging habitat and increase predator presence and foraging activities close to the stream bank edge, which could negatively affect muskrat survival. This riparian-buffer effect would be pronounced in winter when muskrats are most vulnerable (Errington 1946; Clark and Kroeker 1993).

The design and incorporation of direct management practices into conservation efforts requires an understanding of how local and landscape habitat characteristics influence survival of target species. Riparian buffers are a key habitat feature in human-dominated landscapes (Naimon and Décamps 1997) and can improve many environmental, aesthetic, social, and economic conditions associated with these areas (Lovell and Sullivan 2006). My study demonstrated that wider riparian buffers along small streams and agricultural ditches in human-dominated landscapes can improve muskrat survival. I recommend that land managers incorporate natural riparian buffers

into management efforts for wildlife associated with riparian systems. Future research should be directed toward elucidating mechanisms linking riparian-zone width to fitness of stream-dwelling organisms. Experimental investigations of riparian buffers are particularly needed.

Chapter 1 meets the formatting requirements of *Canadian Journal of Zoology*

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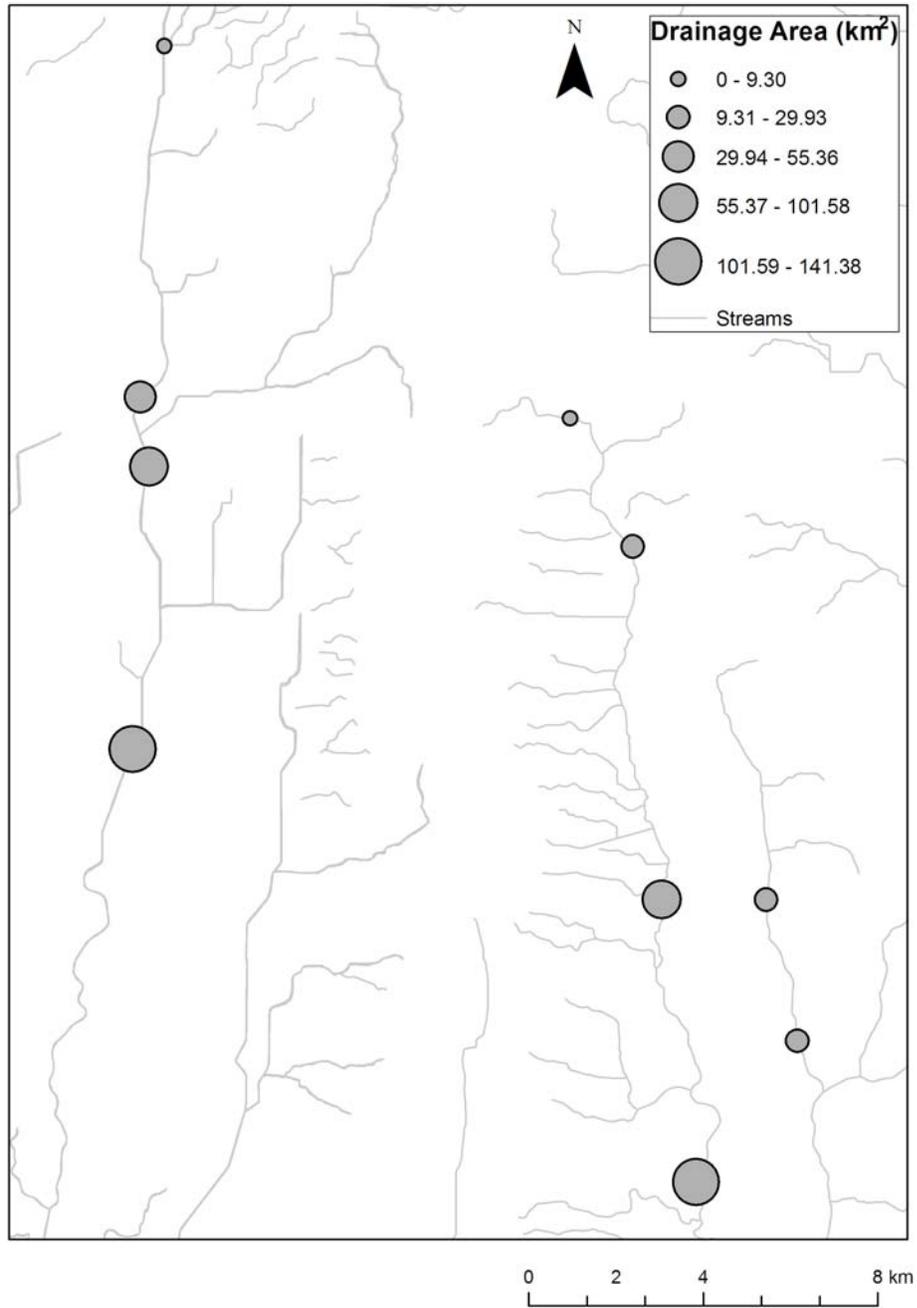
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## 1.6 Tables and Figures

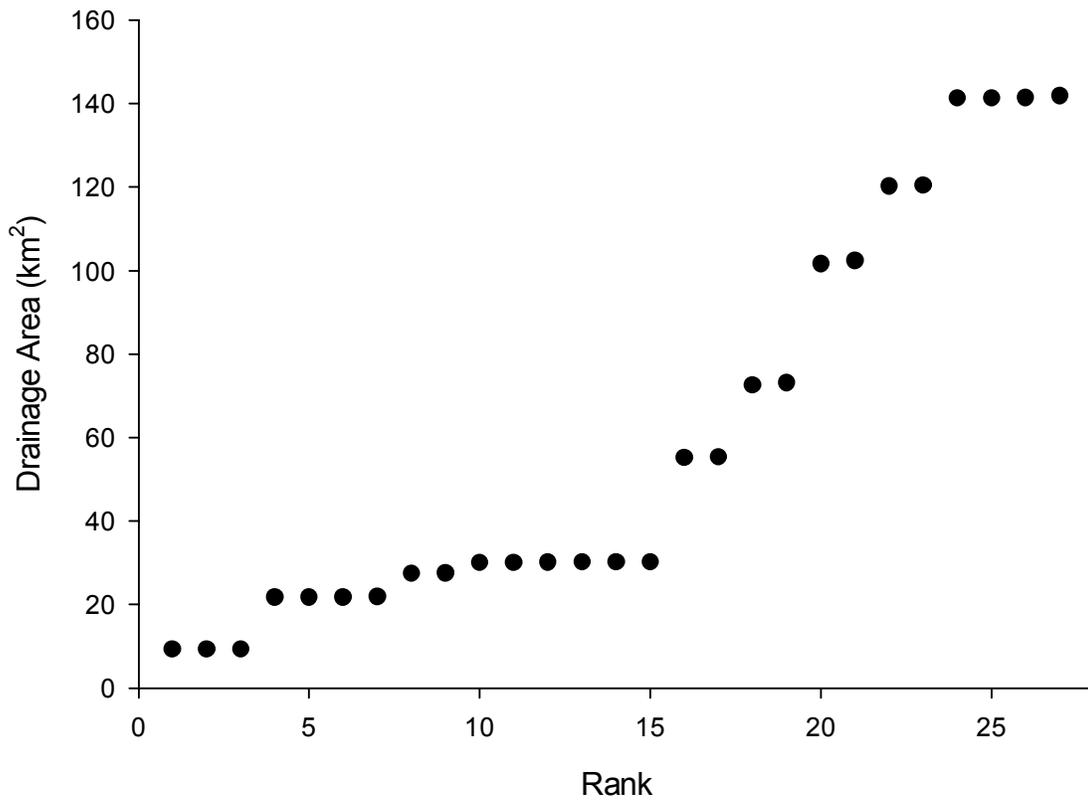
**Table 1.** Ranking of known-fate models for survival of radio-marked riparian muskrats (*Ondatra zibethicus*) in an agricultural landscape in east-central Illinois.

