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Stable Isotope Analysis Of Two Mephitidae Species Reflects Population Trends And Landscape Structure

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STABLE ISOTOPE ANALYSIS OF TWO MEPHITIDAE SPECIES REFLECTS POPULATION TRENDS AND LANDSCAPE STRUCTURE

being

A Thesis Presented to the Graduate Faculty
of the Fort Hays State University
in Partial Fulfillment of the Requirements for
the Degree of Master of Science

by

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This thesis for

the Master of Science Degree

by

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PREFACE

This thesis has been written in five chapters. Chapters one through three of this thesis have been written to conform to the guidelines of the Prairie Naturalist. Chapters four and five have been written to conform to the guidelines set by the Journal of Mammalogy.

ABSTRACT

The eastern spotted skunk (*Spilogale putorius*) is a small omnivorous Carnivora similar in much of its natural history to the commonly found striped skunk (*Mephitis mephitis*). *Spilogale putorius* has experienced drastic population declines over a large portion of its geographic range. Many hypotheses for the decline of *S. putorius* have been proposed. $\delta^{13}C$ and $\delta^{15}N$ isotope analysis provides a unique opportunity to examine diet over an expanded time span. Thus was used on hair sampled from natural history collections, teaching collections, and road kills to examine dietary change for both *S. putorius* and *M. mephitis* from 1852 to 2012.

Because stable isotope values of hair reflect the diet at the time the hair was grown, knowledge of molting patters is necessary when using hair in stable isotope studies. I determined molting patterns in *S. putorius* were similar to *M. mephitis.* When compared to *M. mephitis* molting patterns in *S. putorius* were delayed by approximately a month.

Long-term farm and crop trends have not been examined in Kansas. I examined trends in average farm size, percent of land in farms, number of farms, number of irrigated farms, hectares of woodland, and hectares of17 different crops across Kansas from 1880 to 2007. Trends were observed in most crop types and provided support for a slow transition from small diversely planted farms to large scale monoculture in Kansas.

I analyzed Kansas fur harvest trends for *M. mephitis* and *S. putorius* and detected corresponding declines in Kansas for both species. These declines were correlated with a reduction of maize in the landscape and agricultural intensification.

Studies indicate the presence of melanin in colored feathers affects the $\delta^{13}C$ and $\delta^{15}N$ values of feather samples. I examined the effect of melanin on $\delta^{13}C$ and $\delta^{15}N$ values of hair from 8 mammal species but detected no effect.

The effects of preservation techniques on $\delta^{13}C$ and $\delta^{15}N$ values of mammalian samples are also not well understood. I examined the effect of tanning as a preparation technique on $\delta^{13}C$ and $\delta^{15}N$ values of *M. mephitis.* Tanned hides were depleted in both stable isotopes compared to non-tanned hides.

Diet of *S. putorius* and *M. mephitis* was related to landscape structure. Maize composed the highest proportion of the diet for both *S. putorius* and *M. mephitis* and has experienced change in the diet of *S. putorius* over time. In addition, increased $\delta^{15}N$ variability was observed over time in these species, potentially suggesting decline of or exclusion from historical diet sources.

This research provided useful insights into the effects of landscape structure on a declining mesocarnivore, and provided additional support for dietary change as a contributing factor to the decline of *S. putorius*. When combined, these data potentially provide evidence for a decline in *S. putorius* based in part on a reduction in the amount of maize in the landscape and agricultural intensification.

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Matt Peak at the Kansas Department of Wildlife, Parks, and Tourism was instrumental in obtaining fur harvest data, and I thank him for taking the time to locate the many datasets I requested. I also am grateful to Dr. Ray Lee, Washington State University, for processing my samples and for his quick advice and aid on stable isotope theory and processing.

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Natural History, Hays, Kansas, the Texas Cooperative Wildlife Collection, College Station, Texas, the University of Kansas mammalogy collection, Lawrence, Kansas, the University of Kansas Natural History Museum, Lawrence, Kansas, and the University of Michigan Museum of Zoology, Ann Arbor, Michigan, who made this research possible by allowing access and permission to sample their specimens. I also thank Dr. John Greathouse of the Fort Hays State University Department of Agriculture for access to the University Farm.

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CHAPTER 1

MOLTING PATTERNS OF THE EASTERN SPOTTED SKUNK

Molting of hair fulfills several functions in mammals. Perhaps the foremost role of hair is thermoregulation. Many mammals shed underfur prior to summer, thus reducing the amount of insulation provided and aiding heat dissipation (Ling 1970). Underfur is often replaced in the fall, prior to the onset of winter, which functions to increase the amount of insulation but also replaces hair that has experienced natural wear and might not be as effective for thermoregulation (Ling 1970).

However, regrowth of lost tissues (e.g., hair) is metabolically costly and has been hypothesized to decrease body condition if it occurs during times of food scarcity (Stewart and Macdonald 1997). This is of particular concern to survival in mammals when tissue regrowth occurs in the fall, prior to onset of winter and hibernation (Neuhaus 2000). Evidence for the metabolic cost of molting is inferred from studies that demonstrate timing of molt coincides with food abundance and avoids concurrence with other metabolically costly activities such as reproduction (Ling 1970; Neuhaus 2000; Speth 1969; Stewart and Macdonald 1997; Xin 2003).

Stable isotope analysis increasingly uses hair to characterize diet, migration, and dispersal of cryptic and rare species (Codron et al. 2006; Cryan et al. 2004; Pauli et al. 2012). Because molting has the potential to introduce temporal variation in stable isotope studies, understanding molting patterns is necessary (Greaves et al. 2004).

Information on molting patterns of the eastern spotted skunk, *Spilogale putorius,* is conflicting (Long, 2008; Merrit 1987). This species is listed as threatened or endangered in several states (Gompper and Hackett 2005), and a recent study involving trapping of the eastern spotted skunk in Kansas met with very low trap success (Nilz 2008). As such, traditional methods involving capture and long-term monitoring or sacrifice of individuals for determining molting patterns were not feasible. In this study, I sought to determine molting patterns for the eastern spotted skunk from museum specimens.

Molting patterns in the striped skunk are well documented (Verts 1967). This species undergoes a single molt per year with molt proceeding from anterior to posterior (Verts 1967). Molting begins with the shedding of underfur in April followed by the shedding and subsequent re-growth of guard hair and underfur in July (Verts 1967). Molt is completed by September (Verts 1967).

As such, observed molting measurements from the striped skunk were compared to known molting patterns for this species to determine accuracy of selected indices (Verts 1967). Indices that were accurate in the striped skunk were applied to the eastern spotted skunk to determine molting patterns.

The striped skunk and the eastern spotted skunk rely on similar diet resources, (Crabb 1941; Kelker 1937; Selko 1937), and undergo parturition at approximately the same time (Kinlaw 1995; Wade-Smith and Verts 1982). As diet and reproduction often affect the timing and duration of molt, I expected, given the similarities in diet and reproductive behavior, the onset and duration of molt for the eastern spotted skunk to coincide with that of the striped skunk.

MATERIALS AND METHODS

I examined 71 eastern spotted skunk and 79 striped skunk specimens from the Sternberg Museum of Natural History (Hays, Kansas), and the University of Kansas Natural History Museum (Lawrence, Kansas) (Appendix I). To minimize variation in timing and duration of molt due to climatic variation, I sampled only specimens collected from Iowa, Kansas, Missouri, Nebraska, and Oklahoma.

Stains (1979) indicated breakage and fraying of the distal portion of guard hair is characteristic of older hair. Verts (1967) indicated spring molt in the striped skunk is characterized by loss of underfur, followed by the loss and replacement of guard hair. As such, I chose 3 indices, presence of underfur, presence of wear on hair, and guard hair length, to characterize the stage of molt for each specimen. To determine directionality of molting, I examined 5 positions on the mid-dorsal region of each individual: at the pectoral girdle, posterior to the pectoral girdle, midway between the pectoral and pelvic girdle, immediately anterior to the pelvic girdle, and at the pelvic girdle. I repeated measurements for all study specimens 5 times at each position.

I determined underfur and wear on hair to be present if the presence of underfur or breakage / fraying of hair was indicated by any measurement at that location. I then calculated mean guard hair length at each location.

RESULTS

All positions yielded similar results for the presence of underfur, guard hair length, and presence of wear on hair for both species. As such, directionality could not be determined. Measurements of shedding in the striped skunk indicated underfur was shed rapidly from April to June with re-growth completed by October. The eastern spotted skunk molted later than the striped skunk, with shedding of underfur beginning in June and complete by July. Re-growth of underfur was complete by November. I used measurements taken immediately anterior to the pectoral girdle for analysis of guard hair length and presence of wear on hair and at the pectoral girdle for analysis of the presence of underfur to infer molting patterns for both species (Figure 1.1).

Underfur was present in approximately 100% of striped skunk individuals from January through March then declined to 67% of individuals for April (Figure 1.1). Percentage of individuals with underfur remained low but variable until it increased to 88% in October and approximatly100% of sampled individuals in November. Underfur was present in approximately 100% of eastern spotted skunk individuals from January to May, and dropped to presence in 0% of individuals in July. Underfur was present in 33% of sampled individuals in October and increased to 100% of sampled individuals by November (Figure 1.1).

Mean guard hair length for the striped skunk varied from January through April, with an outlier in May (Figure 1.1). Mean guard hair length dropped to 20 ± 5 mm by September and rapidly increased to 30 ± 6 mm by October. Mean guard hair length for the eastern spotted skunk was 18 ± 1 to 20 ± 2 mm from January to April, and dropped to 15 ± 2 mm by September through October and increased to 19 ± 2 mm and 19± 1 mm in November and December, respectively (Figure 1.1).

Wear on hair varied from presence in 0% of individuals in March and May to 100% of individuals in April and August (Figure 1.1). No patterns for the measurement of wear on hair were consistent with known shedding patterns in the striped skunk (Verts 1967). As such, these results were not applied to the eastern spotted skunk.

DISCUSSION

Measures of underfur presence and guard hair length for the striped skunk generally followed known molting patterns (Verts 1967). Therefore, the metrics of underfur presence and guard hair length could accurately discern molting patterns in the striped skunk and eastern spotted skunk.

Re-growth of guard hair, as indicated by mean guard hair length, corresponded with the re-growth of underfur in both species. A small decline in mean guard hair length was observed in both the striped skunk and the eastern spotted skunk in May and June. These declines probably represent a lack of appropriate sample size. When these points were removed, measures of mean guard hair length indicated guard hair was shed beginning in July and re-grown by October in the striped skunk and was shed by September and re-grown by November in the eastern spotted skunk. Thus, these data provided evidence for a single annual decline in guard hair length indicative of a single molting event per year.

Diet and reproduction are favored hypotheses for the evolution of timing of molt (Ling 1970; Neuhaus 2000; Speth 1969; Stewart and Macdonald 1997; Xin 2003). Given the similarities in diet and reproduction between the striped skunk and eastern spotted skunk, the differences in timing and duration of molt observed in this study were unexpected. A possible explanation for the difference in molt onset might be winter hibernation behavior displayed in populations of the striped skunk but not in the eastern spotted skunk (Kinlaw 1995; Wade-Smith and Verts 1982). It would be adaptive for the striped skunk to complete molt prior to the onset of hibernation in order to maximize heat retention. The absence of hibernating behavior in the eastern spotted skunk might allow additional time for the accumulation of resources to increase body condition, which has been shown to increase the insulative quality of hair (Ling 1970).

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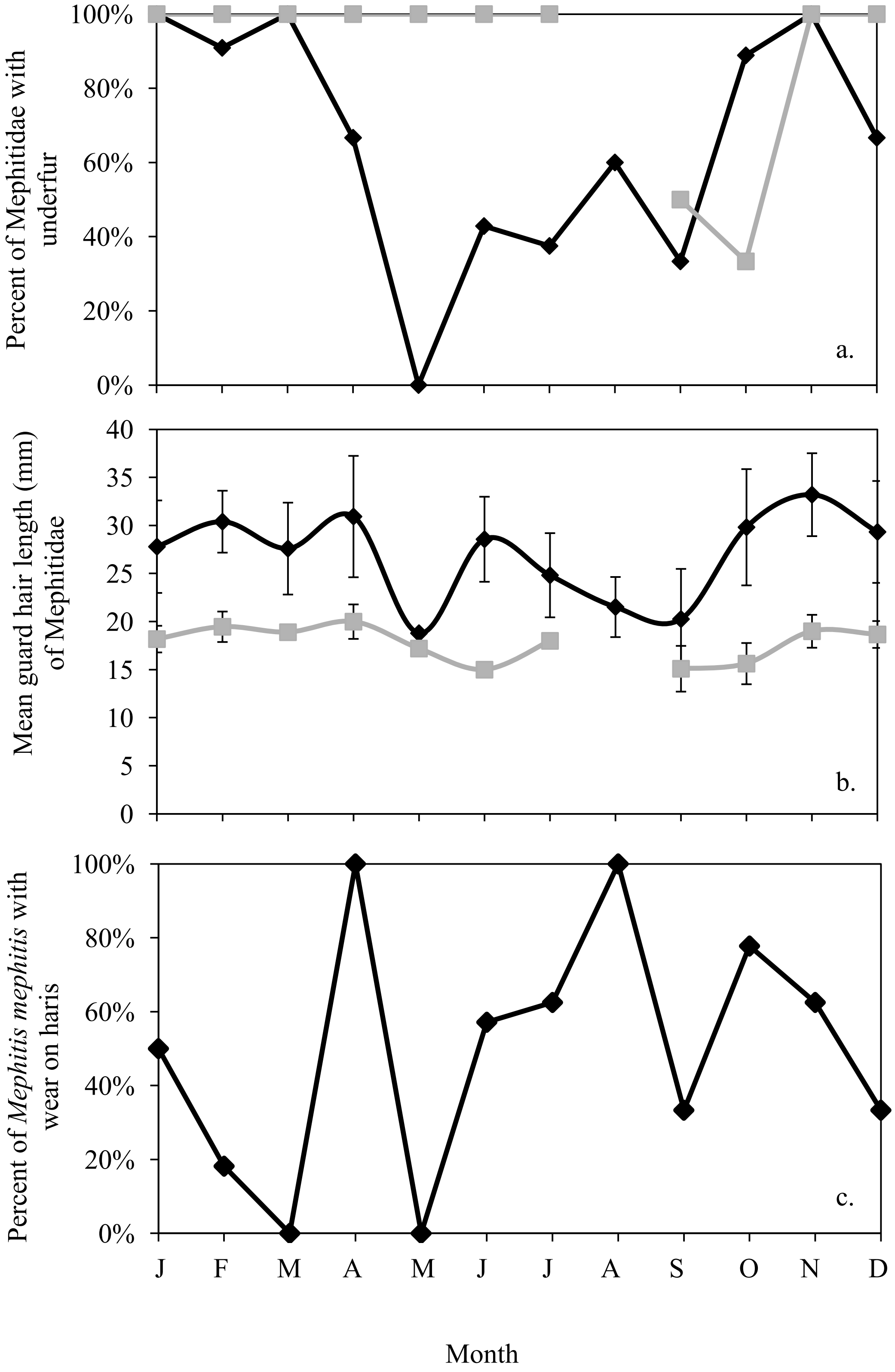
Figure 1.1. Shedding measurements collected from eastern spotted skunk (gray) and striped skunk (black) museum specimens. a. Percent of striped skunk and eastern spotted skunk specimens per month with underfur present at the pectoral girdle. b. Mean guard hair length per month of striped skunk and eastern spotted skunk specimens immediately anterior to the pelvic girdle in millimeters. and c. Percent of striped skunk specimens per month with evidence of wear on hair at the pectoral girdle.


