Research Article

Habitat Use by Meso-Predators in a Corridor Environment

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Abstract

*Red foxes (*Vulpes vulpes*), raccoons (*Procyon lotor*), and striped skunks (*Mephitis mephitis*) are found throughout the United States, wherever there is suitable denning habitat and food resources. Densities of these predators have increased throughout the Intermountain West as a consequence of human alterations in habitat. Within the Bear River Migratory Bird Refuge (hereafter, refuge), in northern Utah, USA, upland nesting habitat for ducks is limited to the levee banks and roadsides. Red foxes, raccoons, and striped skunks, which prey on upland nesting birds, are also abundant on the refuge. We studied red foxes, raccoons, and striped skunks' use of levees and the edges associated with them within a wetland environment. Red fox, raccoon, and striped skunk locations were negatively correlated with distance to the nearest dike (−0.78, −0.69, and −0.45, respectively). Animals incorporated more roads and/or levees into their home ranges than expected by chance ($\bar{x} = 2.6$; $Z < 0.001$); incorporation of levees was greater during the dispersal season than the rearing season ($P = 0.03$). Skunk home ranges (average size, 3.0 km^2) were oriented along roads and levees ($P = 0.03$), whereas raccoon (average size, 3.6 km^2) and fox home ranges (average size, 3.5 km^2) were not ($P = 0.93$, $P = 0.13$, respectively). Fox home ranges in the refuge were more oblong in shape than reported elsewhere ($P = 0.03$). However, home-range shapes of raccoons and striped skunks were similar to previous studies ($P = 0.84$, $P = 0.97$, respectively). The use of roads and levees within the refuge increases the possible travel distance and penetration of predators into wetland environments. This contributes to increased depredation of waterfowl nests and to decreased recruitment. Managers of similar areas might decrease depredation of waterfowl by disrupting the linear pattern of corridors, thereby decreasing the congestion of animal roads and levees. This would, then, decrease the encounter rates of predators and prey.* (JOURNAL OF WILDLIFE MANAGEMENT 70(4):1111–1118; 2006)

Key words

Corridors, habitat use, linear habitat, predators, raccoon, red fox, striped skunk, waterfowl.

Historically, in the Intermountain West of the United States, suitable denning and foraging habitat for red foxes and raccoons was limited. Much of this region was characterized by dry, arable land, dominated by sagebrush and grasses (Foote 1989, Wagner 1995). However, human settlement of the land in the Intermountain West, especially irrigated agriculture, increased the distribution of water throughout the dry landscape. Subsequently, populations of red foxes and raccoons increased in Utah, USA, although neither species was native to the area (Durrant 1952, Zeveloff 1988, Garrettson et al. 1996).

Federal and state wildlife management agencies in Utah, USA, developed several waterfowl management areas during the early 1900s, principally around river deltas flowing into the Great Salt Lake (GSL). Often, the wetland refuges were created by developing levees to impound river water coming into the GSL. Originally created as oases for migratory birds, these wetlands have also become a haven for meso-predators, which prey upon migratory and nesting birds, their nests, and their young.

Agricultural field edges, footpaths, roads, right-of-ways, and similar openings into a habitat may serve as corridors for predators, increasing access into an environment (Askins 1994, Urdang 1995). Furthermore, such corridors may serve to attract and funnel predators into an area, thereby increasing prey exposure and risk (Kuehl and Clark 2002). Ease of travel provided by small roads or paths increases predator travel speed; thus, they can hunt more ground in less time.

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Halpin and Bissonette (1988) noted that foxes used roads and trails to travel through habitat when there was snow cover. Similarly, raccoons usually display directed foraging, moving along edges and corridors to access a hunting area (Urban 1970, Hoffman and Gottschang 1977, Ough 1979). The use of roads may be more pronounced in flooded marshes because predators may be able to move much faster, with less energy expenditure, by traveling on levees rather than wading through marshes.

Many species of waterfowl and game birds use upland areas adjacent to wetlands for nesting (Greenwood and Sovada 1996). For wetlands such as the Bear River Migratory Bird Refuge, which was created by a system of levees, upland habitat is often restricted to the levees and the roads built on top of them. These areas may also concentrate alternative prey for mammalian predators, such as small mammals and invertebrates. Thus, increased depredation of nesting birds or eggs at times may be an opportunistic response to a resource found while searching for other prey in the same area (Cowardin et al. 1983). When nesting areas consist entirely of linear strips of habitat along dirt roads and levee banks, there is an increased chance of predators locating hens and their nests while moving through the area.

Few studies on mammalian corridor use have focused on small- to medium-sized predators. Previous studies of predator–prey interactions along corridors suggest that the predator use of human trails and roads increases the depredation rate of prey (Trewhella and Harris 1990, James and Stuart-Smith 2000). Our objective was to determine how red foxes, raccoons, and striped skunks use levee roads, and the edges associated with them, within a wetland environment. We hypothesized that if red foxes, raccoons, and striped skunks were attracted to levees and dirt roads, their home range might reflect a linear shape. Additionally, their home ranges might reflect the propensity to incorporate roads into space-use patterns. If predators are using similar vegetation types as upland nesting waterfowl, as well as increasing their use of habitat via roads and levees, then there might be an increased potential for predators to impact waterfowl recruitment.