Model	K	$\Delta AIC_c$	$\omega_i$	Deviance
<i>S</i> (season + ripwidth)	3	0.00	0.35	123.40
<i>S</i> (ripwidth)	2	1.47	0.17	126.91
<i>S</i> (season)	2	2.56	0.10	128.00
<i>S</i> (ripwidth + drainarea)	3	3.34	0.07	126.74
<i>S</i> (ripwidth + age)	3	3.50	0.06	126.90
<i>S</i> (season + drainarea)	3	3.55	0.06	126.94
<i>S</i> (.)	1	3.64	0.06	131.09
<i>S</i> (sinuosity)	2	3.91	0.05	129.35
<i>S</i> (season + age)	3	4.47	0.04	129.45
<i>S</i> (drainarea)	2	4.92	0.03	127.87
<i>S</i> (age)	2	5.14	0.03	130.57

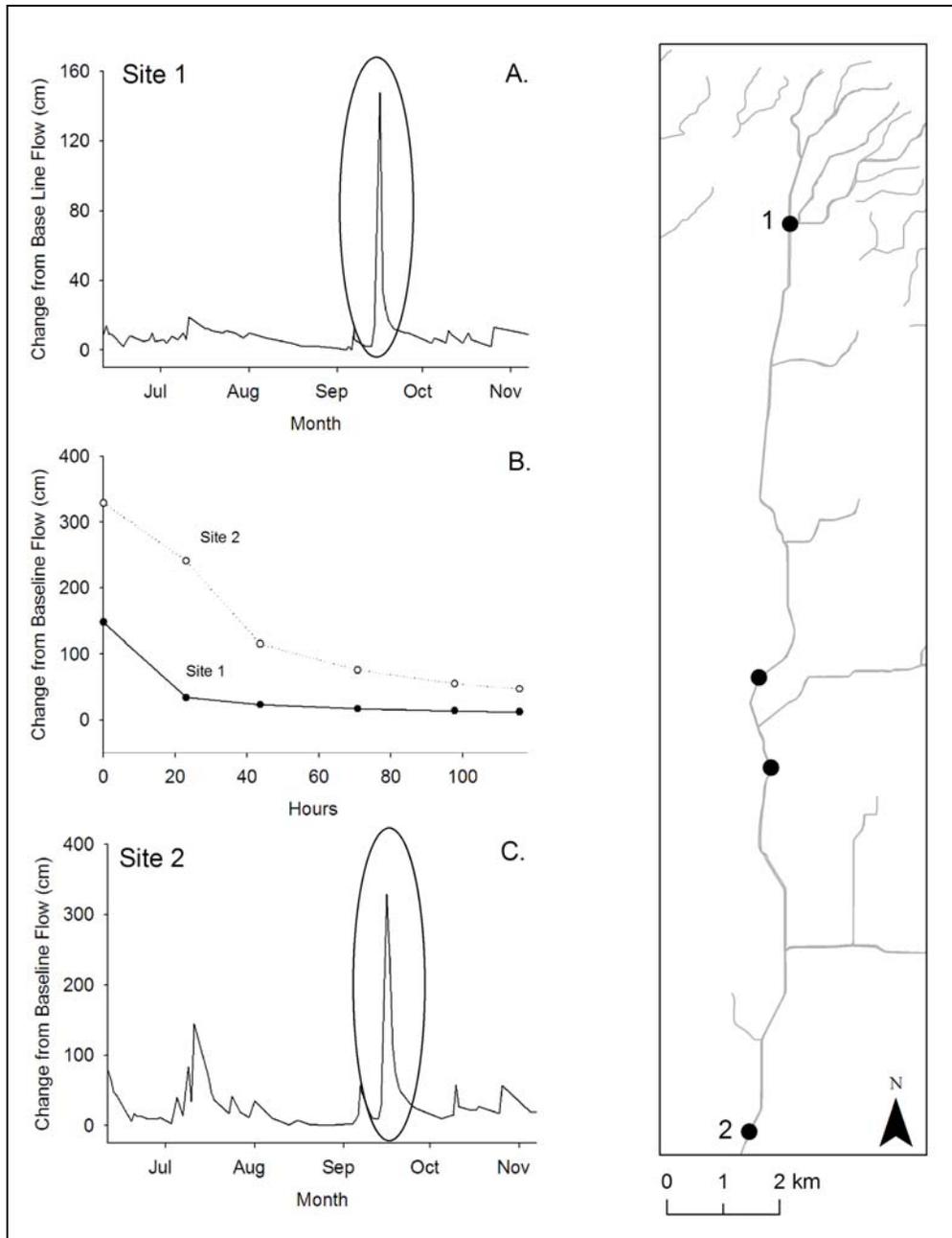
Notes: Models were selected using an information-theoretic approach and ranked by ascending  $\Delta AIC_c$ ; K is the number of estimable parameters including the intercept,  $\omega_i$  is the model weight, and Deviance =  $-2 [\log_e(\text{Likelihood}) \text{ of the model of interest}] \text{ minus } [\log_e(\text{Likelihood}) \text{ of the saturated model}]$ . Explanatory variables include season (winter or non-winter), ripwidth (riparian width), drainarea (drainage area), sinuosity (sinuosity of stream segment), and age (juvenile or adult).