Percent of Mephitidae with underfur
100%
80%
60%
40%
20%
0%
a.
Mean guard hair length (mm) of Mephitidae
40
35
30
25
20
15
10
5
0
b.
Percent of *Mephitis mephitis* with wear on haris
100%
80%
60%
40%
20%
0%
c.
J
F
M
A
M
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J
A
S
O
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Month

CHAPTER 2

TRENDS IN LANDSCAPE STRUCTURE AND CROP ABUNDANCES IN KANSAS

Conversion of natural habitats to agriculture production has changed the landscape of the United States. From 1850 to 1980, 150 million hectares of land were converted to agriculture in the United States (Ramankutty and Foley 1999). Initial conversion of land to agriculture was characterized by increased habitat loss, landscape fragmentation, and decreased natural landscape heterogeneity, and has led to loss of biodiversity (Benton et al. 2003; Huston 2005). Approximately 89% of Kansas is currently considered agricultural land (USDA 2007).

Since this transition to agriculture, there have been numerous revolutions in agricultural practices, which are responsible for further loss of biodiversity. Included among these, was agricultural intensification, characterized by an increase in the intensity of agriculture, a reduction in agricultural crop diversity, and increased field size, resulting in reduced landscape heterogeneity (Benton 2003). Additionally, crop type can affect the local distribution of many species including coyote (*Canis latrans*) and eastern cottontail (*Sylvilagus floridanus*) (Gosselink et al. 2003; Mankin and Warner 1999). As such, changes in the dominant crop type of a region or removal of crop types have the capacity to affect local species distributions as well as community assemblage.

Recently, effort has been made to track historical land use changes across the United States (Brown et al. 2005; Hammer et al. 2004; Ramankutty and Foley 1999; Theobald 2001) and the effects of these changes on biodiversity (Ribic et al. 1998). However, much of the existing research focuses on large-extent trends in agriculture over large time span or on small-extent changes in landscape structure at small time spans. To date, no one has provided a characterization of dominant crop trends in Kansas over the last century or attempted to document the onset of the loss of agricultural diversity and the intensification of agriculture. There is conflict concerning the onset of agricultural intensification in Kansas, and its applicability as an explanation for population trends in Kansas species, such as the eastern spotted skunk (*Spilogale putorius*) (Choate et al. 1973; Sjo 1987). The present study sought to examine historical changes in agricultural practices for timing and duration of shifts in agricultural practices, as well as track the prevalence of crop types in Kansas from 1880 through 2007.

MATERIALS AND METHODS

I compiled data on hectares of woodland and crops planted or harvested, land in farms, number of farms, average farm size, and number of irrigated farms from 1880 to 2007 from the USDA Census of Agriculture. I included crops in analysis if data on hectares planted or harvested were available for several censuses from 1900 to 2007. Seventeen crops categories met this criterion (maize, wheat, sorghum, soybeans, barley, peanuts, cotton, tobacco, hay, oats, rye, flaxseed, potatoes, sugar beets, vegetables, orchards, and berries) and were included in analysis. I graphed all variables against census year and analyzed temporal trends in the variables with Spearman Rank correlations in program R (ver. 2.14.1; R Core Development Team). I corrected for multiple comparisons with the modified false discovery rate (FDR) developed by Benjamini and Yekutieli. As there were 25 comparisons, I adjusted the significance level from $\alpha=0.05$ to $\alpha=0.013$ (Narum 2006). Variables that displayed distinctly bimodal patterns over time were subdivided into 2 groups for correlation analyses based on the minimum data value.

Definitions for crops changed slightly between censuses, and I made an effort to keep measures consistent over time. Maize, wheat, sorghum, and soybeans included crops grown for harvest, silage or forage. Sorghum grown for syrup was not included in some census years and was not included in the sorghum data. “Hay” was defined by the census and included the total hectares of alfalfa, clover, lespedeza, small grains, wild hay, and other species harvested for hay. Due to differences between sampling years, a number of variables were included as combinations of crops. Irish potatoes and sweet potatoes were combined into a “potato” category. “Vegetables” excluded major crops and potatoes, were primarily grown for home use and included sweet corn, melons, green peas, tomatoes, cabbage, and other similar crops. Fruit-bearing trees such as apples, peaches, pears, cherries, plums, grapes, and nut trees were combined in census data into an “orchards” category. “Berries” was a general category and included strawberries, and in some census years blackberries, raspberries, and other small fruits, but their addition was negligible. I omitted years in which definitions between censuses could not be reconciled. I also eliminated years 1982 and 1987 from the analysis, as they were based on survey rather than census.

RESULTS

Eighty-two percent of Kansas land was in farms (including cropland and pasture) by the first census records in 1900, and increased to 96% by 1964 (r_s=0.949, n=11, P< 0.001) (Figure 2.1). Since 1964 land in farms has decreased to 89% by 2007 (r_s=-0.99, *n*=6, *P*<0.001). The number of farms in Kansas has decreased over time (r_s=-0.986, *n*=16, *P*<0.001) from a peak of 177,841 farms in 1910 to 65,531 in 2007 (Figure 2.1). Declines in number of farms per county occurred primarily in mid and eastern Kansas (Figure 2.2). During that time, the average size of farms increased from 97 hectares in 1900 to peak of 303 hectares in 1997 (r_s=0.943, *N*=15, *P*<0.001; Figure 2.1). Average farm size increased predominantly in western Kansas from 1900 to 1930 then advanced east (Figure 2.3). After 1997 there was a slight decrease in average farm size to 286 hectares in 2007, primarily occurring in western Kansas (Figure 2.2, Figure 2.4). The percent of farms with irrigation increased from 1 to 9%, primarily in western Kansas, since the first census record in 1940, (Figure 2.1, Figure 2.4) though this trend only approached significance (r_s=0.718, *N*=11, *P*=0.017).

Wheat was the most abundant crop in Kansas comprising, approximately 17% of all land in Kansas since 1890 (Figure 2.5). Maize, hay, sorghum, woodland, oats, and soybeans comprised from 1 to 7% of the Kansas landscape since 1890 (Figure 2.5). All other crop types comprised less than 0.5% of the Kansas landscape since 1890 (Figure 2.5 through 2.7).

From 1890 to 2007 sorghum and soybeans increased in hectares harvested (r_s=0.771, *n* =14, *P*<0.001 and r_s=0.996, *n*=17, *P*<0.001, respectively; Figure 2.5). Increases in sorghum were located in central and western Kansas (Figure 2.8), whereas soybeans increased primarily in eastern Kansas (Figure 2.9). Hay displayed a nearly significant decrease in hectares harvested until 1940 but has shown a nearly significant increase in hectares harvested since (r_s=-0.943, *N*=6, *P*=0.017 and r_s =0.800, *N*=9,

P=0.014; Figure 2.5). Decreases in hay production predominantly were located in western Kansas prior to 1940 and increased primarily in eastern Kansas after 1940 (Figure 2.10). Maize declined from 16% of the land area in 1900 to 2% in 1964 and has since increased to 7% in 2007, though the latter was only approaching significance (r_s=-0.945, N=13, P<0.001 and r_s=0.942, N=6, P=0.016, respectively; Figure 2.5). Prior to 1964, maize was primarily grown in eastern Kansas. However, after 1964 maize increased predominantly in western Kansas (Figure 2.11). Woodland also declined (r_s=-0.723, N=17, P<0.001), though primarily in eastern Kansas (Figure 2.12). Although wheat showed no significant trends, the crop increased from 3% of land in 1890 and peaked at 25% of Kansas land in 1950 (r_s=0.187, N=17, P=0.456; Figure 2.5), with increases concentrated in western Kansas (Figure 2.13).

All other crop types displayed significant negative correlations with time or no significant trends (Table 2.1). Of the minor crops, cotton increased in the last two census years from 564 hectares harvested in 1992 to 22,643 hectares in 2002 and 16,561 hectares in 2007 (Figure 2.6). Sugar beets peaked in 1974 at 13,118 hectares from 18 hectares in 1900 (Figure 2.6). Tobacco peaked in 1940 at 146 hectares (Figure 2.7).

DISCUSSION

The decline in the percentage of land in farms after the 1964 census was probably a result of declining population in the Great Plains during that period (Brown et al. 2005). The number of farms in Kansas had declined by 62% since 1900, and closely tracked the almost 295% increase in farm size during that period, reflecting a shift from many small farms to a few large farms, associated agricultural intensification. Contrary to published information (Choate et al. 1973; Sjo 1987), this shift from small farms to larger farms did not happen suddenly, but instead was a steady transition from 1900 to 1990. There also did not appear to be evidence for farm abandonment during the dust bowl of the 1930s as has been suggested (Choate et al. 1973). While there was a slight decrease in the number of farms from the 1910s to 1930s, it occurred prior to the dust bowl of the 1930s. Large declines in the number of farms were not observed until 1940. Increases in farms with irrigation from the 1940s through the 1950s and 1960s were probably the result of the invention of more efficient irrigation equipment (Ramankutty and Foley 1999). The disproportionate increase in farms with irrigation in western Kansas probably was due to the increased need for irrigation equipment due to lower annual rainfall in this region.

Land in woodland decreased by approximately 34% over the last century. Most of this decline was observed between 1900 and 1950 and was probably the result of clearing land for agriculture and urban development. By 1920, wheat replaced maize as the most abundant crop in Kansas. Wheat remained the dominant crop in Kansas, with declines in hectares harvested noted in recent years corresponding with an increase in maize.

Many crops that displayed significant declines in hectares planted or harvested decreased from 1900 (earliest records) to the 1950s through the 1960s, when they stabilized. This pattern was especially obvious in many of the minor crops including potatoes, orchards, vegetables, and berries. Notably, the real extent of many of these minor crops, even at peak abundance in the landscape, was negligible when viewed at the county or state level. Oats, hay and maize also displayed a similar patterns. Oats declined rapidly from about 1950 to 1970, when rapid declines became gradual. Hay reached minimum hectares harvested in the1940s, and has slightly increased since 1950s. Maize declined from 1900 through 1965; however, hectares of maize increased after 1965. Increased maize harvested during this time probably was due to increased price of maize due to increased demand for food, livestock feed, and biofuels (Trostle 2008).

The observed decrease in a number of crop types from 1900 through the 1950s and 1960s represented a loss of agricultural diversity and probably was associated with agricultural intensification. Many crops declined after the 1900s, and mostly stabilized by the 1960s, suggesting agricultural intensification was gradual in Kansas. Also, as most of these declines occurred prior to the dust bowl, and declines did not appear to change in magnitude after the dust bowl, there was little evidence the dust bowl initiated the conversion of land to corporate farms and monoculture as has been suggested (Choate et al. 1973).

Other noteworthy changes in crops were the increase in sorghum from 1900 to 1960, when it stabilized, and the increase in soybeans from 1945 to the present. These crops probably replaced crops that displayed declines during this time.

Kansas has had a dynamic history of agriculture. While a reduction in agricultural diversity and an increase in farm size have been observed, rates of change were gradual. In addition, this study noted a loss of agricultural diversity during the 20th century, characterized by the declines in land harvested for most recorded crops. This loss of agricultural diversity impacted only a fraction of the Kansas landscape, and indicated the reduction of these crops in the landscape was unlikely to have caused large-extent declines in biodiversity. However, large-extent changes in dominant crops have been observed. Many of these large scale changes were rapid and widespread. As many of these crops favor different species, possibly they have had large impacts on the community composition and overall biodiversity of Kansas.

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Table 2.1. Results from Spearman Rank correlations for hectares of 12 minor Kansas crops harvested over time. Data were compiled from the United States Department of Agriculture Census of Agriculture. Adjusted significance was α=0.013.

Crop	r_s	*N*	*P*
Barley	-0.327	18	0.185
Berries	-0.939	17	**<0.001**
Cotton	0.404	11	0.218
Flaxseed	-0.285	10	0.427
Oats	-0.827	18	**<0.001**
Orchards	-0.868	13	**<0.001**
Peanuts	-0.991	7	**<0.001**
Potato	-0.874	18	**<0.001**
Rye	-0.581	18	**0.012**
Sugar beets	0.091	12	0.779
Tobacco	-0.527	10	0.123
Vegetables	-0.871	16	**<0.001**

Figure 2.1. a: Percent of land in Kansas farms from 1910 to 2007. b. Number of Kansas farms (black) and average size of Kansas farm in hectares (gray) from 1880 to 2007. c. Number of farms with irrigation in Kansas from 1940 to 2007. Data were compiled from the United States Department of Agriculture Census of Agriculture.

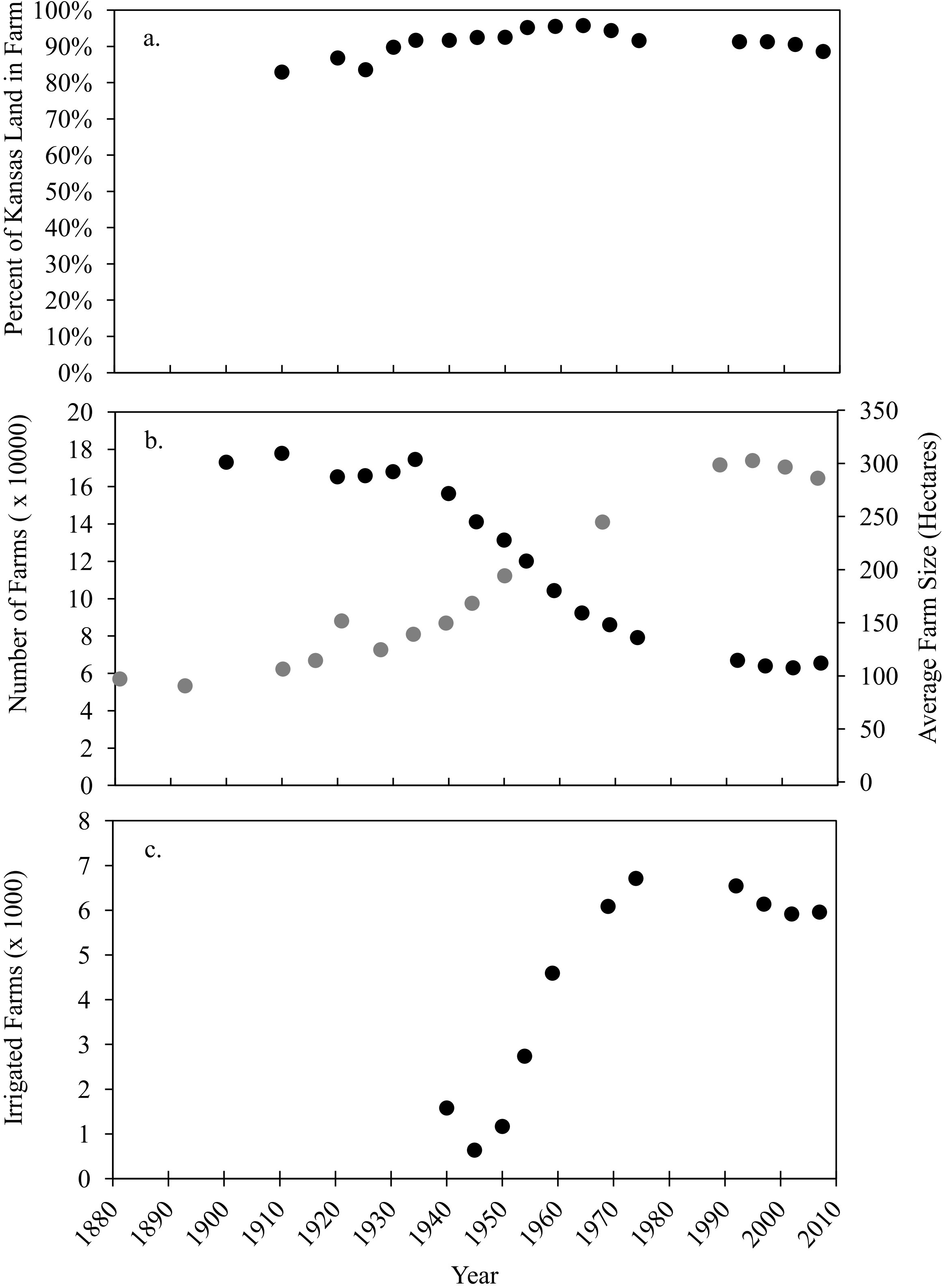

a.
Percent of Kansas Land in Farms
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
b.
Number of Farms (x 10000)
20
18
16
14
12
10
8
6
4
2
0
Average Farm Size (Hectares)
350
300
250
200
150
100
50
0
c.
Irrigated Farms (x 1000)
8
7
6
5
4
3
2
1
0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year

Figure 2.2. Time series depicting the number of farms in Kansas counties from 1900 to 2002. Data were compiled from the United States Department of Agriculture Census of Agriculture.