Study Area

The Bear River Migratory Bird Refuge was created in 1928 from the delta of the Bear River, near the northeastern end of the GSL, Utah, USA. The refuge, with more than 65,000 ha of wetlands, was created to increase feeding and breeding grounds for migratory birds. We conducted our study in the delta section of the refuge, which contained >26,000 ha of wetland habitat. Historically, this area supported the highest densities of nesting waterfowl before the GSL flood. This section of the refuge was created by a system of levees that control the flow of the Bear River into the GSL (Williams and Marshall 1938; Fig. 1). The topography was relatively flat, falling approximately 0.1 m/km to the south, with most elevation at 1,280 m. The area experienced moderate spring and fall seasons, with dry hot summers and short, cold winters. Summer temperatures often exceed 38°C, whereas winters sometimes fell below −23°C. The average annual precipitation ranged from 29 cm in the eastern side of the refuge to 31 cm in the western portion (A. Trout, U.S. Fish and Wildlife Service, unpublished report).

Before 1983, the delta of the refuge was the predominant nesting area for most of the duck species nesting within the refuge, and many other avian species foraged there (Williams and Marshall 1938). The average annual waterfowl production during 1953–1964 was 41,000 ducklings, 2,000 goslings, and 8,000 coots (A. F. Halloran, United States Fish and Wildlife Service, unpublished report). In 1983, the GSL flooded, covering the refuge with salt water for more than 7 years and destroying most of the dikes along with all vegetation (Foote 1989).

During the time that the refuge was under water, red foxes and raccoons, which were previously rare in the area, set up residence around the refuge. As a consequence of the flood and the arrival of these new predators, as few as 100 ducklings per year were produced during the 2000 nesting season at the refuge, as compared with historical levels of more than 79,000 in 1964 (A. F. Halloran, unpublished data). During our study, mammalian predators were identified as the main predators of duck nests at the refuge. Therefore, refuge managers believed mammals to be the primary impediment preventing waterfowl production from returning to historic levels.

Methods

Establishing Predator Locations

We trapped and radiocollared red fox, raccoon, and striped skunk from December 1999 to February 2000. We trapped foxes using neck snares, with deer stops fixed to them, and with foothold traps (Meia and Weber 1995). We trapped raccoons and skunks with box traps baited with commercial cat food (Endres and Smith 1993). To handle the trapped animals, we tranquilized each animal using 0.1 mg/kg of an acepromazine/ketamine mixture (0.01 mg acepromazine and 0.09 mg ketamine; Bigler and Hoff 1974). We then sexed, weighed, and ear-tagged trapped animals

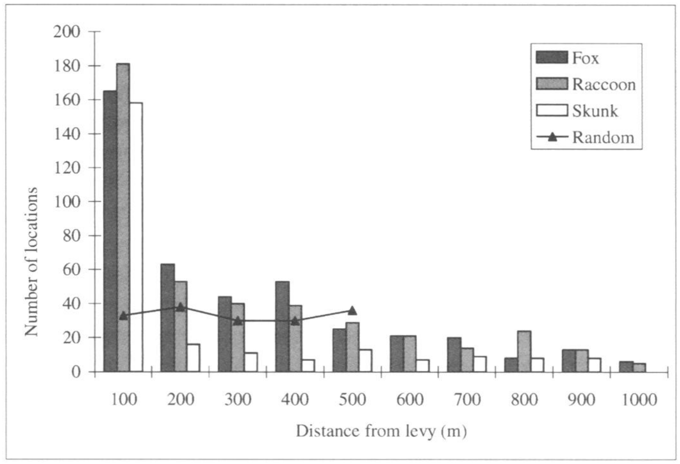

Figure 1. Number of locations of red foxes, raccoons, and striped skunks located within 1,000 m from the nearest levee or road, Bear River Migratory Bird Refuge, Utah, USA, 2000–2002.

with a numbered tag. We only fitted raccoons and foxes weighing >5 kg and skunks weighing >1.5 kg with a radiocollar (Advanced Telemetry Systems, Isanti, Minnesota) to minimize the collaring of subadults (Major and Sherbourne 1987, Gehrt and Fritzell 1998). Upon recovery from the tranquilizer, the animals were released on-site. We conducted trapping periodically to maintain a base level of 10 radiocollared animals per species.

We radiotracked animals throughout the day by dividing the day into 3 time periods: 1) 0800–dusk, 2) dusk to midnight (in winter, this time period was usually from 1800 to 2400 hours), and 3) midnight to dawn (this period was usually from 2400 to 0600 hours, extending to 0700 at the longest part of winter). During each daylight radiotracking session, we visually located animals. Upon locating the animal, we recorded its position using a handheld Global Positioning System (GPS) unit (Magellan Tracker, Thales Navigation, Inc.). During each nocturnal radiotracking session, we estimated animals' locations using triangulation (Mech 1983).

To triangulate the study animals, we drove the levees to find a frequency. Upon hearing a signal, we acquired a bearing for the animal. We then drove to another location to obtain a second bearing. We obtained 2–3 bearings for each location; 3 bearings were preferred. We obtained subsequent bearings within 10 minutes of the last bearing, to minimize the error attributed to animal movement. Bearings were also >20° and <160° apart from each other to further minimize error (Kitchen et al. 2000). There were times when travel by motor vehicles affected the movements of the radiocollared animals; therefore, we discarded locations characterized with sudden predator movements (Ellis 1964).

We analyzed triangulated bearings using the software package Locate (Pacer, Truro, Nova Scotia, Canada) to obtain an estimated location for a particular animal. Locate established an error estimate for locations determined by 3 points. We deleted all estimated locations with an associated error >100 m. In addition, we randomly placed test collars, which were collars unattached to animals, in the refuge so that estimation error for each technician could be established. Each technician triangulated test collars twice a year to maintain a level of integrity through minimal triangulation error.