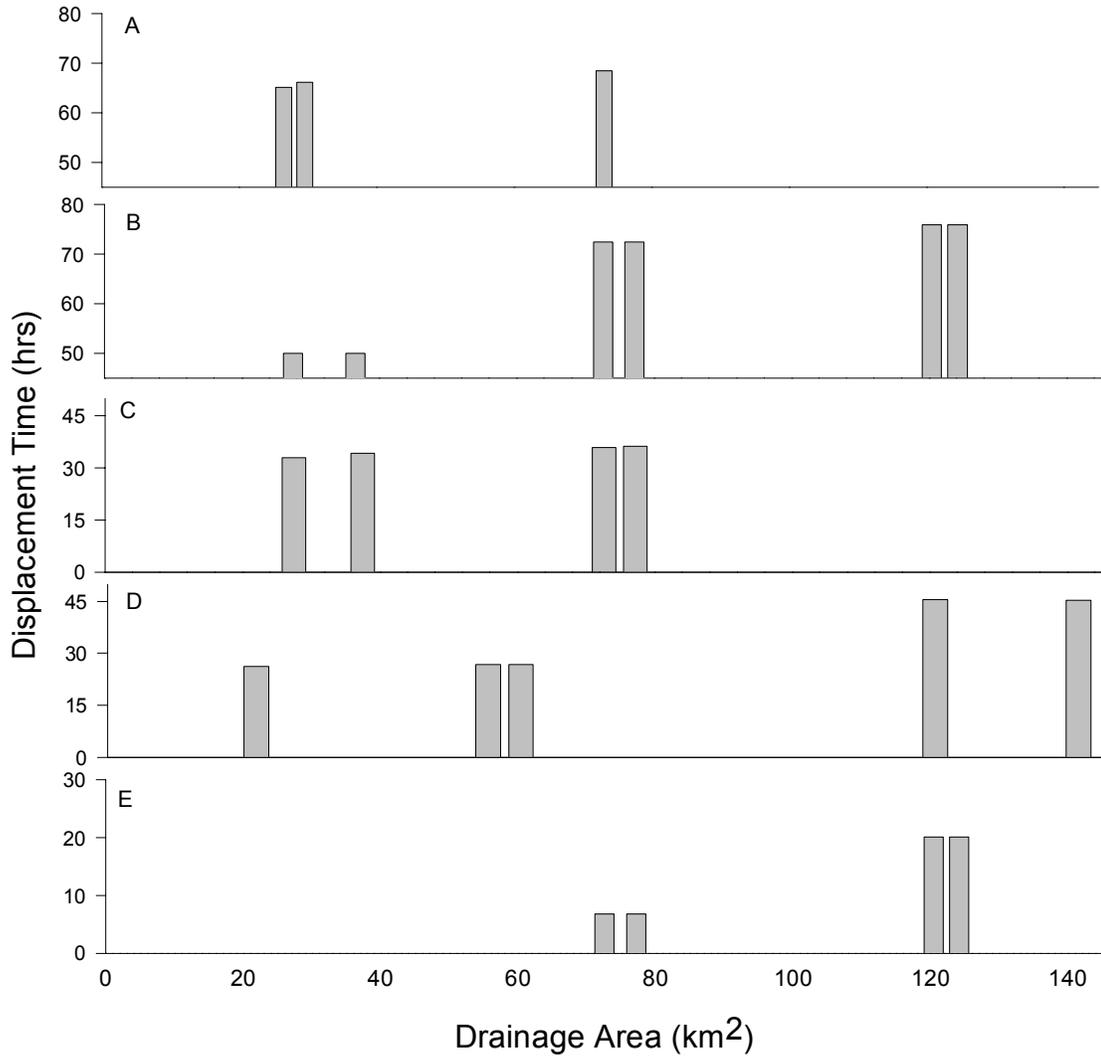
**Figure 1.** Locations of study sites for survival analysis of riparian muskrats (*Ondatra zibethicus*) in the Kaskaskia (left), Embarrass (middle), and Black Slough (right) watersheds. Each site is positioned along a drainage-area gradient within its watershed.



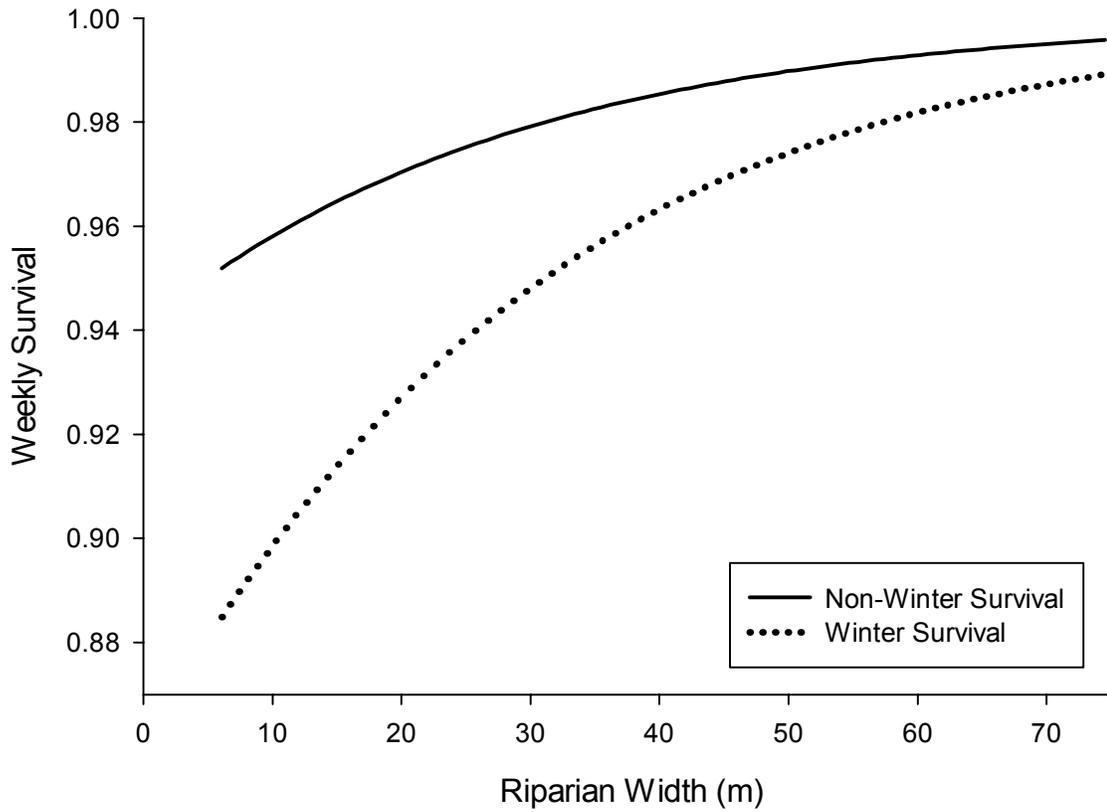
**Figure 2.** Radio-marked riparian muskrats (*Ondatra zibethicus*) were sampled across a drainage-area gradient in east-central Illinois. Each circle represents an individual ( $N = 27$ ) ranked from smallest to largest drainage areas.



**Figure 3.** Relationship between duration of inundation and landscape position within the Kaskaskia watershed. Stream segments farther from the headwaters remain inundated longer than stream segments closer to the headwaters during flooding events. **A.** Hydrograph representing change from baseline flow between the months of June-November 2008 for a site near the headwaters of the Kaskaskia River (Site 1). **B.** Inundation times from peak flow to baseline flow during a single flooding event in September 2008 for study sites 1 and 2 (circled flood event in panels A & C) along the flashiness gradient. **C.** Hydrograph representing change from baseline flow between the months of June-November 2008 for a site further down into the Kaskaskia River watershed (Site 2). Note differences in scale of y-axis for A and C.



**Figure 4.** Displacement times for individual riparian muskrats (*Ondatra zibethicus*), positioned along a flashiness gradient, during 5 floods. Each panel (A - E) represents a discrete flooding event. Individuals located in stream segments that were farther down the flashiness gradient generally were displaced longer than those positioned closer to the headwaters.



**Figure 5.** Weekly survival estimates for radio-marked riparian muskrats (*Ondatra zibethicus*) from the top-ranked (see Table 1) known-fate model (S = season + riparian width).