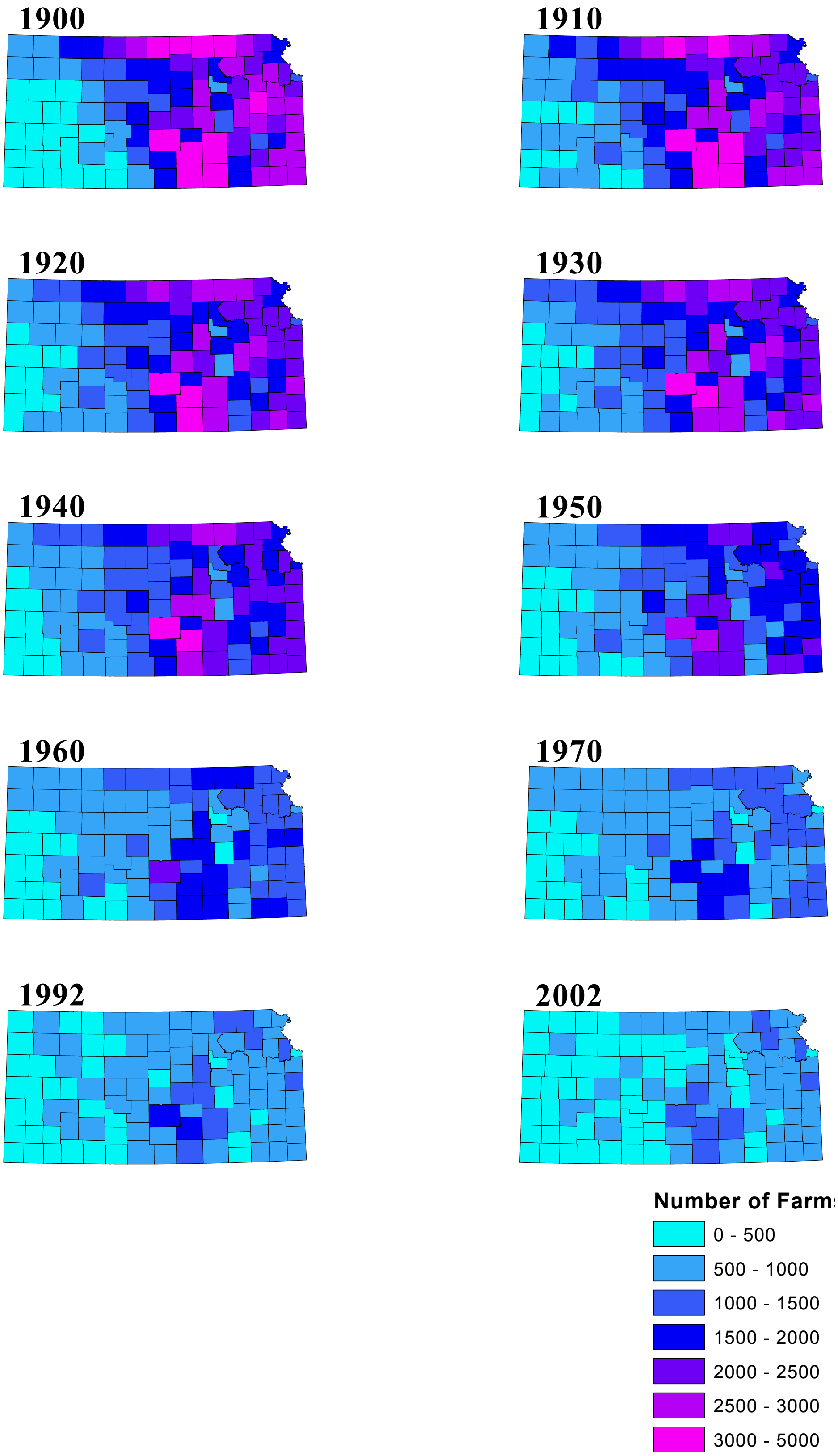

1900
1910
1920
1930
1940
1950
1960
1970
1992
2002
Number of Farm
0 - 500
500 - 1000
1000 - 1500
1500 - 2000
2000 - 2500
2500 - 3000
3000 - 5000

Figure 2.3. Time series depicting the average farm size in hectares for Kansas counties from 1900 to 2002. Data were compiled from the United States Department of Agriculture Census of Agriculture.

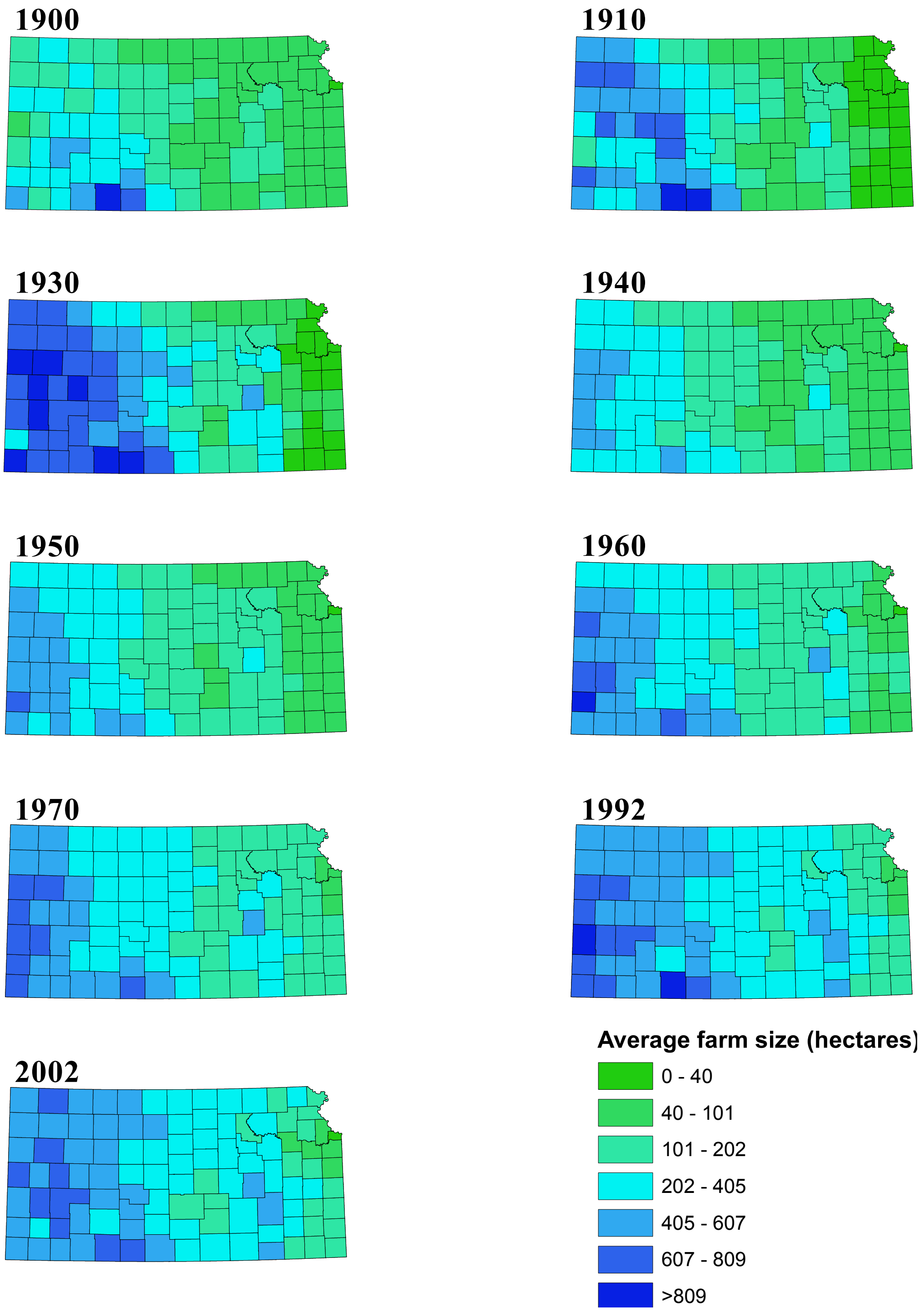

1900
1910
1930
1940
1950
1960
1970
1992
2002
Average farm size (hectares)
0 - 40
40 - 101
101 - 202
202 - 405
405 - 607
607 - 809
>809

Figure 2.4. Time series depicting the number of irrigated farms in Kansas counties from 1940 to 2002. Data were compiled from the United States Department of Agriculture Census of Agriculture.

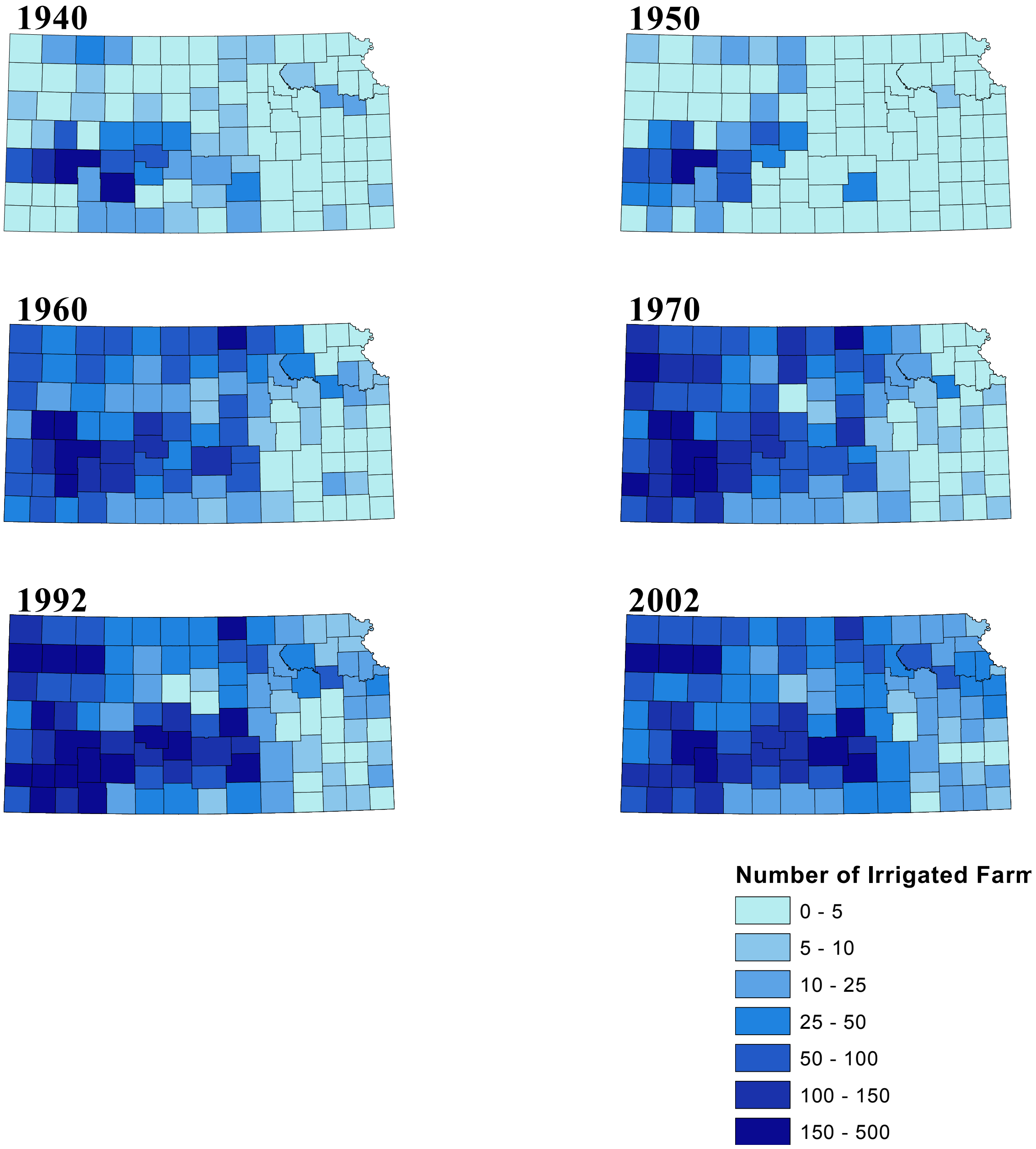

1940
1950
1960
1970
1992
2002
Number of Irrigated Farm
0 - 5
5 - 10
10 - 25
25 - 50
50 - 100
100 - 150
150 - 500

Figure 2.5. Land in hectares of a. extant woodland, b. wheat, c. maize, d. hay, e. sorghum, f. soybeans, g. oats, and h. barley harvested in Kansas. Data were compiled from the United States Department of Agriculture Census of Agriculture.