Linear Aspects of Use

Correlation with levees and roads.—We investigated the relationship between the number of animals found and the distance from the nearest levy. To avoid any bias created by telemetry error, we only analyzed the locations of red foxes, raccoons, and striped skunks that we found visually during the day. Visual observations were exact locations, whereas we estimated the majority of nighttime locations using triangulation. We established visual locations by using radiotelemetry to find the approximate location of the animal within the refuge. Once we detected a radiosignal, we walked or canoed toward the origin of the signal until we acquired a visual sighting of the target animal. We used a handheld GPS to record the animal's location at the time that it was sighted. Often, we found animals while they were sleeping or in dens. However, sometimes we spotted an animal as it arose from its resting spot. When this occurred, we walked to where the animal was when we first sighted it, and we took the GPS location from that spot. However, sometimes when trying to obtain a visual location, it became apparent, through the bearing estimates, that the target animal was moving, although we couldn't see it. In those circumstances, we did not record a visual location, and we did not use that data in analysis of location to the nearest road.

Once we collected the locations, we examined the distance of each animal's location to the nearest levee of the refuge, using GIS/ArcInfo (ESRI, Redlands, California). First, we calculated the distance from each visually sighted location to the nearest road, regardless of the road's condition or use. Then, we grouped those distances into 10-m intervals, up to 1,000 m from the nearest road, and we calculated the number of locations in each interval. We chose 10 m as the distance interval because that was the average width of a levee and its banks; thus, distances of 0–10 m from a road would indicate animals located on a levee. Next, we conducted a nonparametric correlation test of interval data, using Pearson Correlation Coefficients in Statistical Analysis Software (Version 8, SAS Institute, Cary, North Carolina) to determine the relationship between the number of locations found in each interval and the distance from the nearest levee. We hypothesized that the number of animals in each interval would decrease as the distance from the nearest levee increased.

If there was a correlation between the roads and locations, it could have been an effect of the distribution of roads. Therefore, using a random-number generator, we created a subset of 500 locations to compare with the distribution of actual locations. Following the same procedure for fox, raccoon, and skunk locations, we calculated the number of random locations within each 10-m interval. Then, we executed a Pearson Correlation Coefficients test to determine this subset's relationship with distance from the nearest levee. Finally, we compared the random location data set with the locations of red foxes, raccoons, and striped skunks in the refuge, using a Mann–Whitney U test for nonparametric statistics.

Incorporation of roads into home ranges.—The number of roads incorporated into an individual's home range may reflect the extent to which predators prefer home ranges that contain roads. To determine that, we compared the observed number of roads and levees within an animal's home range on the refuge to the expected number of roads. Using ArcView (ESRI), we estimated a home range area for each study animal (95% minimum convex polygon) for the rearing and dispersal season. We defined the rearing season as March 15–July 15; the dispersal season lasted from July 15–November 15 (Kitchen et al. 2000). For each home range, we determined the number, length (km), and location of roads that were used within a home range. To estimate expected use, we randomly placed 10 polygons onto a map of the refuge and its roads, and we calculated the length of levees overlapped by each polygon. Each polygon represented a home range of 3.5 km^2, which is the average size of a fox and raccoon home range within the refuge (Frey 2004), to the scale of the map of the refuge. Next, we conducted a signed-rank, nonparametric t-test, comparing the relationship of the levees (no. of roads used, total kilometers of roads, location of home range) in the randomly created home ranges to those of the observed home ranges. We repeated this process 10 times for comparison.

Orientation of home ranges.—We also evaluated the importance of the location of a road or trail within each home range. Roads and trails may be randomly incorporated into the home ranges, or animals may orient their home ranges around roads. For each home range, we determined the largest axis, which was the longest straight line that could be drawn through the home range. Then, we measured the angle created by the crossing of this axis with the nearest road. In the event that >1 road was incorporated into a home range, we used the measurement for the intersection of the axis with the longest road within the home range. If home ranges were randomly oriented in the habitat relative to roads, then the mean angle between this created axis and the road incorporated in the home range should be 45°, with a range from 0° (parallel) to 90° (perpendicular). If home ranges were oriented along roads, the mean angle between the axis and the incorporated road would be similar to 0°; home ranges arranged perpendicular to roads would have a mean angle similar to 90°. Therefore, we conducted a signed-rank nonparametric t-test to determine whether home-range axes were randomly oriented around roads and trails ($\bar{x} = 45°$), oriented along roads ($\bar{x} < 45°$) or oriented away from roads ($\bar{x} > 45°$).

Shape of home range.—If the study animals frequently used roads and areas near them, their home ranges should reflect that. If a predator makes extensive use of levees and roads, its home range should be linearly shaped. To determine whether animals within the refuge were using roads extensively, we measured the length-to-width ratio of each red fox, raccoon, and striped skunk home range (95% minimum convex polygon). A circular or square home-range shape would have a ratio close to 1. The more linear the shape of the home range, the larger the length-to-width ratio would be. To compare the findings of the home-range shape of the refuge to other regions of the world, we examined literature concerning home ranges, territories, and habitat use for foxes, raccoons, and striped skunks (Table 1). We used only articles with figures of home ranges for analysis. For each figure, we measured the length and width of the printed home range, in millimeters. Then, we created a length-to-width ratio from those measurements, for comparison.

Table 1. Published literature used to establish mean length-to-width ratios for home-range shape-comparisons of red foxes, raccoons, and striped skunks.