## CHAPTER 2

### HOME RANGES AND SPACE USE OF MUSKRATS IN RESTRICTED LINEAR HABITATS

#### 2.1 Introduction

Knowledge of a species' spatial ecology is critical for directing conservation efforts, especially for species that are rare (Schooley & Branch 2006), exploited for harvest (Koen et al. 2007) or occur in highly disturbed, human-dominated habitats (Beasley et al. 2007, Tucker et al. 2008). Estimating home-range size is one common approach for quantifying space requirements for a particular species (Powell 2000). Home-range sizes also can be used to discern suitable habitat requirements (Mitchell et al. 2002) and direct future management efforts (Lambert et al. 2008). Patterns of space use within home ranges also provide insights into how animal movements are related to habitat heterogeneity (Wauters et al. 1994, Chamberlain et al. 2007).

Modern agricultural production within the midwestern USA has resulted in loss of ~98% of the natural wetlands in Illinois, USA (Suloway & Hubbell 1994). Furthermore, many small headwater streams in the region have been channelized to accept runoff from adjacent tile-drained agricultural fields, thus increasing the variability of their flow regimes (King et al. 2009). These dramatic landscape modifications have affected the distribution of muskrats (*Ondatra zibethicus*), a species obligately associated with semi-aquatic habitats, by restricting most of their suitable habitat to linear small streams and agricultural ditches. Muskrats are an economically important furbearer species in the region. For example, an estimated 439,796 muskrats were harvested in Illinois from

1998-2008, accounting for ~25% of all furbearers harvested (1,728,208) during that period (Lischka et al. 2010).

Data describing space use by muskrats are limited and mostly apply to individuals occurring in wetland habitats (Errington 1939a, Sather 1958, MacArthur 1978, MacArthur 1980). Errington (1939a) reported muskrats range an average of 256 m from the shoreline into the marsh. Sather (1958) recaptured muskrats 70 m from lodge shelters, whereas MacArthur (1978, 1980) reported average movement distances of 150-230 m away from lodge or burrow shelters. Again, these coarse estimates of movements were made in 2-dimensional habitats. The unique structure of linear habitats can influence the spatial ecology of species (Serena et al. 1998, van der Ree & Bennett 2003, Pattishall & Cundall 2008, Gomez et al. 2010), and comparative studies of space use have reported differences in home-range size between species in linear and 2-dimensional habitats (Quin 1995, van der Ree & Bennett 2003).

It is unclear to what extent muskrats use upland habitat within their home ranges. Errington (1938, 1941) observed muskrats moving to upland habitats to selectively forage on non-native food sources (e.g., corn, apples). However, Dixon (1922) reported that muskrats forage exclusively on vegetation within the stream channel. Published data characterizing space-use patterns of muskrats occurring within linear riparian areas are extremely limited (Brooks 1985), although these areas constitute much of the available habitat for muskrats in the midwestern USA.

My objectives were to determine the size of home ranges for muskrats in riparian areas, identify which factors predict home-range shape and size, and elucidate how muskrats use space within their home range. I predicted that muskrats in small streams

and agricultural ditches would use upland habitat (e.g., row-crop agriculture) adjacent to streams as well as areas along stream-bank edges. Because muskrats in 2-dimensional habitats are considered central-place foragers (MacArthur et al. 1997), I predicted muskrats positioned in linear stream habitats would also spend most time in or near established burrows. I addressed these objectives by tracking movements of radio-marked muskrats within highly linear stream habitats in a human-dominated agroecosystem.

## **2.2 Materials and Methods**

### *Study area*

Champaign County is located in east-central Illinois (40°12'N, 88°26'W), and is located within the Grand Prairie region of the U.S.A. My study area (~71,715 ha) is comprised of relatively level topography and dominated by row-crop agriculture. Due to increased agricultural production and extensive drainage projects, 98% of the county's historical wetlands have been lost (McCauley & Jenkins 2005). Currently, 85% of the landscape is characterized by soybean (40%) and corn (45%) production, while historical wetlands cover only 0.9% of the region (Suloway & Hubbell 1994, McCauley & Jenkins 2005). Consequently, agricultural ditches and small streams now provide most of the available habitat for muskrats. The region receives ~171 cm of annual precipitation, and average temperatures range from -8.5 to 30.0° C (National Climatic Data Center 2010).

I selected 10 sites positioned within stream segments in 3 distinct watersheds (Kaskaskia River, Embarrass River, and Black Slough; Fig. 6). All sites were located within 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> order stream segments (Strahler 1957) and positioned within

varying-sized drainage basins ( $\bar{x} = 63.57 \text{ km}^2$ , range = 9.30 – 141.82  $\text{km}^2$ ). Stream channel geomorphology also varied between sites, with average thalweg depths ranging from 0.23 – 0.55 m, and average wetted width ranging from 3.14 – 11.41 m. Reed canary grass (*Phalaris arundinacea*), an aggressive non-native species, was the dominant stream bank vegetation at all sites. Broom sedge (*Andropogon* spp.), big bluestem (*Andropogon gerardii*), goldenrod (*Solidago* spp.), willow (*Salix* spp.), eastern cottonwood (*Populus deltoides*), and Indian grass (*Sorghastrum nutans*) dominated upland riparian vegetation.

#### *Capture and radiomarking*

I livetrapped muskrats using single-door, collapsible traps (Tomahawk Live Trap Inc., Tomahawk, WI; Model 202). Trapping was conducted opportunistically from 6 July - 19 November 2007 and from 14 June 2008 - 29 November 2008 depending upon water levels and minimum temperatures. I fastened live traps on adjustable trap platforms (2-cm thick plywood, 76 x 25 cm) attached to three stabilizing legs (1.5-cm PVC pipe, 91-cm long; Schooley & Branch 2006) and placed them along stream bank edges near active muskrat burrows or in areas with abundant muskrat sign (e.g., tracks, scat, and clippings). Platform height was adjusted daily to compensate for varying water levels. Traps were baited with either apple or carrot, opened 1 hr before sunset, and then checked 1-2 hr after sunrise the following day.

In 2007, I fitted captured muskrats with a 25-g radio transmitter (Advanced Telemetry Systems, Isanti, MN; Model 1565) affixed to a cable-tie collar. Transmitter attachment was completed at the site of capture. Some mortality of muskrats in 2007 may have been indirectly linked to this radiomarking method (i.e., chafing was noted

around the neck of some recovered carcasses). Therefore, I used radio-transmitter implants for muskrats in 2008. I transported captured muskrats to a sterile surgical laboratory at the Small Animal Clinic at the University of Illinois College of Veterinary Medicine and pre-medicated individuals with 0.2 mg/kg atropine sulfate and 0.5 mg/kg medetomidine, then induced surgical anesthesia by facemask using 5% isoflurane and 0.6 L/min oxygen. I surgically implanted a 14-g radio transmitter (Advanced Telemetry Systems, Model M1215) it into the peritoneal cavity of each muskrat (MacArthur 1980, Zschille et al. 2008). Post-surgery, each muskrat was administered 0.25 mg/kg atipamazole, 0.2 mg/kg meloxicam, and 0.1 ml of penicillin. After being held for  $\geq 2$  hrs to monitor recovery, I released muskrats at their point of capture. In both years, passive integrated transponder (PIT) tags (Schooley et al. 1993) were used to mark individual muskrats. All trapping and radiomarking procedures were conducted in accordance with the University of Illinois Institutional Animal Care and Use Committee Protocol # 07105.