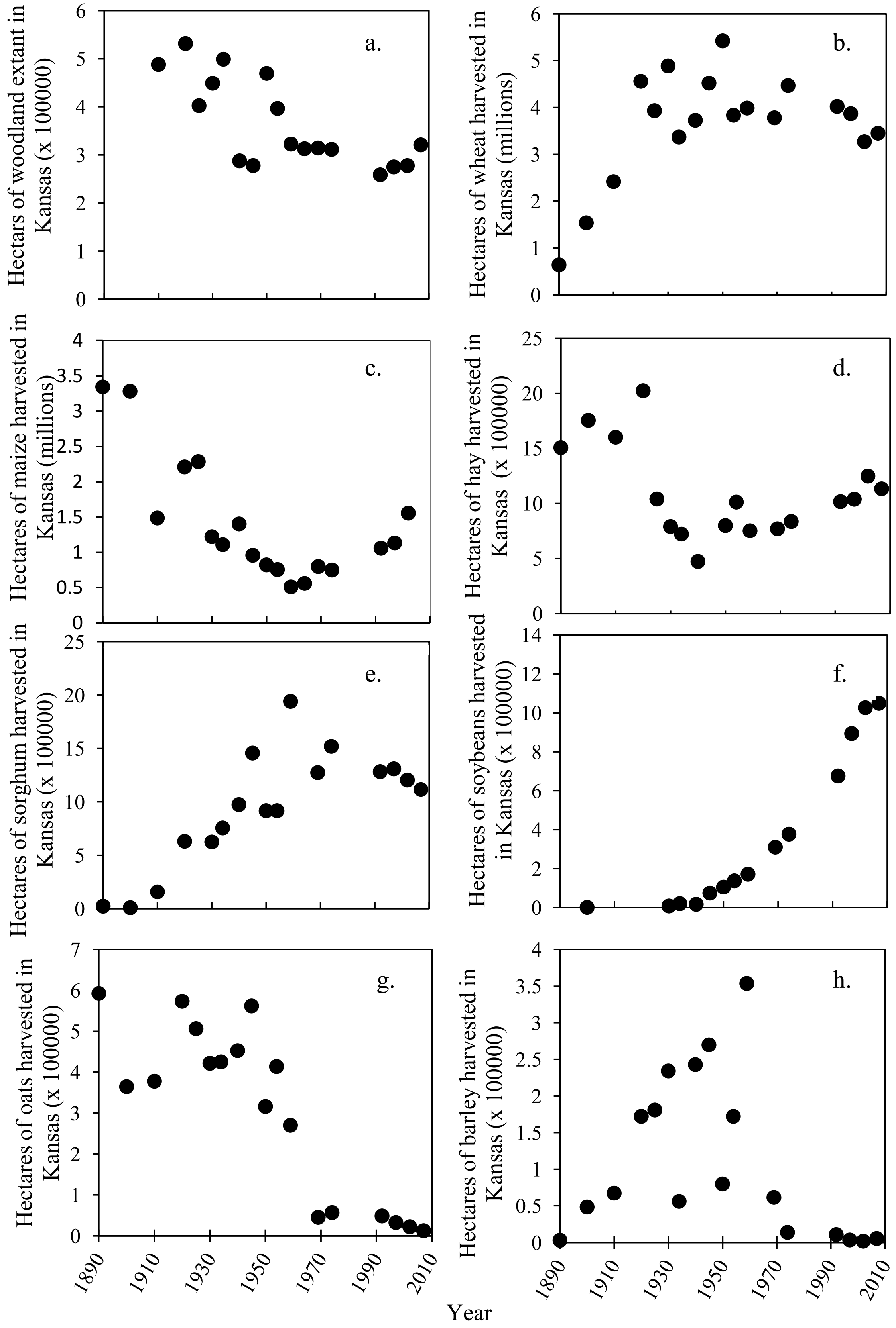

a.
Hectars of woodland extant in Kansas (x 100000)
0
1
2
3
4
5
6
b.
Hectares of wheat harvested in Kansas (millions)
0
1
2
3
4
5
6
c.
Hectares of maize harvested in Kansas (millions)
0
0.5
1
1.5
2
2.5
3
3.5
4
d.
Hectares of hay harvested in Kansas (x 100000)
0
5
10
15
20
25
e.
Hectares of sorghum harvested in Kansas (x 100000)
0
5
10
15
20
25
f.
Hectares of soybeans harvested in Kansas (x 100000)
0
2
4
6
8
10
12
14
g.
Hectares of oats harvested in Kansas (x 100000)
0
1
2
3
4
5
6
7
h.
Hectares of barley harvested in Kansas (x 100000)
0
0.5
1
1.5
2
2.5
3
3.5
4
1890
1910
1930
1950
1970
1990
2010
Year

Figure 2.6. Land in hectares of a. rye harvested, b. flaxseed harvested, c. potato harvested, d. extant orchards, e. cotton harvested, f. vegetables harvested, g. sugar beets harvested, and h. extant berries in Kansas. Data were compiled from the United States Department of Agriculture Census of Agriculture.

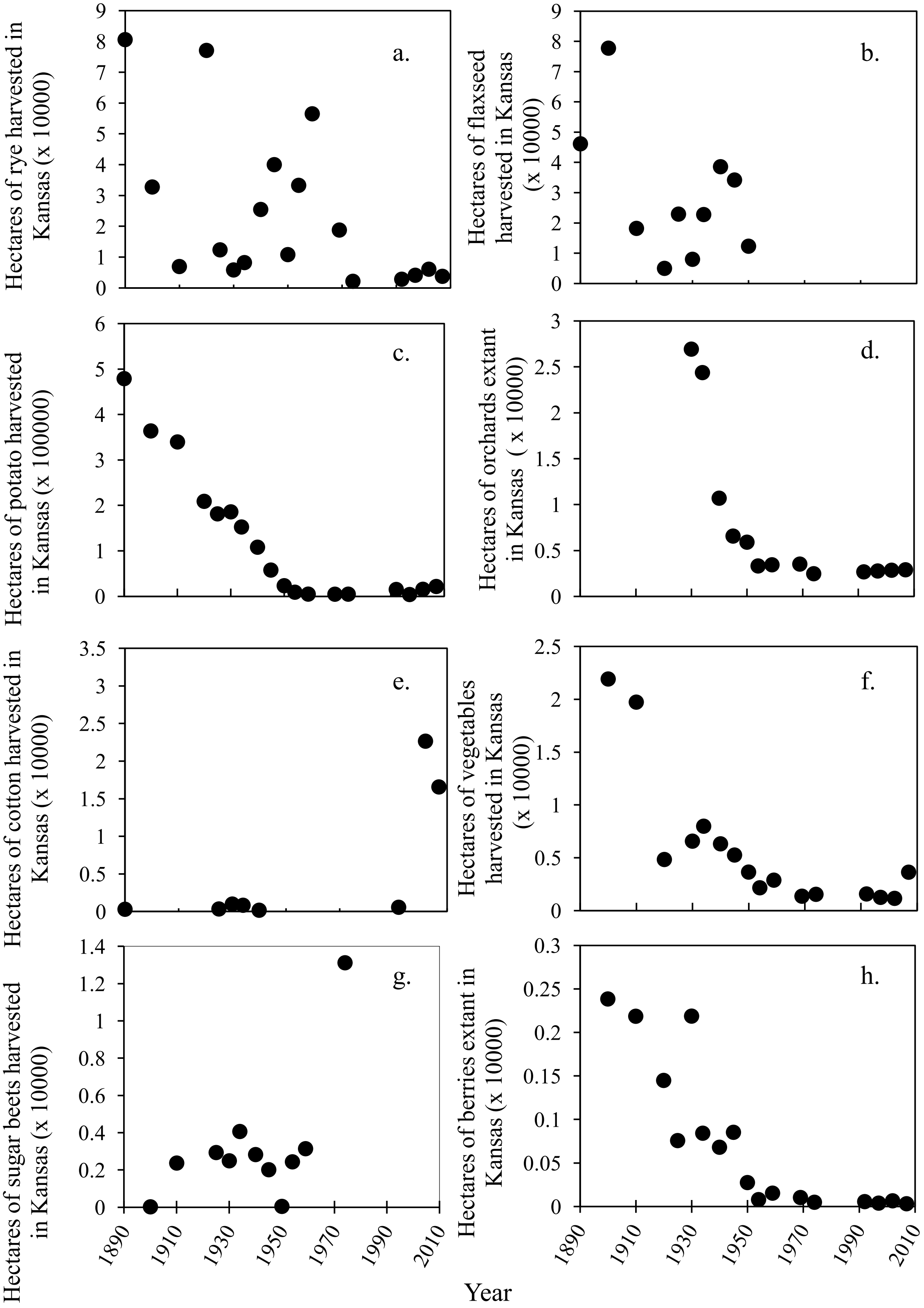

a.
Hectares of rye harvested in Kansas (x 10000)
0
1
2
3
4
5
6
7
8
9
b.
Hectares of flaxseed harvested in Kansas (x 10000)
c.
Hectares of potato harvested in Kansas (x 100000)
0
1
2
3
4
5
6
d.
Hectares of orchards extant in Kansas (x 10000)
0
0.5
1
1.5
2
2.5
3
e.
Hectares of cotton harvested in Kansas (x 10000)
0
0.5
1
1.5
2
2.5
3
3.5
f.
Hectares of vegetables harvested in Kansas (x 10000)
0
0.5
1
1.5
2
2.5
g.
Hectares of sugar beets harvested in Kansas (x 10000)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
h.
Hectares of berries extant in Kansas (x 10000)
0
0.05
0.1
0.15
0.2
0.25
0.3
1890
1910
1930
1950
1970
1990
2010
Year

Figure 2.7. Land in hectares of a. peanuts and b. tobacco harvested in Kansas. Data were compiled from the United States Department of Agriculture Census of Agriculture.

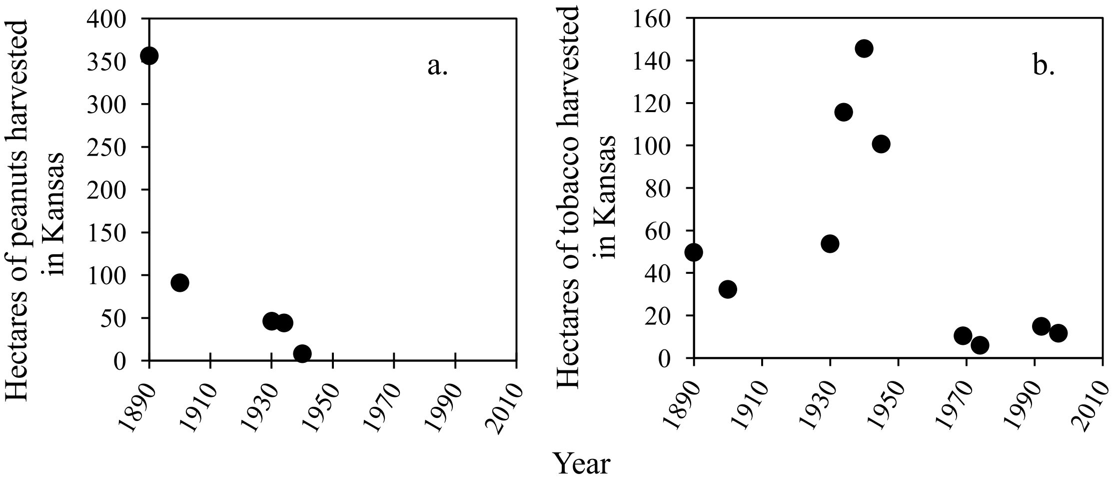
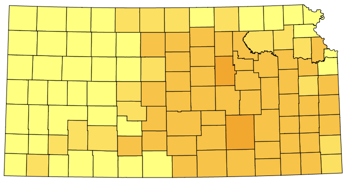
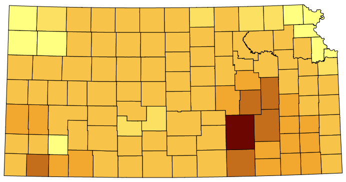

Hectares of peanuts harvested in Kansas
400
350
300
250
200
150
100
50
0
1890
1910
1930
1950
1970
1990
2010
a.
Hectares of tobacco harvested in Kansas
160
140
120
100
80
60
40
20
0
1890
1910
1930
1950
1970
1990
2010
b.
Year

Figure 2.8. Time series depicting hectares of sorghum harvested in Kansas counties from 1900 to 2002. Data were compiled from the United States Department of Agriculture Census of Agriculture.

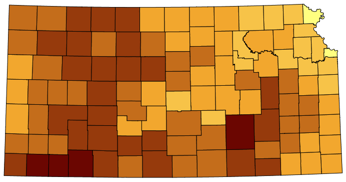
1900



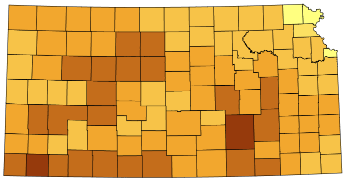
1910



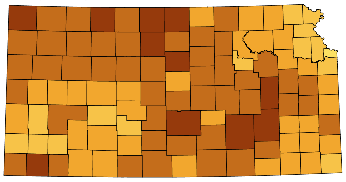
1920



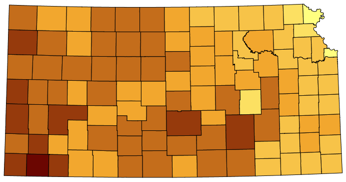
1930



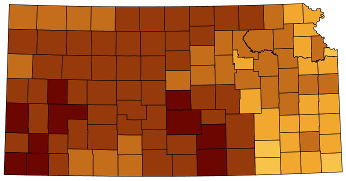
1940



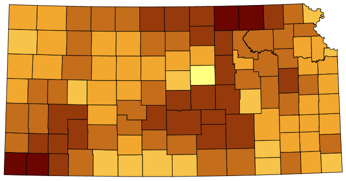
1950



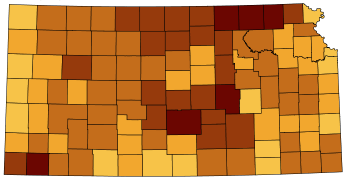
1960



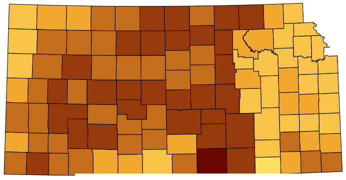
1970



1992



2002



Sorghum (hectares)

- ■ 0 - 202
- ■ 202 - 405
- ■ 405 - 4047
- ■ 4047 - 8094
- ■ 8094 - 16187
- ■ 16187 - 32374
- ■ >32374

Figure 2.9. Time series depicting hectares of soybeans harvested in Kansas counties from 1900 to 2002. Data were compiled from the United States Department of Agriculture Census of Agriculture.