Species	Reference	$\bar{x}$ ratio	Region	Setting	n[a]
Raccoon	Fritzell (1978)	1.46	N.D.	Rural	8
Raccoon	Gehrt and Fritzell (1998)	1.66	Tex.	Rural	3
Raccoon	Jordan (1986)	1.36	Md.	Rural	11
Raccoon	Slate (1985)	2.29	N.J.	Suburban	19
Red fox	Adkins and Scott (1998)	2.13	Toronto, Canada	Suburban	4
Red fox	Coman et al. (1991)	2.00	Victoria, Australia	Rural	4
Red fox	Harris (1980)	1.50	Bristol, United Kingdom	Urban	8
Red fox	Hough (1980)	1.42	Oxford, United Kingdom	Urban	4
Red fox	Jones and Theberge (1982)	3.00	B.C., Canada	Rural	4
Red fox	Klett (1978)	2.22	La.	Rural	4
Red fox	MacDonald and Newdick (1980)	2.14	Oxford, United Kingdom	Urban	10
Red fox	Meek and Saunders (2000)	2.47	N.S.W., Australia	Suburban	5
Red fox	Meia and Weber (1995)	1.63	Switzerland	Rural	4
Red fox	Pandolfi et al. (1997)	1.85	Italy	Rural	5
Red fox	Phillips and Catling (1991)	1.87	SE Australia	Rural	5
Red fox	Poulle et al. (1994)	1.55	France	Rural	5
Red fox	Sargeant (1972)	1.56	Minn.	Rural	3
Red fox	Saunders et al. (2002)	1.72	N.S.W., Australia	Rural	8
Red fox	Schloeder (1988)	1.42	W.Va.	Rural	3
Red fox	Sunquist (1989)	1.80	Fla.	Rural	4
Red fox	Travaini et al. (1993)	1.31	Spain	Rural	7
Red fox	Tsukada (1997)	1.75	Japan	Rural	6
Red fox	White et al. (1996)	1.71	Bristol, United Kingdom	Urban	5
Striped skunk	Bixler and Gittleman (2000)	3.54	Tenn.	Rural	12
Striped skunk	Lariviere and Messier (1998)	1.78	Sask., Canada	Rural	18

[a] Abbreviation: n, number of home ranges.

Using past studies, we measured 98 red fox home ranges in 16 regions of the world in urban, suburban, and rural settings. Additionally, we measured the shapes of 41 raccoon home ranges, from 5 regions in North America, in rural and suburban settings. Published literature of striped skunk home ranges was scarcer; therefore, we used only 30 home ranges from 2 studies, in 2 regions of North America. Both were in rural settings (Table 1).

Next, we conducted an ANOVA using Statistical Analysis Software (SAS) to compare the length-to-width ratios of home ranges for each species from our study with those calculated from the literature; this allowed us to determine whether the shapes of the home ranges of our study animals differed from those reported in past studies.

Results

Linear Aspects of Use

Distance from levee or road.—For each species, we found most locations within 1,000 m of the nearest levee. There were 418 raccoon locations (99.5% of all day locations) within 1,000 m of the nearest levee. There was a strong inverse correlation between the distance from the nearest levee and the number of raccoon locations. In other words, we counted fewer animals as the distance interval increased ($r = -0.69$, $P < 0.001$; Figs. 1, 2). We found similar results for red foxes. We recorded 418 locations (100%) for foxes within 1,000 m of the nearest levee. Fewer fox locations occurred as the distance from the levee increased ($r = -0.78$, $P < 0.001$; Figs. 1, 2). We recorded 237 locations (100%) for skunks within 1,000 m of the nearest levee. We found fewer skunk locations as the distance from a levee increased ($r = -0.45$, $P < 0.0001$; Figs. 1, 2).

In contrast, there was no correlation to the number of random locations found within each distance interval ($r = -0.19$, $P = 0.54$; Figs. 1, 2). Random points were distributed differently than actual red fox (df = 1, $U = 2{,}945$, $P = 0.004$), raccoon (df = 1, $U = 2{,}793$, $P = 0.06$), and skunk (df = 1, $U = 3{,}090$, $P = 0.001$) locations.

Incorporation of roads.—Within the refuge, actual home ranges incorporated an average of 2.5 roads, whereas mean expected home range incorporated 1.3 roads. The difference between actual and randomly located home ranges was significant ($\chi^2 = 38.32$, df = 7, $P < 0.001$). Red fox, raccoon, and striped skunk home ranges incorporated a similar number of roads within their home ranges ($F = 0.40$, df = 2, $P = 0.68$; Fig. 3). The study animals incorporated more roads within home ranges during the dispersal season than in the rearing season ($F = 5.30$, df = 1, $P = 0.03$; Fig. 3).

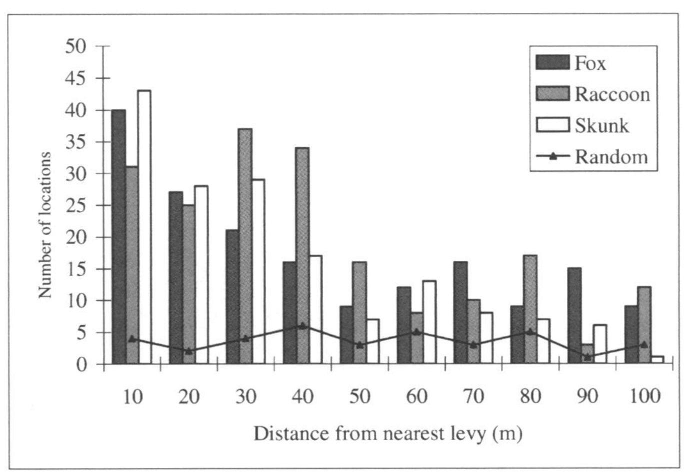

Figure 2. Number of locations of red foxes, raccoons, and striped skunks located within 100 m of the nearest levee or road, Bear River Migratory Bird Refuge, Utah, USA, 2000–2002.