### *Home-range analysis*

Most individuals (20 of 26) were marked between September and November each year. Although some individuals were radiotracked throughout the year, most muskrats were radiotracked during fall-winter (September - March). Muskrat activity is mostly diurnal or crepuscular during these seasons (MacArthur 1980), so tracking effort was concentrated during those times. I determined locations of muskrats  $\geq 2$  times per week using ground-based telemetry. I used a 3-element Yagi antenna and receiver (Advanced Telemetry Systems, Model R410) to find the general location of muskrats. If an individual was in a ground burrow, I determined the exact location by removing the Yagi

antenna and using the receiver and antenna cord to locate the strongest signal along the bank. If muskrats were found foraging in the open, I recorded the exact location at the time the animal was encountered. I recorded all locations using a hand-held GPS unit (Garmin International Systems, Olathe, KS; Model GPS 76) with Wide Area Augmentation System (WAAS) capabilities that provided 2-3 m accuracy.

In my study area, muskrat habitat was confined to narrow, linear stream channels surrounded by row-crop agriculture. Commonly used home-range estimators (e.g., minimum convex polygons and kernel density estimators) can overestimate home-range sizes (Blundell et al. 2001, Downs & Horner 2008) and underestimate travel distances in these linear habitats (Knight et al. 2009). Furthermore, kernel density estimators can substantially overestimate the amount of “used” area when there are multiple relocations at a single place (Seaman & Powell 1996, Pattishall & Cundall 2008) such as a burrow. Measuring the linear distance within the extent of a species known movements has provided accurate home-range estimates for individuals within restrictive linear habitats (Serena et al. 1998, van der Ree & Bennett 2003, Melero et al. 2008, Pattishall & Cundall 2008). I estimated linear home ranges (LHR) for individual muskrats by measuring the total meandering stream channel length between the most upstream point and the most downstream point using linear measuring tools in ArcMap 9.2 and maps obtained from digital orthophoto quadrangles (DOQs). None of the home ranges included branching within the stream system.

Methods for estimating sample size requirements for LHRs are not well developed. Instead, I estimated the minimum number of locations necessary by bootstrapping area-observation curves (Animal Movement Extension to ArcView 3.3; Environmental

Systems Research Inc. 2006) using 100% minimum convex polygons (MCP). I used a subset of muskrats ( $n = 17$ ) that occurred in straight streams (MCP performs poorly for more sinuous streams). For these individuals, LHR was correlated with MCP ( $r = 0.92$ ,  $P < 0.0001$ ). Generally, 20 locations were adequate to estimate home ranges. Based on this criterion, 16 muskrats had sufficient sample sizes, and another 10 were borderline ( $\geq 15$  locations). I used all 26 individuals in my analysis, but checked whether my inferences were robust to sample size (see Results).

I constructed a set of candidate models *a priori* to determine effects of covariates on LHRs of muskrats. Covariates included number of burrows (burrows), age class (age class), vegetation PCA (vegetation), coefficient of variation for water level (CV), number of locations (locations), wetted width of stream (wetted width), width of the riparian zone (riparian), and year animals were radiomarked (year). The number of burrows used by each muskrat was determined by radiotelemetry. Age class (juvenile or adult) was determined by weight at capture, which was effective because trapping was conducted during summer-fall when weight differences between young-of-the-year and adults were clear (Errington 1939b). Determining the sex of live juvenile muskrats could not be done with certainty (Dozier 1942), so I did not include the sex of muskrats in my analysis. The percent cover by vegetation (channel vegetation, bank vegetation, and floodplain vegetation) was measured every 50 m within each muskrat's home range, and then averaged to obtain a single mean value per LHR. These vegetation cover variables were highly correlated ( $r \geq 0.60$ ,  $P < 0.001$ ), so I combined them using a Principal Components Analysis (PROC PRINCOMP; SAS Institute Inc. 2009) into a single variable (vegetation) based on Principal Component 1. Instability of the hydrologic

regime can affect survival of muskrats (Kinler et al. 1990) and alter movement patterns of small mammals inhabiting riparian areas (Anderson et al. 2000). I quantified hydrologic stability within home ranges of muskrats by calculating the coefficient of variation of water-level change from baseline flow at each site. Water levels were measured  $\geq 1$  time per week from a bridge nearest each muskrat home range ( $\bar{x} = 0.26$  km; range = 0.00 – 1.18 km) with a Sonin<sup>®</sup> ultra-sonic measuring device. The wetted width of the stream and width of the riparian zone (area of vegetation between the edge of the stream and adjacent row-crop fields) were measured every 50 m within each muskrat's home range and then averaged. The 'year' variable represented potential differences in unmeasured environmental conditions between years (2007 and 2008) and effects of radiomarking method.

I used general linear models (PROC GENMOD, SAS Institute Inc. 2009) to model my response variable, LHR, as a function of up to 3 covariates. Competing models were evaluated using an information-theoretic approach with  $\Delta AIC_c$  values of  $\leq 2$  indicating models with substantial support (Burnham & Anderson 2002).

### *Space use*

I used a Morisita Index ( $I_M$ ; Morisita 1962) to investigate space use within home ranges of riparian muskrats.  $I_M$  is an index of dispersion that represents the degree of aggregation within a defined study extent, and is independent of sample size (Hurlbert 1990). A random dispersion pattern is represented by values of  $I_M < 1$ , with aggregated patterns of dispersion indicated by  $I_M > 1$ . I calculated the degree of aggregation by dividing stream segments within each animal's LHR into 10-m 'bins' using measuring

tools in ArcMap 9.2 and DOQs. I counted relocation points of each muskrat in each bin and then calculated an  $I_M$  value for each individual (Krebs 1999: pp 216) as

$$I_M = n \left( \frac{\sum x_i^2 - \sum x_i}{(\sum x_i)^2 - \sum x_i} \right)$$

where  $n$  = number of 10-m bins in an individual's home range, and  $\sum x_i$  = sum of all bin counts for individual  $i$ . I compared differences in  $I_M$  values between adult and juvenile muskrats using a Mann-Whitney test (SAS Institute Inc. 2009) with a cutoff value of  $P \leq 0.05$ .

### 2.3 Results

Twenty-six radiomarked muskrats (6 collared in 2007, 20 implanted in 2008) were used to analyze movements and space use within small streams and agricultural ditches. Individual muskrats were relocated an average of 39 times (SE = 5.35, range = 15 – 104), for a total of 1025 relocations. Muskrats were never located >3 m away from the water's edge (Fig. 7) indicating individuals in my study area did not generally use upland habitat or surrounding agriculture for foraging.