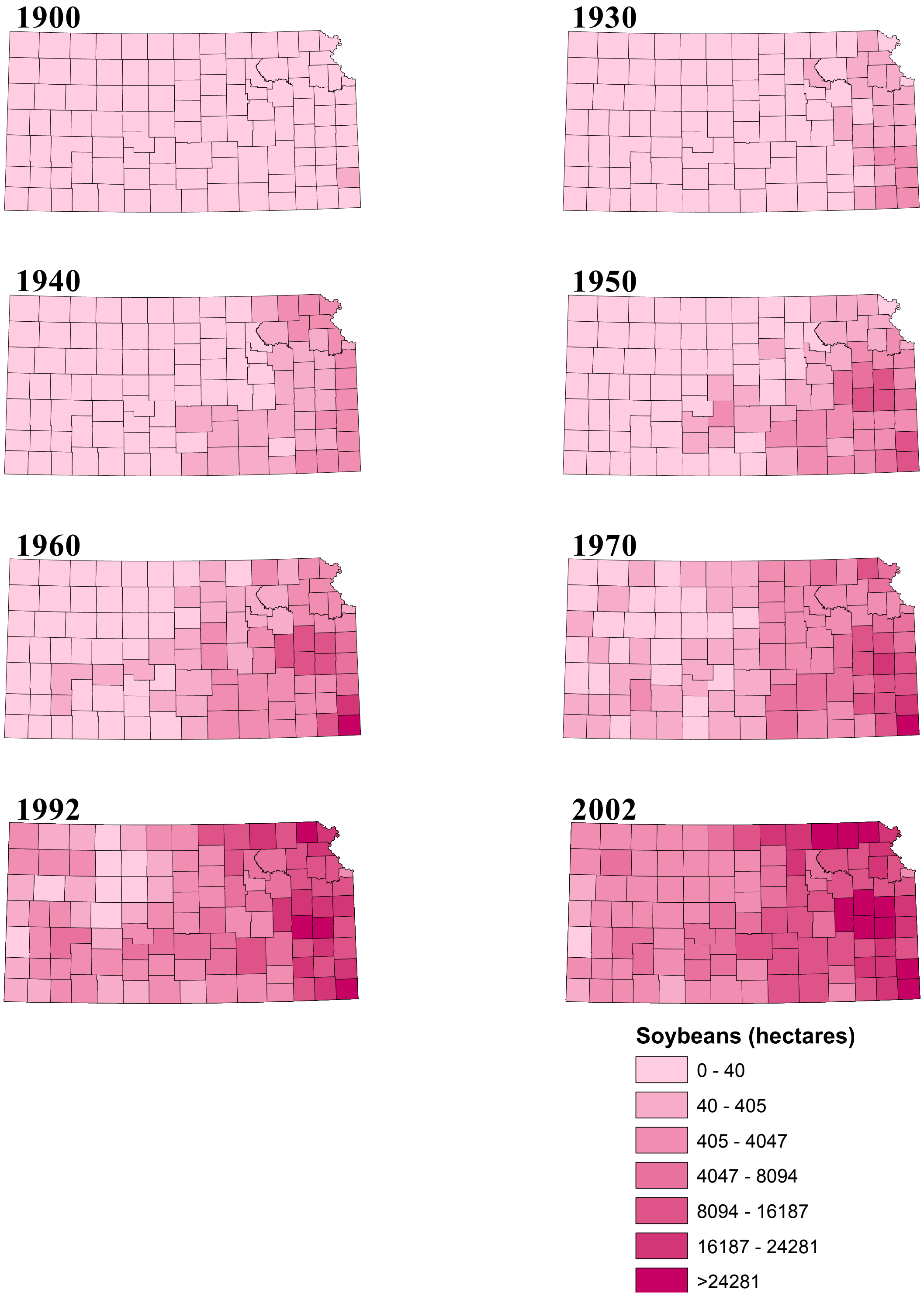
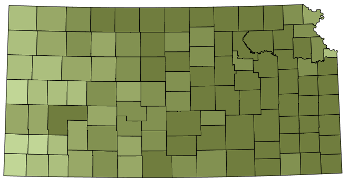
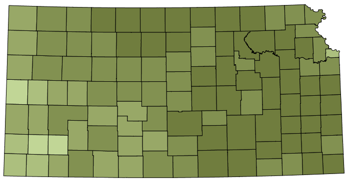

1900
1930
1940
1950
1960
1970
1992
2002
Soybeans (hectares)
0 - 40
40 - 405
405 - 4047
4047 - 8094
8094 - 16187
16187 - 24281
>24281

Figure 2.10. Time series depicting hectares of hay harvested in Kansas counties from 1900 to 2002. Data were compiled from the United States Department of Agriculture Census of Agriculture.

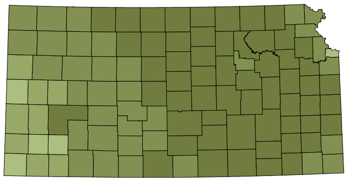
1900



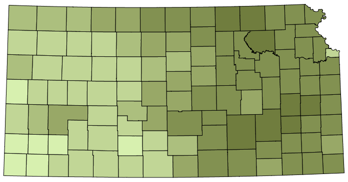
1910



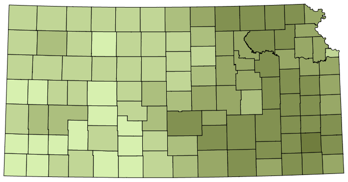
1920



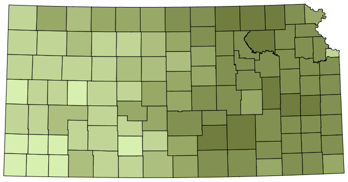
1930



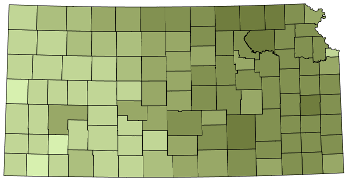
1940



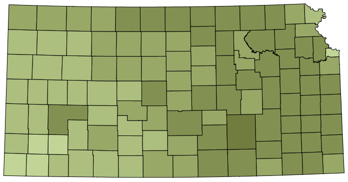
1950



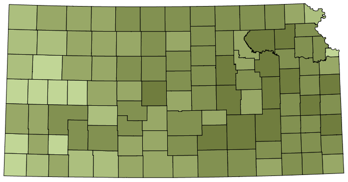
1960



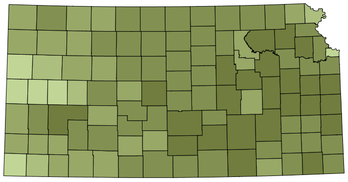
1970



1992



2002

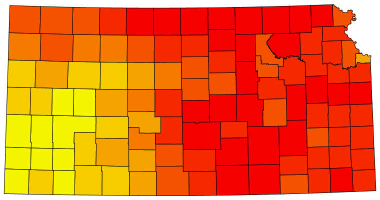


Hay (hectares)

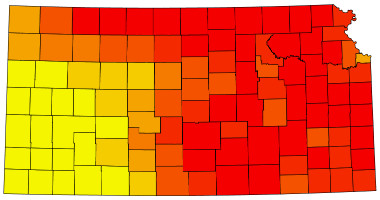
🟩 0 - 405
🟩 405 - 2023
🟩 2023 - 4047
🟩 4047 - 8094
🟩 8094 - 16187
🟩 16187 - 24281
🟩 >24281

Figure 2.11. Time series depicting hectares of maize harvested in Kansas counties from 1890 to 2002. Data were compiled from the United States Department of Agriculture Census of Agriculture.

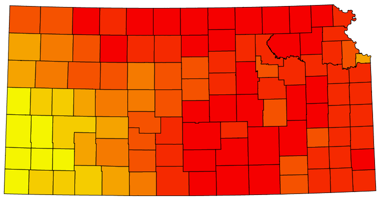
1890



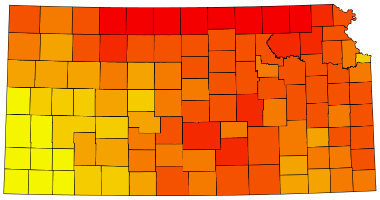
1900



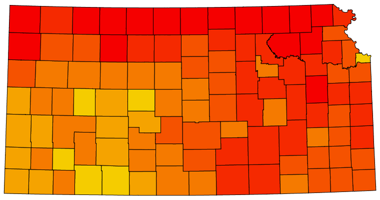
1910



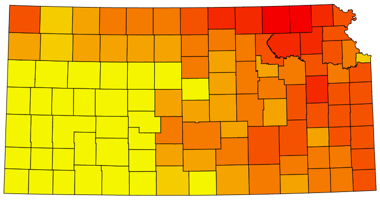
1920



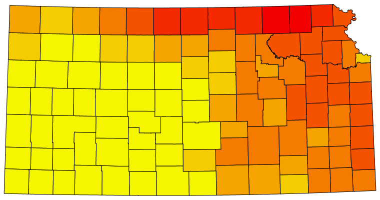
1930



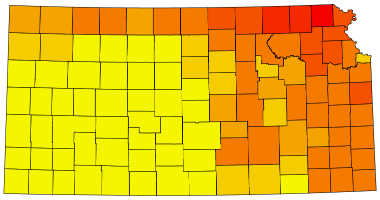
1940



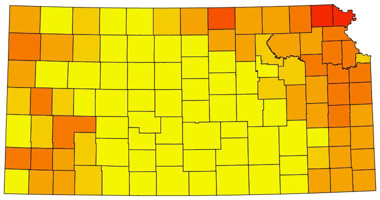
1950



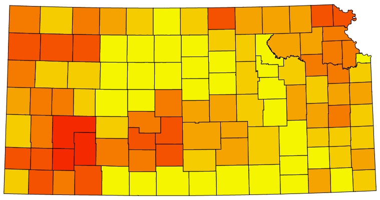
1960



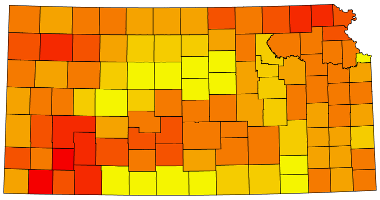
1970



1992



2002



Maize (hectares)

- 🟨 0 - 2023
- 🟨 2023 - 4047
- 🟧 4047 - 8094
- 🟧 8094 - 16187
- 🟧 16187 - 28328
- 🟥 28328 - 40469
- 🟥 >40469

Figure 2.12. Time series depicting hectares of extant woodland in Kansas counties from 1910 to 2002. Data were compiled from the United States Department of Agriculture Census of Agriculture.

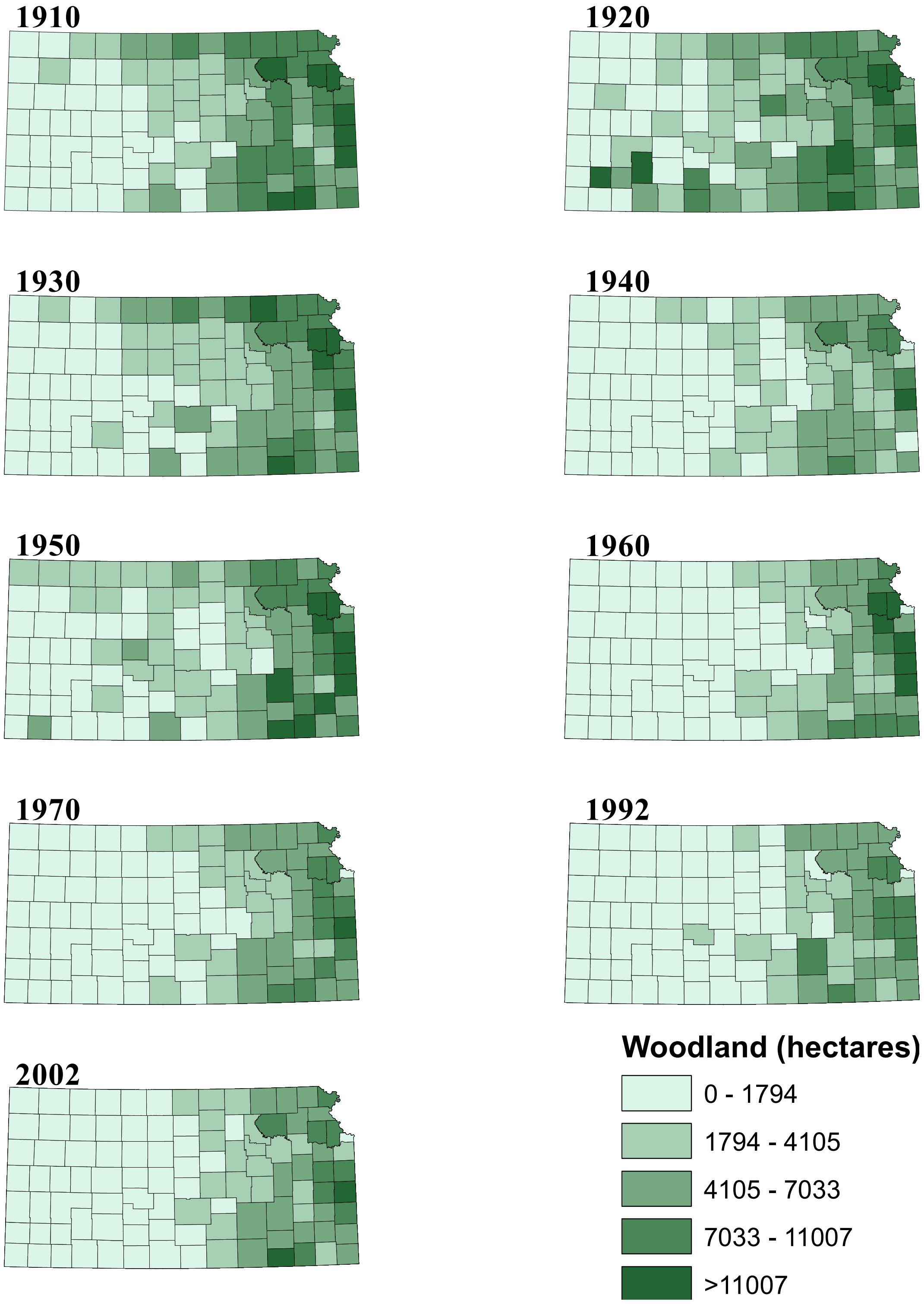
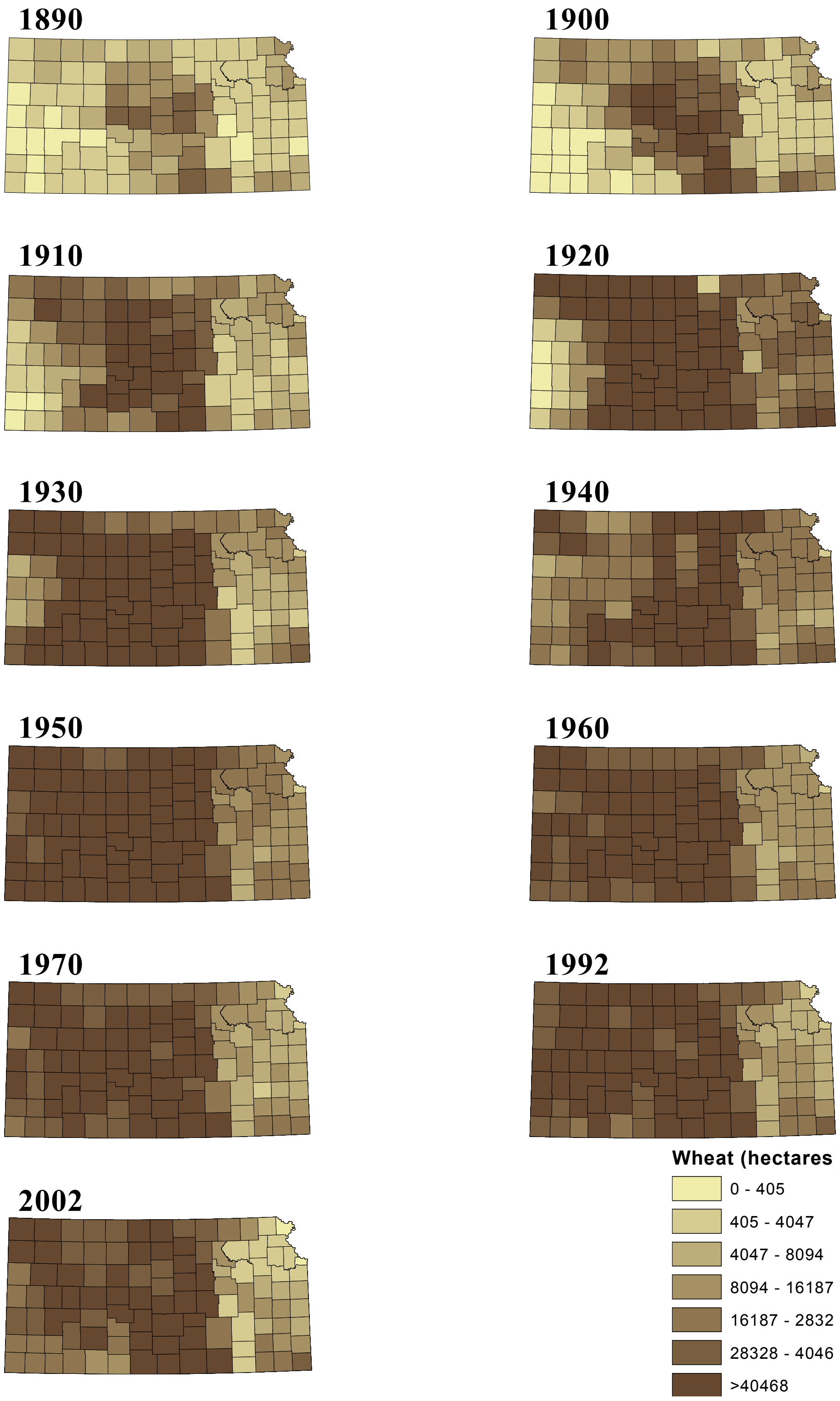

1910
1920
1930
1940
1950
1960
1970
1992
2002
Woodland (hectares)
0 - 1794
1794 - 4105
4105 - 7033
7033 - 11007
>11007

Figure 2.13. Time series depicting hectares of wheat harvested in Kansas counties from 1890 to 2002. Data were compiled from the United States Department of Agriculture Census of Agriculture.