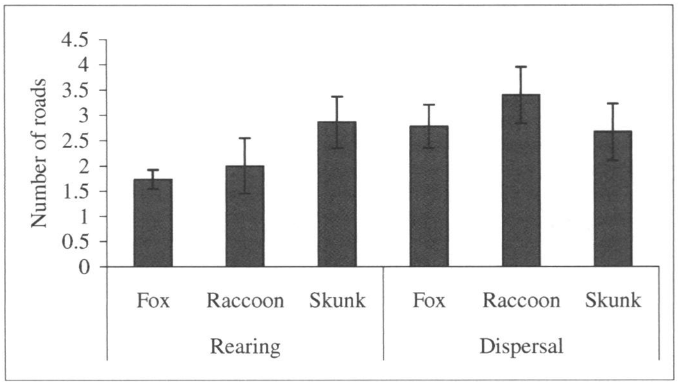

Figure 3. Mean number of roads contained within home ranges by red foxes, raccoons, and striped skunks on Bear River Migratory Bird Refuge, Utah, USA, 2000–2002.

Red fox home ranges incorporated 3.5 km of roads during the dispersal season and 3.4 km of roads during the rearing season (Table 2, Fig. 4). Raccoon home ranges incorporated an average of 7.1 km of roads during the dispersal season and 3.3 km during the rearing season (Table 2, Fig. 5). Additionally, skunks had, in their home ranges, an average of 5.2 km of roads during the dispersal season and 3.2 km during the rearing season (Table 2, Fig. 6). The length (km) of roads incorporated into the home ranges of each species was similar ($F = 0.51$, df $= 2$, $P = 0.61$). Study animals incorporated more kilometers of roads into home ranges during the dispersal season than the rearing season ($F = 6.28$, df $= 1$, $P = 0.02$). Study animals' home ranges in the refuge incorporated more kilometers of roads than home ranges that were randomly placed in the refuge ($t = 4{,}893$, $P < 0.001$). Home ranges were not oriented along roads for foxes ($\bar{x} = 33.7°$, $S = -4$, $P = 0.89$), raccoons ($\bar{x} = 44.5°$, $S = -7$, $P = 0.85$), or skunks ($\bar{x} = 23.3°$, $S = -14.5$, $P = 0.34$).

Shape of home ranges.—Red fox and raccoon home ranges on the refuge had length-to-width ratios of 2.1 and 1.8, respectively (Table 3). Home ranges of red foxes and raccoons calculated from past studies had mean length-to-width ratio of 1.8 and 1.7, respectively (Table 3). Skunk home ranges in the refuge had mean length-to-width ratios of 2.5 (Table 3). Skunk home ranges figured in past studies had a mean length-to-width ratio of 2.5 (Table 3). The length-to-width ratios of red fox home ranges in the refuge were greater than those figured in previous studies ($t = 2.34$, df $= 32$, $P = 0.03$). However, home range length-to-width ratios of raccoons and skunks in the refuge were similar to those figured in previous studies ($t = -0.21$, df $= 65$, $P = 0.84$; $t = 0.04$, df $= 20$, $P = 0.97$; respectively).

Table 2. Mean kilometers of roads incorporated into raccoon, red fox, striped skunk home ranges, by season, compared with the expected value, Bear River Migratory Bird Refuge, Utah, USA, 2000–2002.

Factor	Season	*n* polygons	$\bar{x}$	SE
Raccoon	Rearing	12	3.3	1.1
	Dispersal	12	7.1	1.4
Red fox	Rearing	11	3.4	0.5
	Dispersal	8	3.5	0.5
Striped skunk	Rearing	7	3.2	0.7
	Dispersal	5	5.2	2.2
Expected	—	90	2.3	0.2

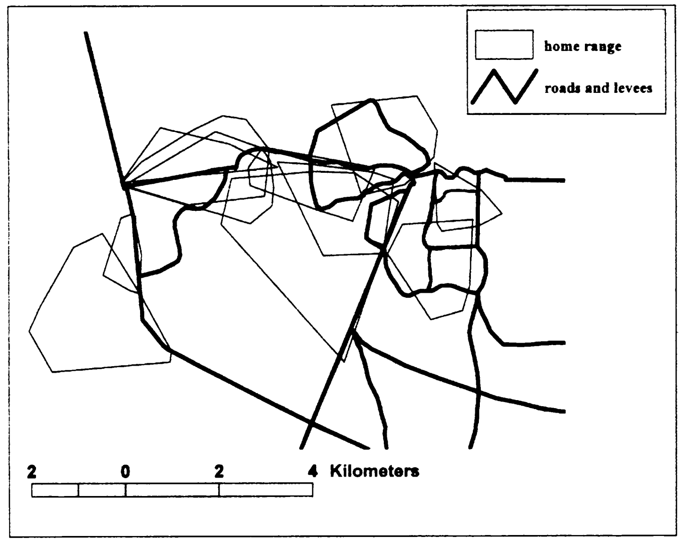

Figure 4. Location of fox home ranges (95% minimum convex polygon) during the rearing season in relation to the roads and levees present on Bear River Migratory Bird Refuge, Utah, USA, 2000–2002.