My best approximating model indicated that length of muskrat LHRs was influenced by age class and the number of burrows used (Table 2). Adult muskrats had longer LHRs ( $\bar{x} = 804$  m, SE = 171,  $n = 5$ ) than did juveniles ( $\bar{x} = 529$  m, SE = 53,  $n = 21$ ). Average LHR of combined age classes was 582 m (SE = 56). Muskrats used an average of 6.54 burrows (range = 3 – 13), and length of LHRs was related positively to number of burrows used (Fig. 8). My only other competing model ( $\Delta AIC_c < 2$ ) also included the variable 'year' (Table 2). However, the addition of 'year' to my most supported model

did little to improve model fit (Table 2), indicating this additional parameter was not informative (Anderson 2008). A similar analysis using only muskrats with  $\geq 20$  locations ( $n = 16$ ) also suggested that LHRs were related to age class and number of burrows—the only 2 models with substantial support included those two predictors.

Mean  $I_M$  values indicated that space use by muskrats was highly aggregated ( $\bar{x} = 10.92$ , SE = 1.50,  $n = 26$ ). Adult muskrats had higher  $I_M$  values ( $\bar{x} = 19.87$ , SE = 2.24,  $n = 5$ ) than did juveniles ( $\bar{x} = 8.79$ , SE = 1.37,  $n = 21$ ;  $z = 2.862$ ,  $P = 0.004$ ). The frequency of locations as a function of linear distance along LHRs suggested space use was aggregated around established burrows (see Fig. 9 for a representative example).

## 2.4 Discussion

The results of this study demonstrate how muskrats, a species affected by large-scale landscape change, use space within restrictive linear habitats. Home ranges of muskrats were highly linear and confined to the contour of stream bank edges. Contrary to my prediction, muskrats did not freely move upland and into adjacent row-crop agricultural fields to forage. This pattern suggests that available vegetation along the stream edge, which was primarily reed canary grass, provided sufficient forage. Muskrats used space non-randomly within LHRs with most movements occurring near established burrows. These results are consistent with other studies in wetlands (MacArthur 1978, MacArthur et al. 1997) and support my hypothesis that burrow-dwelling muskrats occurring in small streams and agricultural ditches also should be considered as multiple central-place foragers.

Muskrats occurring in restrictive riparian habitats had highly linear home ranges, and the shape of their LHRs largely depended upon the sinuosity of the stream segment. However, my original prediction that muskrats inhabiting small streams and agricultural ditches would use upland habitat (e.g., row-crop agriculture) adjacent to stream edges was not supported. Errington (1938, 1941) reported that muskrats living in drainage ditches in Iowa foraged extensively on corn (*Zea mays*) in adjacent fields and transported the corn stalks back to their feeding platforms. In my study area, I did not detect muskrats foraging on corn (transported stalks, damage to agricultural fields, or actual observations) even though it was growing  $\leq 6$  m from the stream edge in some instances. Reed canary grass is a ubiquitous non-native grass associated with variable flooding regimes (Kercher et al. 2004) and most wetlands in Illinois (Matthews & Endress 2008). Reed canary grass was also the dominant bank vegetation at all of my sites, and I observed muskrats extensively foraging on reed canary grass (visual observations, cached in burrows, and on feeding platforms). Although the nutritional value of reed canary grass to native herbivores is unclear (Miller & Nelson 1995), the species has been linked with high abundances of some small mammals (*Microtus* spp., *Blarina brevicauda*) in the region (Spyreas et al. 2009). Reed canary grass in highly altered riparian habitats could provide enough suitable vegetation so that muskrats do not have to forage far from the stream edge. However, further investigations are needed to clarify the influence of reed canary grass on muskrats occurring in these riparian habitats, especially in winter when reed canary grass is dormant.

Adult muskrats had longer LHRs than did juveniles, and LHRs of riparian muskrats were positively related to number of burrows used per individual. It is unclear why

juveniles had smaller LHRs than adults. In wetland habitats, intraspecific aggression within muskrat populations is intensified as older juveniles move into new territories (Errington 1939a). A possible explanation is that intraspecific aggression in restricted riparian habitats could limit the space available to smaller individuals, thus constricting their home range. My estimate of the mean number of burrows used per muskrat (~7) is >3 times higher than that reported by Brooks (1985). Among other reasons, muskrats use burrows for protection from predators (Messier & Virgl 1992). In my region, highly linear strips of riparian habitat are exploited by several species that could prey on muskrats (e.g., *Canis latrans*, *Vulpes vulpes*, *Neovison vison*; Gosselink et al. 2003, Bluett et al. 2006). Muskrats may be multiple central-place foragers that restrict most of their movements to areas in or around established burrows in part to remain close to refugia while foraging to reduce predation risk. Thus, individuals with longer home ranges would require more burrows to reduce the risk of predation while traveling between burrows or exploiting resources in different parts of their home range.

Designing and implementing management and conservation efforts requires an understanding of how landscape structure can influence a target species' space use patterns (Chapin et al. 1998). Agricultural production in the midwestern USA has drastically altered the landscape, resulting in the creation of unnatural, linear strips of riparian habitat that represent most of the available habitat for semi-aquatic organisms in the region. Muskrats occurring in these highly linear habitats restrict much of their movements to stream bank edges, essentially occupying a 1-dimensional home range. Future research should be directed towards elucidating how the linear structure of these habitats influences dispersal and gene flow in these areas. Experimental studies

investigating overland dispersal and habitat selection of muskrats in highly altered agroecosystems are especially needed.