1890
1900
1910
1920
1930
1940
1950
1960
1970
1992
2002
Wheat (hectares
0 - 405
405 - 4047
4047 - 8094
8094 - 16187
16187 - 2832
28328 - 4046
>40468

CHAPTER 3

HISTORICAL POPULATION TRENDS IN KANSAS MEPHITIDAE

Two members of the family Mephitidae are native to Kansas, the eastern spotted skunk (*Spilogale putorius*) and the striped skunk (*Mephitis mephitis*). The eastern spotted skunk is the smaller of the 2 species, weighing 0.2 to 0.5 kg compared to 1.2 to 5.3 kg in the striped skunk. Both species are generalist omnivores with similar diets, although the striped skunk is generally more insectivorous (Crabb 1941; Dixon 1925; Selko 1937). Habitat preferences appear to overlap in these species, although many studies emphasized the importance of young forests or thick woody cover for eastern spotted skunk habitat, whereas the striped skunk is a habitat generalist (Choate et al. 1973; Kinlaw 1995; Lesmeister et al. 2009, 2008; Lesmeister et al. 2010; Reed and Kennedy 2000; Van Gelder 1959).

The eastern spotted skunk has declined throughout much of its geographic range (Choate et al. 1973; Gompper and Hackett 2005; Landholt and Genoways 2000; Leopold 2010; Sasse and Gompper 2006; Wires and Baker 1994). The eastern spotted skunk is now listed as vulnerable, imperiled, or critically imperiled over much of its distribution (Figure 3.1; Patterson et al. 2003). The striped skunk is considered secure throughout its range (Figure 3.2; Patterson et al. 2003), though there has been a slight decrease in population size in Nebraska (Landholt and Genoways 2000).

Range wide declines in the eastern spotted skunk are unexpected given its large geographic range and opportunistic feeding behaviors (Gompper and Hackett 2005). In addition, during the same time period, many species in the order Carnivora with these characteristics have increased in population size (Gompper and Hackett 2005).

Numerous hypotheses have been proposed to explain the decline of the eastern spotted skunk. Choate et al. (1973) suggests this species expanded in both its range and population numbers throughout the 1800s and the observed declines in populations during the 1900s are a return to historical population numbers. Others have disagreed, suggesting current populations must be lower in many states than historically, citing declines in fur harvest records despite increased demand for pelts (Gompper and Hackett 2005; Landholt and Genoways 2000). Landscape change, disease, or pesticides as contributing factors in the decline of the eastern spotted skunk also have been suggested (Choate et al. 1973; Gompper and Hackett 2005; Landholt and Genoways 2000). The latter hypotheses are supported as this species has been considered extirpated or nearly extirpated in several states in the historical geographic range (Leopold 2010; Patterson et al. 2003).

While research has been undertaken to understand more about the biology of the eastern spotted skunk, little research has focused on historical causes of its population decline (Gompper and Hackett 2005). To examine potential causes of decline in the eastern spotted skunk, a solid understanding of the population dynamics of this species is needed. While studies have examined population trends in many states, published work detailing population trends in Kansas is limited. Therefore, this study sought to examine population trends of the eastern spotted skunk and a similar species, the striped skunk, in Kansas.

MATERIALS AND METHODS

As direct measures of long-term population trends are not available for many species, it is common to use fur harvest records to examine long-term population trends when they are available (Gompper and Hackett 2005; Landholt and Genoways 2000; Leopold 2010; Sasse and Gompper 2006). However, fur harvest records lack data for some years, vary due to changes in monitoring procedures over time, and do not represent the exact number of individuals sacrificed. As such, a few assumptions need to be addressed for my dataset. The number of pelts sold in Kansas was the only measure of harvest available for the eastern spotted skunk and striped skunk until the 1970s. Although this did not represent the exact number of animals actually harvested in Kansas for a particular year, when examined over time, deviations should be negligible (Gompper and Hackett 2005). In addition, the number of pelts sold was replaced by the number of pelts collected as the recorded measure of harvest for the striped skunk in 1970, 1973, and 1976 to 2010. There was not a unidirectional trend between these 2 measures, so they were both used in the dataset to obtain the largest time span.

I compiled annual data from the Kansas Department of Wildlife, Parks, and Tourism and United States Fish and Wildlife Service Wildlife Leaflets Series on the number of striped skunk and eastern spotted skunk harvested in Kansas, average pelt price, season length, and number of trapping licenses sold for the state of Kansas from 1920 to 2012. I defined harvest as the number of pelts collected and/or sold. I calculated a measure of trapping effort by multiplying season length by the number of trapping licenses sold.

Similar to Gompper and Hackett (2005), I divided the data into 2 periods: decline period (1928 to1947) and post decline (1948 to 2012) for both the eastern spotted skunk and the striped skunk. To determine period of decline, I examined the relationship between eastern spotted skunk harvested and trapping effort for large changes in slope.

Mephitidae harvest appears to be primarily by-catch in the pursuit of target furbearer species, and the number of individuals harvested appears to be related to trapping effort and pelt price (Gompper and Hackett 2005; Sasse and Gompper 2006). Linear regression was used to examine the relationship between trapping effort and annual harvest for the striped skunk and the eastern spotted skunk both during and after the decline. To examine the relationship between pelt price, trapping effort, and annual harvest, I conducted multiple linear regressions for these variables for the periods pelt price was available. All statistical analyses were performed in program R (ver. 2.14.1; R Core Development Team).

RESULTS

Highest recorded harvest of the eastern spotted skunk in Kansas occurred in 1930 at 117,309 pelts sold, after which harvest declined until 1948 with 2,965 pelts sold (Figure 3.3). Harvest continued to decline at a slower rate until 1977, when the eastern spotted skunk was state listed in Kansas as threatened and the trapping season closed. The highest recorded harvest of striped skunk displayed a similar trend occurring in the first recorded year, 1928, at 279,647 pelts sold. Harvest decreased from 1928 to1948 (16,973). After 1948, harvest of the striped skunk had fluctuated from 1,100 to 23,297 individuals (Figure 3.3).

Trapping effort was positively related to eastern spotted skunk harvested for the period of decline from 1930 to1948 (F=12.47, df=1, 11, P=0.004, adjusted R^2=0.489). However trapping effort was not a predictor after the initial decline (F=0.583, df=1, 22, P=0.45, adjusted R^2=-0.018). Trapping effort was positively related to striped skunk pelts sold in both decline (F=18.01, df=1, 12, P=0.001, adjusted R^2=0.567) and post decline periods (F=32.75, df=1, 52, P<0.001, and adjusted R^2=0.375), although the model better described variation in harvest during the decline.

The multiple regression, including annual harvest, pelt price, and trapping effort for years when pelt price was available (1960 to 2010), significantly predicted harvest for the striped skunk (F=10.36, df=2, 48, P<0.001, and adjusted R^2=0.436) (Figure 3.4). In the model both pelt price and trapping effort was positively related to annual harvest of the striped skunk. The same model was not significant for years pelt price was available for the eastern spotted skunk (1961 to 1977) (F=0.819, df=2, 14, P=0.46, adjusted R^2=-0.023) (Figure 3.5).

DISCUSSION

Both the eastern spotted skunk and the striped skunk exhibited similar declines in individuals harvested from 1930 and 1928 until 1948, after which harvest declined at a slower rate in the eastern spotted skunk and appeared to stabilize in the striped skunk. Declines observed in my study began earlier than has been described in prior studies (Gompper and Hackett 2005; Landholt and Genoways 2000), and might represent and earlier onset of the cause of the decline in Kansas. Declines in annual harvest of the eastern spotted skunk and the striped skunk were observed even when accounting for trapping effort, and generally correspond to the magnitude of population decline reported in other studies (Gompper and Hackett 2005; Landholt and Genoways 2000; Sasse and Gompper 2006; Wires and Baker 1994). Considering the similarities in life history of the striped skunk and the eastern spotted skunk, the observed declines probably resulted from the same cause.

While harvest of the eastern spotted skunk stabilized around 50 to 200 pelts sold per year, harvest of the striped skunk stabilized at a few thousand pelts sold or individuals harvested, with harvests in some years still in the tens of thousands. Trapping effort during the decline was a significant predictor of harvest for the eastern spotted skunk. However, trapping effort did not have a significant effect on harvest of this species post-decline. When put into the context of population declines, these results indicated that populations of eastern spotted skunk declined to a point where individuals were rare and additional trapping effort had little effect on harvest of this species post decline. Although post-decline trapping success of the striped skunk decreased as well, increased trapping effort still resulted in increased capture of the striped skunk. This suggested that while the striped skunk had declined in Kansas, it still retained a sizeable population within the state.

Trapping effort better explained harvest variation for the eastern spotted skunk and striped skunk than pelt price, a trend also observed in the literature (Gompper and Hackett 2005; Sasse and Gompper 2006). The harvest of these species is primarily a result of by-catch in the pursuit of more desirable species such as raccoon (*Procyon lotor*), fox (*Vulpes* spp.), and other furbearers (Gompper and Hackett 2005; Sasse and

Gompper 2006). Peak harvests of the striped skunk in 1979 and 2007 correspond with peaks in pelt price and number of licenses sold during this time. This pattern suggested that striped skunk might be targeted for trapping when pelt prices were high, a trend previously noted in harvest records for the eastern spotted skunk (Gompper and Hackett 2005). Additionally, peaks in the number of fur harvest licenses sold from 1930 to 1931, and another less steep peak in the late 1970s early 1980s, were observed that might have complicated interpretation of results (Figure 3.6). Lack of significance in the model containing pelt price for the eastern spotted skunk post decline was also consistent with the literature (Gompper and Hackett 2005).

Population declines as a result of overharvest do not appear to have merit as a hypothesis for the decline of the eastern spotted skunk or the striped skunk (Gompper and Hackett 2005). In addition, after 34 years of law prohibiting harvest of the eastern spotted skunk, this species is still considered rare, and only a handful of sightings have been reported in recent years (Peek 2008). These results indicated a severe population decline of the eastern spotted skunk had occurred in Kansas.

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Figure 3.1 Map displaying the distribution of the eastern spotted skunk, including its State Conservation Rank (Patterson et al 2003). Distribution maps adapted from Patterson et al. (2003).

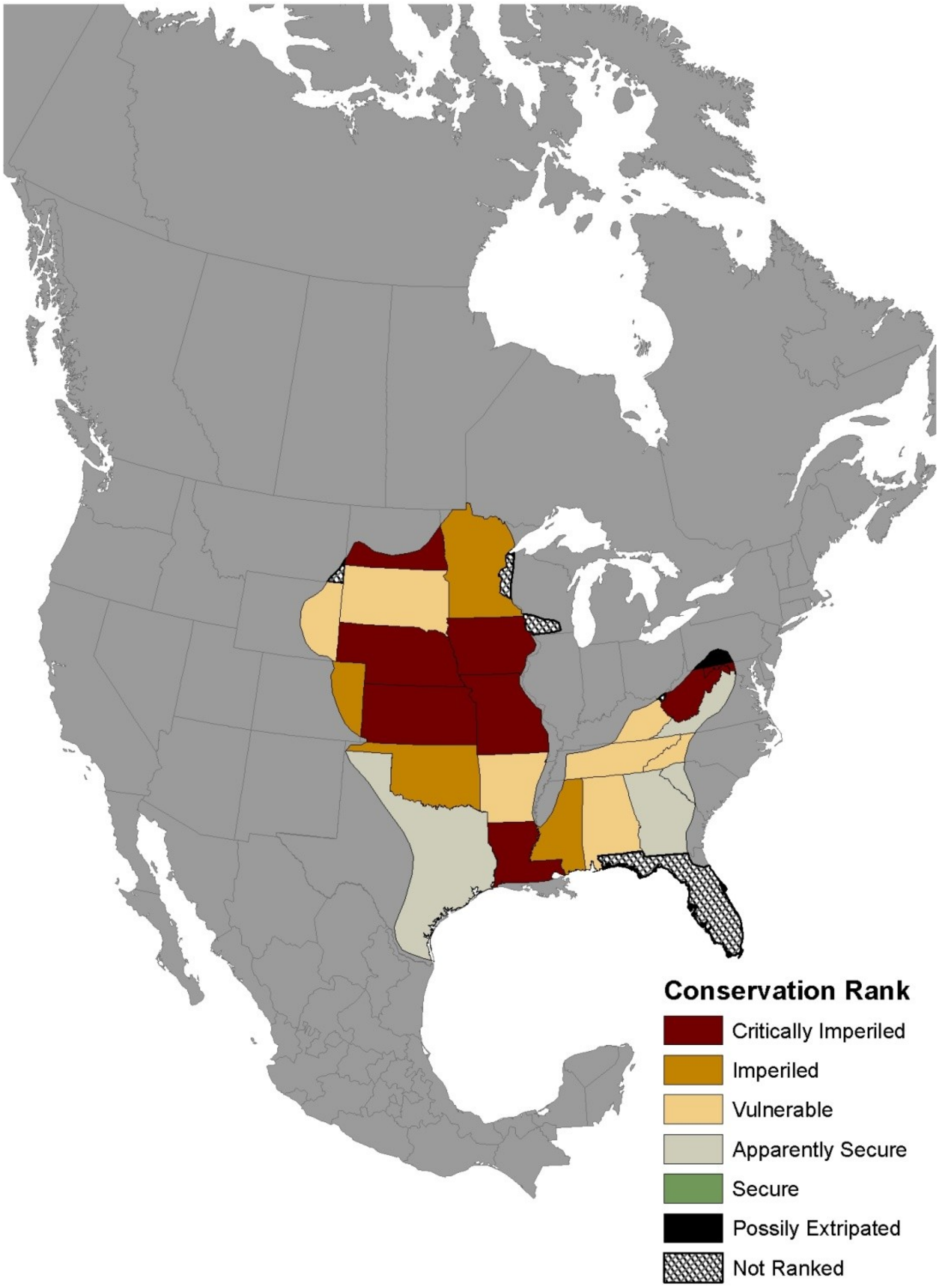

Conservation Rank
Critically Imperiled
Imperiled
Vulnerable
Apparently Secure
Secure
Possily Extripated
Not Ranked

Figure 3.2. . Map displaying the distribution of the striped skunk, thought to be secure throughout its geographic distribution (Patterson et al 2003). Distribution maps adapted from Patterson et al. (2003).