Discussion

Use of Levees and Roads

Red foxes, raccoons, and striped skunks concentrated their day activities to the levees of the refuge. Additionally, roads were also a focus of these predators' activities, as evidenced by the presence of the roads in the animals' home ranges. During periods of high water, red foxes and striped skunks probably relied on the dense vegetation found along the levees for dry, sheltered resting sites. Because of their ability to travel through shallow water and forage for aquatic invertebrates and fish (Dorney 1954, Urban 1970),

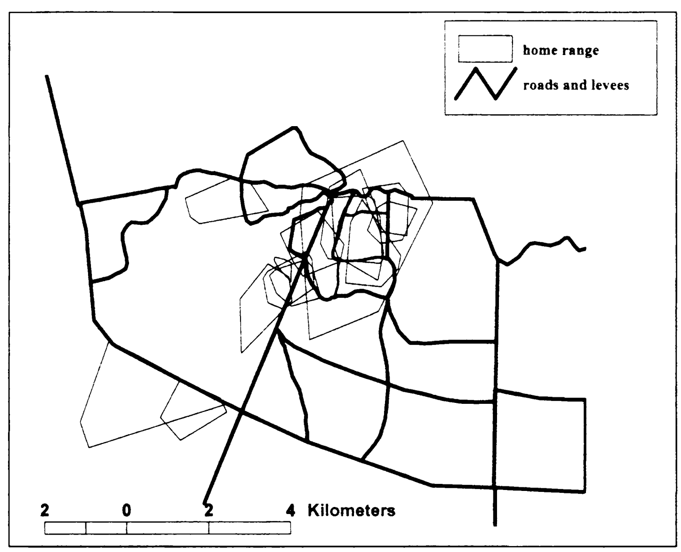

Figure 5. Location of raccoon home ranges (95% minimum convex polygon) during the rearing season in relation to the roads and levees present on Bear River Migratory Bird Refuge, Utah, USA, 2000–2002.

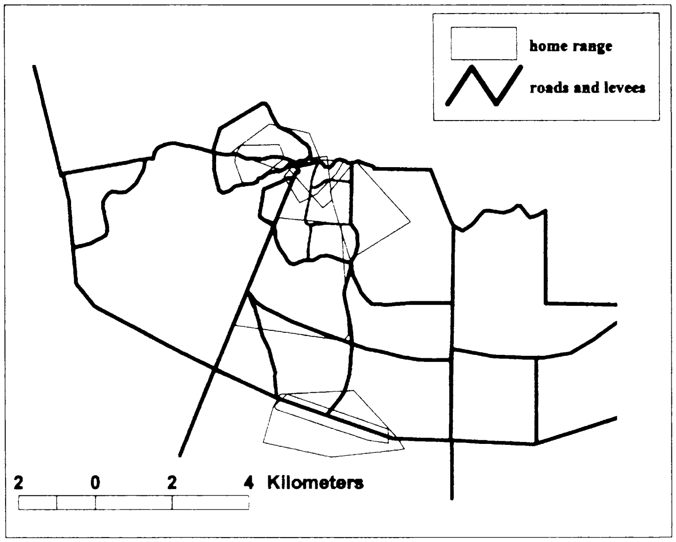

Figure 6. Location of striped skunk home ranges (95% minimum convex polygon) during the rearing season in relation to the roads and levees present on Bear River Migratory Bird Refuge, Utah, USA, 2000–2002.

raccoons were probably less dependent on the levees during the high-water periods. Instead, they could spend the day resting on matted rushes within emergent vegetation. During low-water periods, the majority of vegetation was found along the banks and wet meadows, possibly contributing to the linearity of day locations and home-range shapes.

Our results only took into account day locations; however, our study animals were active in the crepuscular and nocturnal time periods. Whereas these animals are also known to have limited movements during the day, it can be said that day locations classified as resting periods for our study animals. Although we could not definitively determine how linear the home ranges would be during the night, without incorporating a large error bias, we could make some inferences.

Even during times of low water, such as during summer months, the levees contained more suitable vegetative cover for nesting ducks than other sections of the refuge, and most ducks selected the levees as resting sites (Williams and Marshall 1938). Frey (1994) determined that red foxes, raccoons, and striped skunks were attracted to areas with emergent vegetation (found predominantly along the levee banks), presumably via their search for food. Thus, waterfowl nesting along the dikes increased the foraging opportunities for predators there. Additionally, wetland edges provided a diverse array of prey items (Greenwood et al. 1999), which may have increased the attractiveness of this habitat for striped skunks (Phillips et al. 2003). The shallow water along the edges of the levees also provided the opportunity for raccoons to capture carp and, consequently, would be an area for scavenging by skunks and red foxes. Therefore, it is logical to determine that these predators were continuing to use the areas close to the levee banks even after they awoke.

Table 3. Comparison of home range length-to-width ratios of red foxes, raccoons, and striped skunks from past studies to Bear River Migratory Bird Refuge, Utah, USA, 2000–2002.

	Data set					
	BRMBR[a]			Literature		
Species	n[a]	$\bar{x}$ ratio	SE	n	$\bar{x}$ ratio	SE
Raccoon	26	1.8	0.11	41	1.8	0.15
Red fox	23	2.1	0.17	53	1.7	0.08
Striped skunk	12	2.5	0.63	30	2.5	0.4

[a] Abbreviations: BRMBR, Bear River Migratory Bird Refuge; n, number of independent home-range polygons.

The levee banks were also the only source of upland habitat available for den sites within the refuge. During late spring–early summer, when mothers were denning and before young animals left the dens, parental red foxes, raccoons, and striped skunks would necessarily be restricted to the levee banks during the day. This may have impacted our results slightly. The effect of denning was limited by the fact that we collected data year-round, not just during the rearing season. Additionally, only a fraction of our study animals (females of each species and male foxes) were involved in rearing young. Those animals not responsible for rearing young would not necessarily be limited to the levee banks during the birthing and early rearing periods.