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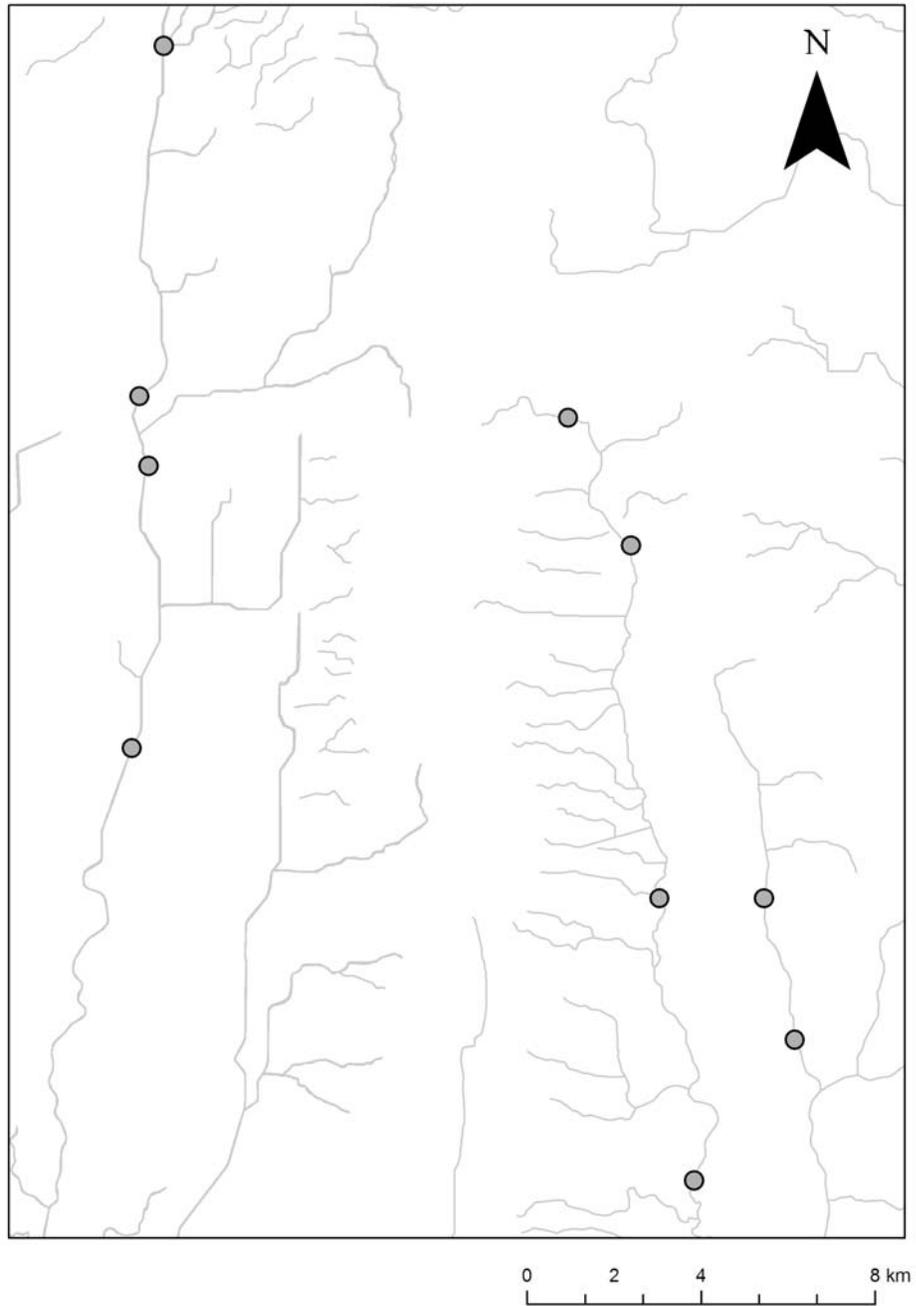
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## 2.6 Tables and Figures

**Table 2.** Ranking of models predicting linear home range (LHR) size of radiomarked muskrats (*Ondatra zibethicus*) within small streams in an agricultural landscape.

Model	K	$\Delta AIC_c$	$\omega_i$	Log Likelihood
LHR(burrows + age class)	4	0.00	0.71	-173.72
LHR(burrows + age class + year)	5	1.91	0.38	-173.13
LHR(burrows)	3	9.02	0.01	-179.64
LHR(burrows + vegetation)	4	11.15	0.00	-179.29
LHR(age class)	3	12.82	0.00	-181.54
LHR(.)	2	14.39	0.00	-183.61
LHR(CV)	3	14.39	0.00	-183.61
LHR(locations)	3	14.45	0.00	-182.35
LHR(age class + year)	4	14.96	0.00	-181.20
LHR(year)	3	15.36	0.00	-182.81
LHR(wetted width)	3	16.45	0.00	-183.36
LHR(riparian)	3	16.72	0.00	-183.49

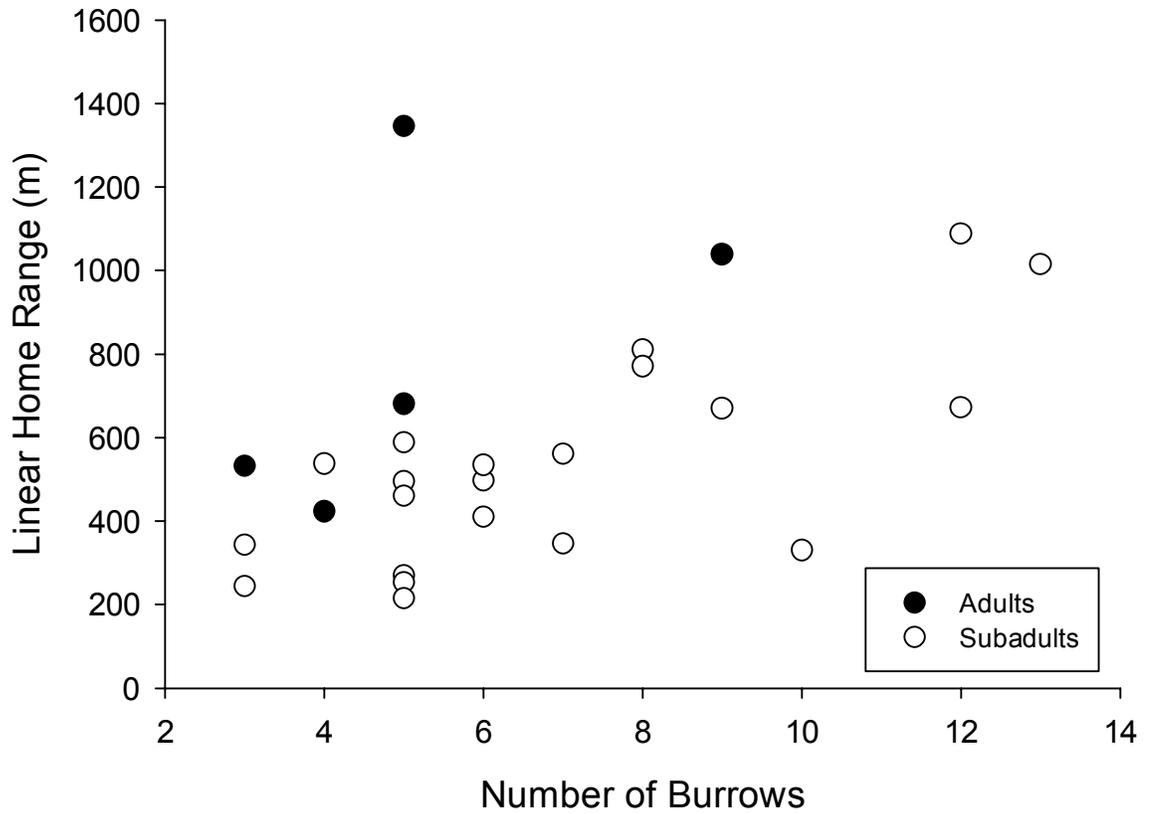
Notes: Models are ranked by ascending  $\Delta AIC_c$ ; K is number of parameters in the model including the intercept and error term,  $\omega_i$  is the model weight, and Log Likelihood is used for assessing goodness of fit. Independent variables include burrows (number of burrows within an individual's home range), age class (Adult or Juvenile), vegetation (Vegetation PCA coefficients), CV (coefficient of variation in water levels), year (2007 or 2008), wetted width (wetted width of the stream), locations (number of relocations per individual), and riparian (riparian width).