Conservation Rank
Critically Imperiled
Imperiled
Vulnerable
Apparently Secure
Secure
Possily Extripated
Not Ranked

Figure 3.3. a. Number of eastern spotted skunk pelts sold in Kansas per year from 1928 to 1980. Large declines in the number of pelts sold were observed from 1930 to 1948. Gradual declines occurred from 1948 until 1978 when the season for eastern spotted skunk closed. Declines in individuals harvested after 1980 are probably due to the species being listed as threatened in Kansas. and b. Number of striped skunk pelts sold (1928 to 1969, 1971, 1972, 1974, and 1975) or individuals harvested (1970, 1973, and 1976 to 2010) in Kansas per year. Large declines in individuals harvested were observed from 1928 to1948. Harvest had fluctuated since 1948. Data obtained from the Kansas Department of Wildlife, Parks, and Tourism and the United States Fish and Wildlife Service Wildlife leaflets.

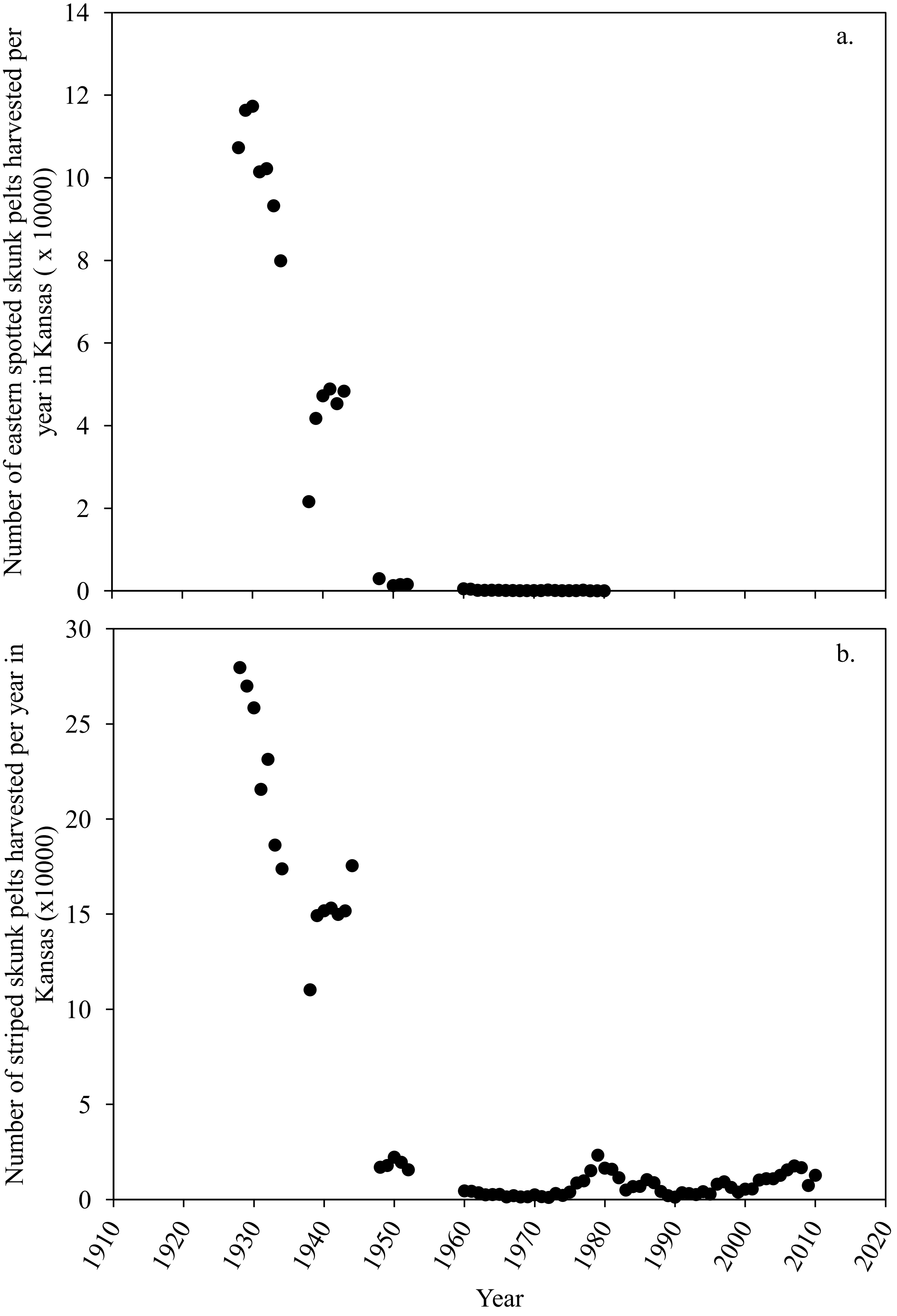

a.
Number of eastern spotted skunk pelts harvested per year in Kansas (x 10000)
0
2
4
6
8
10
12
14
b.
Number of striped skunk pelts harvested per year in Kansas (x10000)
0
5
10
15
20
25
30
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

Figure 3.4. Annual average pelt price for the striped skunk in Kansas (gray bars) adjusted by inflation, number of trapping licenses sold in Kansas (blue line), and the number of striped skunk pelts sold (1928 to 1969, 1971, 1972, and 1974, 1975) or individuals harvested (1970, 1973, and 1976 to 2010) in Kansas per year (black dots). Data were obtained from the Kansas Department of Wildlife, Parks, and Tourism and the United States Fish and Wildlife Service Wildlife Leaflets Series.

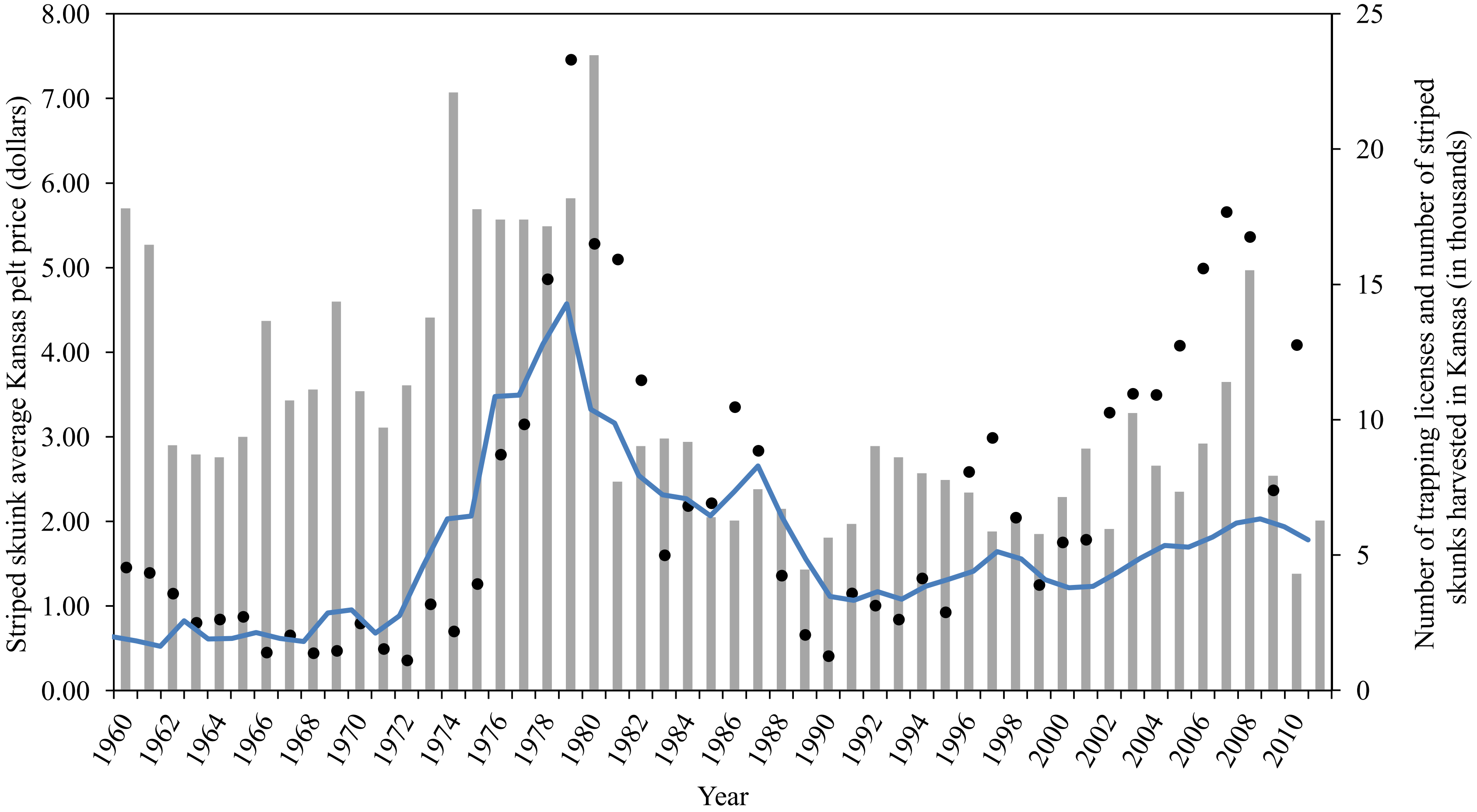

Striped skuink average Kansas pelt price (dollars)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Number of trapping licenses and number of striped skunks harvested in Kansas (in thousands)
25
20
15
10
5
0
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Year

Figure 3.5. Annual average pelt price for the eastern spotted skunk in Kansas (gray bars) adjusted by inflation, the number of trapping licenses sold (blue line), and the number of eastern spotted skunk pelts sold in Kansas per year (black dots). The number of trapping licenses sold during this time varied from 1,657 in 1962 to 14,284 in 1979. Data were obtained from the Kansas Department of Wildlife, Parks, and Tourism and the United States Fish and Wildlife Service Wildlife Leaflets Series.

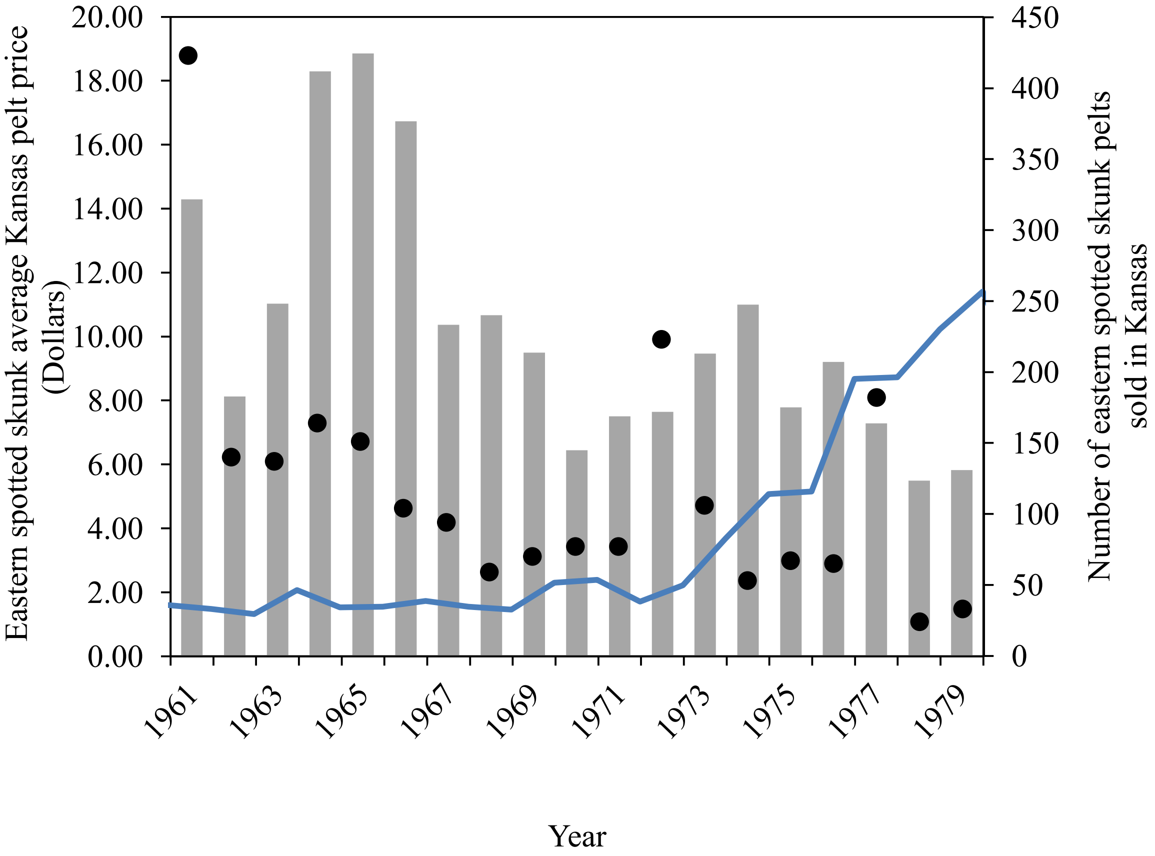
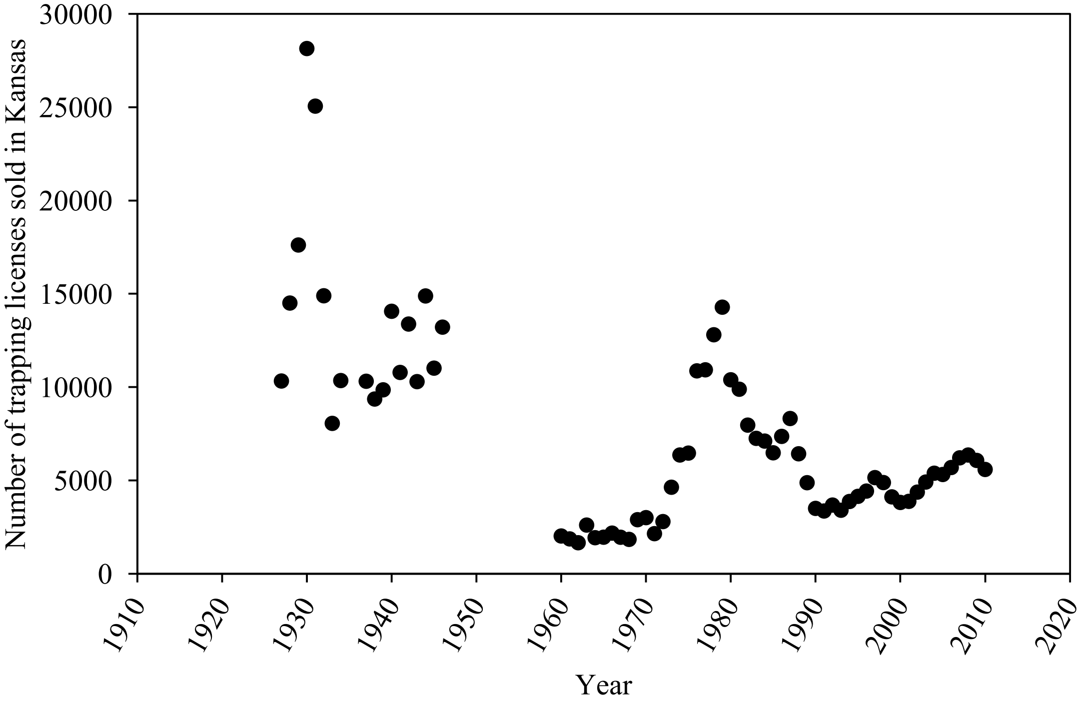

Eastern spotted skunk average Kansas pelt price (Dollars)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
Year
450
400
350
300
250
200
150
100
50
0
Number of eastern spotted skunk pelts sold in Kansas

Figure 3.6. Annual number of trapping licenses sold in Kansas. Data were obtained from the Kansas Department of Wildlife, Parks, and Tourism.