The use of these roads and trails while foraging may have increased the distance traveled and the amount of hunting ground covered by predators in a night. That increased the opportunity for predators to locate and depredate foraging and nesting waterfowl and shorebirds. Phillips et al. (2003) suggested that patches of habitat that were repeatedly selected by predators are likely to be efficiently searched, with high levels of depredation in those specific areas. If foxes, raccoons, and skunks on the refuge were searching the habitat along the roads and trails within their home range on a daily basis, the result may be an increased likelihood that any nest located there would be found by at least one predator.

Home-Range Shape

Theoretically, a circular home range or one with a length-to-width ratio of 1 would be the most energetically efficient shape in terms of reaching the most area with the least movement (Ables 1969). This is assuming that resources were evenly distributed across the landscape and that the predator started foraging from the center of its home range each evening. We hypothesized that in linear environments, such as the refuge, resources were not distributed evenly, and predators would have a linearly shaped home range rather than circular. However, we found that length-to-width ratios for raccoons and striped skunks were similar to those reported elsewhere and not linear. Yet, red foxes had higher length-to-width ratios on the refuge than home ranges reported elsewhere. This may have occurred because red foxes used the refuges roads for travel more than the other 2 predator species.

Predator uses of levees and roads have implications for the success of nesting birds in managed wetlands. Historically, nesting waterfowl in the refuge used vegetation cover on the banks of the levees as nesting habitat (Williams and Marshall 1938, Crabtree 1983). However, at the time of our study, raccoons, striped skunks, and red foxes were making extensive use of the same habitat as nesting waterfowl. Few duck nests located on the refuge's levees could complete nest incubation without being located by a predator. Hence, there was little duck production in the refuge during the years of our study because of high rates of nest predation.

Management Implications

We recommend that methods to create a spatial separation between the levee habitat used by predators and the habitat used by waterfowl would be beneficial to the management of this refuge and similar habitats. Essentially, managers might try to disrupt the linear nature of the refuge to reduce the ease of travel and congestion of activity in these areas. Additionally, we recommend that managers interested in increasing waterfowl recruitment in corridor environments consider methods to control predator numbers during the waterfowl-nesting season when the use of the dikes by both predators and prey are greatest.

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Literature Cited

Ables, E. D. 1969. Home range studies of red foxes. Journal of Mammalogy 50:108–122.

Adkins, C. A., and P. Stott. 1998. Home ranges, movements and habitat associations of red foxes, *Vulpes vulpes*, in suburban Toronto, Ontario, Canada. Journal of Zoology (London) 244:335–346.

Askins, R. A. 1994. Open corridors in a heavily forested landscape: impact on shrubland and forest-interior birds. Wildlife Society Bulletin 22:339–347.

Coman, B. J., J. Robinson, and C. Beaumont. 1991. Home range, dispersal and density of red foxes (*Vulpes vulpes*) in Central Victoria. Wildlife Research 18:215–223.

Cowardin, L. M., A. B. Sargeant, and H. F. Duebbert. 1983. Problems and potentials for prairie ducks. The Naturalist 34(4):4–11.

Crabtree, R. L., L. S. Broome, and M. L. Wolfe. 1983. Effects of habitat characteristics on gadwall nest predation and nest-site selection. Journal of Wildlife Management 53:129–137.

Dorney, R. S. 1954. Ecology of marsh raccoons. Journal of Wildlife Management 2:217–225.

Durrant, S. D. 1952. Mammals of Utah, taxonomy and distribution. University of Kansas, Lawrence, USA.

Ellis, R. J. 1964. Tracking raccoons by radio. Journal of Wildlife Management 28:363–368.

Endres, K. M., and W. P. Smith. 1993. Influence of age, sex, season and availability on den selection by raccoons within the Central Basin of Tennessee. American Midland Naturalist 129:116–131.

Foote, A. L. 1989. Response of nesting waterfowl to flooding in Great Salt Lake wetlands. Great Basin Naturalist 4:614–617.

Frey, S. N. 2004. Habitat use and movements of predators on a managed waterfowl refuge. Dissertation, Utah State University, Logan, USA.

Fritzell, E. K. 1978. Habitat use by prairie raccoons during the waterfowl breeding season. Journal of Wildlife Management 42:118–127.

Garrettson, P. R., F. C. Rohwer, J. M. Zimmer, B. J. Mense, and N. Dion. 1996. Effect of mammalian predator removal on waterfowl and non-game birds in North Dakota. Transactions of the North American Wildlife and Natural Resource Conference 61:94–101.

Gehrt, S., and E. K. Fritzell. 1998. Resource distribution, female home range dispersion and male spatial interactions: group structure in a solitary carnivore. Animal Behaviour 55:1211–1227.

Greenwood, R. J., A. B. Sargeant, J. L. Piehl, D. A. Buhl, and B. A. Hanson. 1999. Foods and foraging of prairie skunks during the avian nesting season. Wildlife Society Bulletin 27:823–832.

Greenwood, R. J., and M. A. Sovada. 1996. Prairie duck populations and predation management. Transactions of the North American Wildlife and Natural Resources Conference 61:31–42.

Halpin, M. A., and J. A. Bissonnette. 1988. Influence of snow depth on prey availability and habitat use by red fox. Canadian Journal of Zoology 66:587–592.

Harris, S. 1980. Home ranges and patterns of distribution of foxes (*Vulpes vulpes*) in an urban area, as revealed by radiotracking. Pages 685–690 *in* C. J. Amlaner and D. W. MacDonald, editors. A handbook on biotelemetry and radiotracking. Pergamon, Oxford, England.

Hoffman, C. O., and J. L. Gottschang. 1977. Numbers, distribution, and movements of a raccoon population in a suburban residential community. Journal of Mammalogy 58:623–636.