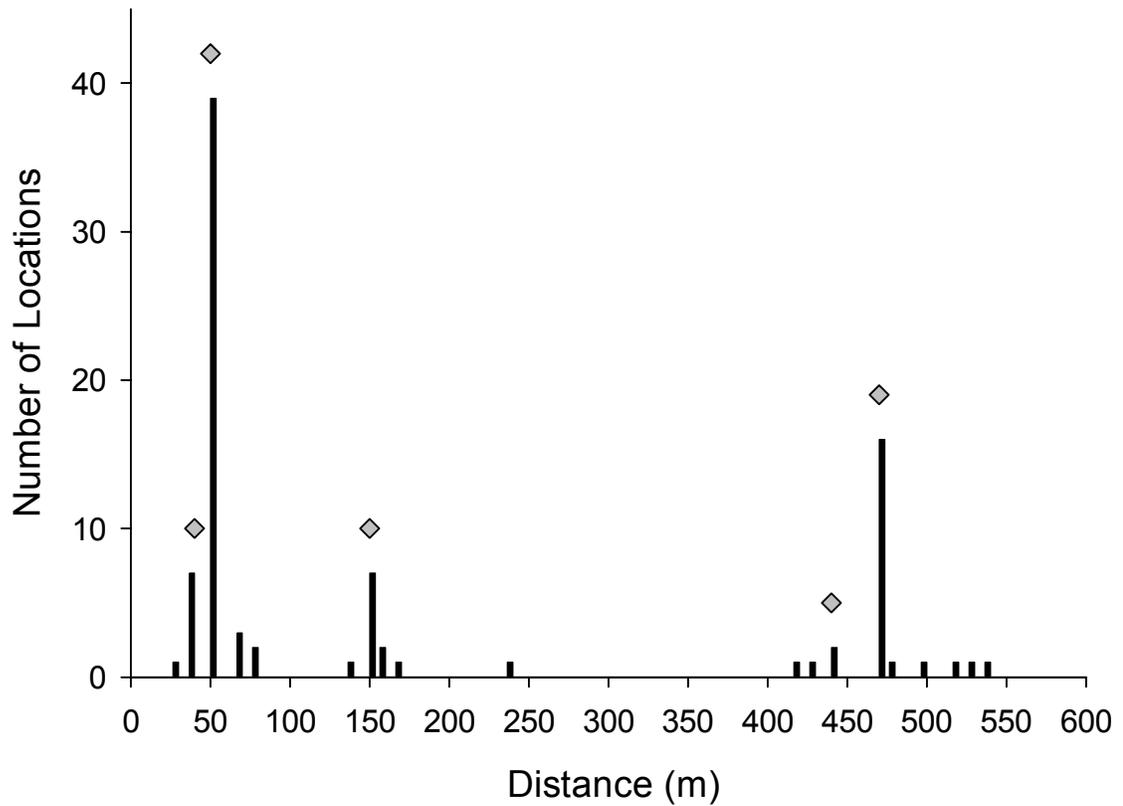
**Figure 6.** Locations of study sites for space-use analysis of riparian muskrats (*Ondatra zibethicus*) in small streams in east-central Illinois, USA. Sites are positioned within 3 distinct watersheds: Kaskaskia River (left), Embarrass River (middle), and Black Slough (right).



**Figure 7.** Locations for a radiomarked juvenile muskrat (*Ondatra zibethicus*) from the Black Slough watershed in east-central Illinois, 27 September 2008 – 28 February 2009. This stream segment had a narrow, grass riparian zone that was adjacent to row-crop agriculture.



**Figure 8.** Relationship between home-range size and number of burrows for adult and juvenile riparian muskrats (*Ondatra zibethicus*) within small streams in an agricultural landscape. Each circle represents an individual muskrat ( $n = 26$ ).



**Figure 9.** Utilization distribution representing space use within the linear home range (LHR) of an adult muskrat (*Ondatra zibethicus*) within a small headwater stream. Diamonds represent locations of established burrows within the LHR. The frequency of relocations distributed along this restricted home range indicates that space use is aggregated around established burrows.

## CHAPTER 3

### SUMMARY

Over the last century, modern farming in the Grand Prairie region, USA, has drastically altered the landscape (Urban 2005). These large-scale landscape changes have included drainage of historical wetlands and channelizing most of the regions small streams and agricultural ditches. The loss of critical wetland habitat has shifted the distribution of muskrats to highly altered riparian habitats, which can have unstable flow regimes (King et al. 2009). Although muskrats are an economically important furbearer in the region (Lischka et al. 2010), the ecological mechanisms affecting muskrat survival and spatial ecology in restricted linear habitats are relatively unclear.

Using radiotelemetry, I found that muskrats occurring in small streams and agricultural ditches were displaced from bank burrows and into adjacent upland habitat during flood events. Displacement times varied throughout the watershed, with individuals positioned farther from the headwaters (in larger drainage basins) displaced longer than those positioned closer to the headwaters (in smaller drainage basins). Although displacement times of muskrats during flooding events depended upon position within the watershed, survival was not related to landscape position. In fact, most mortalities were a result of mink predation along the stream edge during non-flooding periods. Muskrats occurring in stream segments with larger riparian buffers had higher survival rates than those positioned in stream segments with smaller riparian buffers. This effect was especially strong in the winter season. It is unclear why muskrats occurring in stream segments with larger riparian buffers had higher survival. Simberloff and Cox (1987) postulate that predators in narrower corridors should be more effective at

catching prey. In my region, riparian buffers surrounding stream segments are used by many potential muskrat predators (e.g., *Canis latrans*, *Vulpes vulpes*, *Neovison vison*; Gosselink et al. 2003, Bluett et al. 2006). Narrow riparian corridors could potentially attract foraging predators closer to the stream edge; however, more experimental research is needed to confirm this hypothesis.

My research demonstrates that muskrats occurring in highly altered small streams and agricultural ditches constrain most of their movements to stream bank edges. Riparian muskrat home ranges were linear and influenced by age class and number of burrows used per individual. Individuals with longer linear home ranges used more burrows within their home range. Adults had longer linear home ranges than did juveniles. I did not detect riparian muskrats freely moving into upland habitat (e.g., row-crop agricultural fields) to forage despite corn (*Zea mays*) and soybeans (*Glycine max*) growing  $\leq 6$  m from the stream edge in some instances. Reed canary grass (*Phalaris arundinacea*), an aggressive non-native grass species associated with dynamic flow regimes (Kercher et al. 2004), was the dominant vegetation cover at all of my sites. I observed muskrats extensively foraging on reed canary grass; however, the nutritional value of this ubiquitous grass to muskrats is unclear. Muskrats use space non-randomly within home ranges, with most movements aggregated around established burrows. My results are consistent with other studies in natural wetland habitats (MacArthur et al. 1997), indicating that muskrats are multiple central-place foragers.

Modern agricultural production has converted the Grand Prairie region from vast tall-grass prairies interspersed with seasonal wetlands to an intensively developed row-crop monoculture (Suloway & Hubel 1994, Urban 2005). Small streams and agricultural

ditches now provide most of the available habitat for semi-aquatic organisms occurring in this human-dominated landscape. My research has provided insight into how muskrats use space within these restricted linear habitats. I have also provided an example of how riparian buffers adjacent to highly altered small streams and agricultural ditches can increase the fitness of muskrats living in these habitats. Future research should elucidate how muskrat dispersal and gene flow is affected by the continuous linear structure of riparian habitat. Experimental research also is needed to link riparian width to fitness for semi-aquatic species.

Chapter 3 meets the formatting requirements for *Wildlife Biology*

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