Hough, N. G. 1980. The ranging behavior of a maturing female red fox, *Vulpes vulpes*. Pages 691–696 *in* C. J. Amlaner and D. W. MacDonald, editors. A handbook on biotelemetry and radiotracking. Pergamon, Oxford, England.

James, A. R. C., and A. K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. Journal of Wildlife Management 64:154–159.

Jones, D. M., and J. B. Theberge. 1982. Summer home range and habitat utilization of the red fox (*Vulpes vulpes*) in a tundra habitat, northwest British Columbia. Canadian Journal of Zoology 60:807–812.

Jordan, R. A. 1986. Raccoon use of farmland habitats on Remington Farms. Thesis, West Virginia University, Morgantown, USA.

Kitchen, A. M., E. M. Gese, and E. R. Schauster. 2000. Long-term spatial stability of coyote (*Canis latrans*) home ranges in southeastern Colorado. Canadian Journal of Zoology 78:458–464.

Klett, S. B. 1978. Home ranges, movement patterns, habitat use and interspecific interactions of red foxes and coyotes in northwest Louisiana. Thesis, Colorado State University, Ft. Collins, USA.

Kuehl, A. K., and W. R. Clark. 2002. Predator activity related to landscape features in northern Iowa. Journal of Wildlife Management 66:1224–1234.

Lariviere, S., and F. Messier. 1998. Spatial organization of a prairie striped skunk population during the waterfowl nesting season. Journal of Wildlife Management 62:199–204.

MacDonald, D. W., and M. T. Newdick. 1980. The distribution and ecology of foxes (*Vulpes vulpes*) in urban areas. Urban Ecology 2:123–135.

Major, J. T., and J. A. Sherbourne. 1987. Interspecific relationships among coyotes, bobcats, and red fox in western Maine. Journal of Wildlife Management 51:606–616.

Mech, L. D. 1983. Handbook of animal radio-tracking. University of Minnesota, Minneapolis, USA.

Meek, P. D., and G. Saunders. 2000. Home range and movement of foxes (*Vulpes vulpes*) in coastal New South Wales, Australia. Wildlife Research 27: 663–668.

Meia, J. S., and J. M. Weber. 1995. Home ranges and movements of red foxes in central Europe: stability despite environmental changes. Canadian Journal of Zoology 73:1960–1966.

Ough, W. D. 1979. Influence of probability and magnitude of reward upon raccoon foraging behavior. Thesis, University of Nebraska, Lincoln, USA.

Pandolfi, M., P. Forconi, and L. Montecchiari. 1997. Spatial behaviour of the red fox (*Vulpes vulpes*) in a rural area of central Italy. Italian Journal of Zoology 64:351–358.

Phillips, M., and P. C. Catling. 1991. Home range and activity patterns of red foxes in Nadgee Nature Reserve. Wildlife Research 18:677–686.

Phillips, M. L., W. R. Clark, M. A. Sovada, D. J. Horn, R. R. Rolf, and R. J. Greenwood. 2003. Predator selection of prairie landscape features and its relation to duck nest success. Journal of Wildlife Management 67:104–114.

Poulle, M. L., M. Artois, and J. J. Roeder. 1994. Dynamics of spatial relationships among members of a fox group (*Vulpes vulpes*). Journal of Zoology, London 233:93–106.

Sargeant, A. J. 1972. Red fox spatial characteristics in relation to waterfowl predation. Journal of Wildlife Management 36:225–236.

Saunders, G., J. McIlroy, M. Berghout, B. Kay, E. Gifford, R. Perry, and R. Van deVan. 2002. The effects of induced sterility on the territorial behaviour and survival of foxes. Journal of Applied Ecology 39:56–66.

Schloeder, C. A. 1988. Home ranges, habitat selection, and activity patterns of gray and red foxes in West Virginia. Thesis, West Virginia University, Morgantown, USA.

Slate, D. 1985. Movement, activity, and home range patterns among members of a high-density suburban raccoon population. Dissertation, Rutgers University, New Brunswick, New Jersey, USA.

Sunquist, M. E. 1989. Comparison of spatial and temporal activity of red foxes and gray foxes in north-central Florida. Florida Field Naturalist 17:11–18.

Travaini, A., J. J. Aldama, R. Laffitte, and M. Delibes. 1993. Home range and activity patterns of red fox, *Vulpes vulpes*, breeding females. Acta Theriologica 38:427–434.

Trewhella, W. J., and S. Harris. 1990. The effects of railway lines on urban fox numbers and dispersal movements. Journal of Zoology 221:321–326.

Tsukada, H. 1997. A division between foraging range and territory related to food distribution in the red fox. Journal of Ethology 15:27–37.

Urban, D. 1970. Raccoon populations, movement patterns, and predation on a managed waterfowl marsh. Journal of Wildlife Management 34:372–382.

Urdang, L. 1995. The American century dictionary. L. Urdang, editor. Oxford University, New York, New York, USA.

Wagner, F. H. 1995. Ecosystem management of natural resources in the Intermountain West. Utah State University, Logan, USA.

White, P. C. L., G. Saunders, and S. Harris. 1996. Spatio-temporal patterns of home range use by foxes (*Vulpes vulpes*) in urban environments. Journal of Animal Ecology 65:121–125.

Williams, C. S., and W. H. Marshall. 1938. Duck nesting studies, Bear River Migratory Bird Refuge, Utah. Journal of Wildlife Management 2:29–45.

Zeveloff, S. I. 1988. Mammals of the Intermountain West. University of Utah, Salt Lake City, USA.

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