30000
25000
20000
15000
10000
5000
0
Number of trapping licenses sold in Kansas
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

CHAPTER 4

EFFECTS OF HIDE TANNING AS A PREPARATION TECHNIQUE ON $\delta^{13}C$ AND $\delta^{15}N$ VALUES OF HAIR

Carbon and nitrogen stable isotope analyses have become a valuable and popular tool for determining food web relationships. This popularity can be attributed to a number of factors. First, sample collection and preparation is fairly easy and inexpensive (Fry 2006; Hobson and Wassenaar 2008). Second, many sample types have been used successfully in analysis, and have the potential to provide information from a range of time periods including current diet composition to seasonal or yearly diet changes (Hobson 1999). Third, the amount of material required for analysis is small, approximately 0.5 mg for most analyses, and these samples often can be collected with minimal effect on many organisms (Codron et al. 2006). Fourth, diets can be more effectively determined in cryptic or rare species, than when using direct observation, collection of scat, or specimen capture (Codron et al. 2006). Fifth, stable isotope values of many samples are assumed to remain fixed over time or can be preserved. Such studies can use natural history collections to view changes in diet over large time periods (Hilderbrand et al. 1996; Hilton et al. 2006).

While natural history collections have potential for stable isotopes analysis, researchers need to understand the effects of preservation techniques on the stable isotope values of samples in these collections. Many studies have identified changes in stable isotope values of samples as a result of preservation (Dannheim et al. 2007; Edwards et al. 2002; Fleming et al. 2011; Sarakinos et al. 2002; Syvaranta et al. 2011). Incorporating these samples into stable isotope analysis has the potential to lead to skewed results and erroneous conclusions (Dannheim et al. 2007; Edwards et al. 2002; Fleming et al. 2011; Sarakinos et al. 2002; Syvaranta et al. 2011).

Understanding the direction and magnitude of the effects of preservation on stable isotope analysis can allow researchers to overcome differences in preparation techniques through the application of correction factors. Numerous studies have identified and suggested appropriate correction factors for the effects of commonly used preservation chemicals on $\delta^{13}C$ and $\delta^{15}N$ values for a variety of taxa (Edwards et al. 2002; Syvaranta et al. 2011; Ventura and Jeppesen 2009). Many of these studies also have identified taxon dependent effects of preservation (Edwards et al. 2002; Sarakinos et al. 2002; Syvaranta et al. 2011; Ventura and Jeppesen 2009); however, no study has addressed the effects of preservation techniques on mammals.

The majority of mammals housed in natural history collections are in the form of study skins and preparation techniques for these skins vary with time period and natural history collection. Skins in natural history collections can be separated into 3 general classes: 1. Taxidermy mounts, in which the skin is placed over a frame to depict a “real life” posture of the animal. These skins might be tanned or dried. 2. Dried skins are generally stretched over fibrous material, sewed back together, and laid flat, or occasionally left to dry flat with no stuffing and the hide exposed. And 3, tanned skins, undergo a chemical process to alter the physical structure of the skin and preserve it.

Tanning was a commonly used historical method of skin preservation of medium to large-sized mammals (Jackson 1926). Use of tanning has decreased over time, but tanning is still used as a method of preservation in large mammals in many natural history collections. In this study, I examine effects of hide tanning versus hide drying on $\delta^{13}C$ and $\delta^{15}N$ values of hair collected from natural history collections.

MATERIALS AND METHODS

The striped skunk (*Mephitis mephitis*) is a member of the order Carnivora and the family Mephitidae; it is common in natural history collections. Historical preparations of this species include tanned and non-tanned specimens. Using the Mammal Networked Information System (MaNIS), I identified specimens of *M. mephitis* for sampling. I sampled 4 hairs from the dorsal region anterior to the pelvic girdle on each of 380 *M. mephitis* specimens housed in collections at the National Museum of Natural History (Washington, D.C.), the Museum of Vertebrate Zoology (Berkeley, California), the Texas Cooperative Wildlife Collection (College Station, Texas), the Sternberg Museum of Natural History (Hays, Kansas), the University of Kansas Natural History Museum (Lawrence, Kansas), and the University of Michigan Museum of Zoology (Ann Arbor, Michigan) (Appendix II). I made an effort to select white hair in the same growth stage and within the same region of the specimen. Museums often lacked records on preparation techniques of historical specimens, so I classified specimens as “tanned” or “not tanned” through observation. As it was difficult to distinguish tanned specimens from dried and flattened specimens, specimens were marked as tanned if they were a “flat” specimen. While, undoubtedly, some of these specimens were dried specimens, results using this approach would be conservative measures of the difference between preparation techniques.

To remove surface oils, I soaked hair in chloroform for 24 hours and rinsed 3 times (Keith and Leonard 2008, pers. comm.). I then cut samples into 5 mm sections, weighed to 0.5 mg, and placed into tin capsules. A GV Instruments Isoprime mass spectrometer with a Costech elemental analyzer was used to analyze samples for $\delta^{13}C$ and $\delta^{15}N$. All stable isotope data were reported in per mil notation ($\delta X = [R_{sample}/R_{standard}) -1] \times 1000$, where R is the stable isotope ratio $^{13}C/^{12}C$ or $^{15}N/^{14}N$). Repeated analysis of standards indicated measurement error of approximately 0.5‰ for $\delta^{13}C$ and 0.3‰ for $\delta^{15}N$.

The decrease in atmospheric $\delta^{13}C$ values, caused by the input of fossil fuel emissions, known as the Suess effect (Keeling et al. 1979), also decreases the $\delta^{13}C$ values of animal samples. Temporal changes in $\delta^{13}C$ values of animal samples due to the Suess effect are highly predictable, and correcting for this effect has been shown to increase comparability of $\delta^{13}C$ data in long-term datasets (Hilton et al. 2006; Long et al. 2005; Verburg 2006). I corrected for the Suess effect in this dataset by 0‰ to 1.77‰ (Francey et al. 1999; Keeling et al. 2001; Long et al. 2005).

No tanned specimens were available for sampling after 1966; therefore, I did not include specimens collected after 1966 to reduce temporal variation in the dataset. Studies have shown juvenile and sub-adult mammals have enriched $\delta^{15}N$ values compared to adult mammals, due to additional $^{15}N/^{14}N$ fractionation associated with nursing (Newsome et al. 2006). Thus, juveniles and sub-adults were not included in analyses.

To assess the effect of tanning on $\delta^{13}C$ and $\delta^{15}N$ values, I used a Welch two sample t-test to analyze the stable isotope hair data. To help ensure observed differences were not the result of spatial and temporal variation in the collection of samples, I also used analyses of covariance (ANCOVA) for both $\delta^{13}C$ and $\delta^{15}N$ to analyze the data, incorporating latitude, longitude, and year as covariates. I ran statistical analyses in program R (ver. 2.14.1; R Core Development Team).

RESULTS

Mean $\delta^{13}C$ was depleted approximately 1.4‰ in tanned specimens (-17.6 ± 2.0‰) compared to non-tanned specimens (-16.3 ± 0.7‰; Welch two sample t-test, t=4.361, df=161.647, P<0.001). Mean $\delta^{15}N$ also was depleted in tanned specimens (7.2 ± 1.2‰) by approximately 0.8‰ when compared to non-tanned specimens (8.0 ±0.4‰, t=3.779, df=167.313, P<0.001).

Preparation technique had a significant effect on $\delta^{13}C$ values of hair after the covariates were removed (ANCOVA; F=22.721, df=1, 338, P<0.001). Longitude was related to $\delta^{13}C$ values (F=4.267, df=1,338, P=0.040), but latitude (F=3.109, df=1,338, P=0.080) and year (F=0.166, df=1,338, P=0.684) had no significant affect. Preparation technique also had a significant effect on $\delta^{15}N$ values of hair after covariates were removed (ANCOVA; F=26.417, df=1, 340, P<0.001). Latitude (F=13.111, df=1,340, P<0.001), longitude (F=51.340, df=1,340, P<0.001), and year (F=5.958, df=1,340, P<0.001) were related to $\delta^{15}N$.

DISCUSSION

My results for the effect of tanning on $\delta^{13}C$ were comparable to those from studies examining the use of formalin for fixation in fluid specimens, and generally greater than effects of ethanol (cf. Table 1 in Sarakinos et al. 2002). Tanning had a greater effect on $\delta^{15}N$ values than did formalin or ethanol as a preservative with the exceptions of formalin in winter flounder and marine zooplankton (Bosley and Wainright 1999; Sarakinos et al. 2002).

The tanning process presents possible explanations for the depletions in $\delta^{13}C$ and $\delta^{15}N$. The process of baiting uses enzymes to remove non-structural proteins (Covington 2009). If the proteins that are removed by the enzymes are enriched $\delta^{13}C$ and $\delta^{15}N$ relative to other portions of the hair, then removal of these proteins might explain the depletions observed in these stable isotopes. Deliming involves the addition of acids or acidic salts to the skins. While the effects of acids on stable isotope values are controversial, treatment of samples with acids has been shown to affect stable isotope values of some species (Bosley and Wainright 1999; Bunn et al. 1995).

Additionally, tanning methods involving the soaking of skins in ethanol or similar organic solvents could explain the observed depletions; however studies have indicated the effect of ethanol on $\delta^{13}C$ and $\delta^{15}N$ values of samples is less than was observed in my study (Sarakinos et al. 2002). Furthermore, use of tannic acid in tanning, derived from bark of C_3 plants was common until the mid-1900s (Covington 2009). As tannic acid was historically derived from C_3 plants, it likely has similar stable isotope values to the original plant, and exchange with or accumulation of light C_3 carbon and primary producer nitrogen from the tannic acid solution by tanned hides could be a possible explanation for the lower $\delta^{13}C$ and $\delta^{15}N$ values of higher trophic level *M. mephitis* observed in this study. Similar explanations for exchange or accumulation of carbon are suggested to explain alterations in stable isotope ratios due to fixation in formalin or ethanol (Edwards et al. 2002).

In the general context of food web studies, the effects of tanning on $\delta^{13}C$ and $\delta^{15}N$ values were small when compared to the differences between C_3 (-24‰ to - 34‰) and C_4 (-6‰ to -19‰) plants and a trophic enrichment factor between 3‰ to 5‰ for $\delta^{15}N$ (Peterson and Fry 1987; Smith and Epstein 1971). However, recent studies have indicated small variations in stable isotope values used in Bayesian mixing models, similar in magnitude to the effect of tanning; have a substantial effect on the assignment of diet proportions (Bond and Diamond 2011). Therefore, it is imperative these effects are corrected for when conducting mixing model analyses by using a Bayesian framework.

The differences between the means for tanned hides and non-tanned hides in this study for both $\delta^{13}C$ and $\delta^{15}N$ were conservative measures due to the probable inclusion of non-tanned dried skins as tanned skins. The true difference between means could be greater. In addition, numerous tanning methods have been used and these methods vary in the chemicals used (Covington 2009). Logically, these different procedures could affect stable isotope values differently.

Additional experiments are needed to identify variations in stable isotope values due to different tanning processes, if these specimens are to be of use in stable isotope analyses. In addition, a paucity of studies has focused on identifying the effects of other preservation techniques used in dry collections. Numerous pesticides and pest deterrents have been used in natural history collections. The effects of repeated exposure to these chemicals on δ^{13}C and δ^{15}N values of animal samples have not been evaluated. Examining the effects of preservation practices on stable isotope values should be a priority, as these practices have the potential to affect interpretation of results from stable isotope analysis.

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CHAPTER 5

SPATIAL AND TEMPORAL DIET ANALYSIS OF TWO MEPHITIDAE AS DETERMINED BY $\delta^{13}C$ AND $\delta^{15}N$ STABLE ISOTOPE ANALYSIS

Stable isotope analysis has become a valuable tool in ecological studies. Because stable isotope values of animal samples reflect those of the diet, stable isotopes are used widely in food web and trophic level studies (Fry 2006). The most commonly used stable isotopes in such studies are carbon and nitrogen. $\delta^{13}C$ can provide an indication of the initial food source. In terrestrial systems, $\delta^{13}C$ can be used to differentiate C_3 plants from C_4 plants (Smith and Epstein 1971). $\delta^{15}N$ can indicate trophic level, as it shows a stepwise enrichment of 2.6‰ to 3.4‰ with every trophic level (Deniro and Epstein 1978). While many types of samples are available for stable isotope analysis, hair is particularly useful because it is metabolically inert after growth. As such, $\delta^{13}C$ and $\delta^{15}N$ values reflect the diet at the time the hair was grown (Roth and Hobson 2000). This allows researchers to determine the diet of an organism over time. In addition, the stability of $\delta^{13}C$ and $\delta^{15}N$ values of hair allows researchers to use historical samples from natural history collections. While the benefits of museum collections for determining diets of rare or elusive species via stable isotope analysis has been documented, the use of stable isotope analysis in detecting dietary changes over time has just recently started to receive attention (Hilton et al. 2006; Jaeger and Cherel 2011; Norris et al. 2007). Researchers have used natural history collections to examine diets in declining marine species over the course of their decline (Hilton et al. 2006; Jaeger and Cherel 2011; Norris et al. 2007). However, studies of terrestrial species have yet to use stable isotope analysis in a similar manner. Studies such as these provide opportunity to analyze the effects of widespread changes caused by agricultural intensification and urbanization on terrestrial communities in the 19th and 20th centuries (Hilton et al. 2006; Norris et al. 2007).

The eastern spotted skunk (*Spilogale putorius*) is a small mesocarnivore in the family Mephitidae, similar in ecology to the striped skunk (*Mephitis mephitis*). Both species have a similar diet composition, although *M. mephitis* is considered more insectivorous (Selko 1937). *Mephitis mephitis* uses a variety of habitat types and is thought to be a habitat generalist (Cervantes et al. 2002; Rosatte et al. 2011; Wade-Smith and Verts 1982; Weissinger et al. 2009). While habitat preferences between both species appear to overlap, a preference for dense vegetation by *S. putorius* has been emphasized in the literature (Lesmeister et al. 2009). However, few studies have been conducted on habitat use of *S. putorius* in agricultural landscapes, and *S. putorius* is known to intensively use croplands in agriculture areas (Crabb 1948). In addition, studies have identified a propensity in both species to use rural outbuildings as den sites (Choate et al. 1973; Crabb 1948; Lariviere et al. 1999).

Once common, *S. putorius* has declined throughout much of its range and is now classified as vulnerable, imperiled, critically imperiled, or extirpated in almost every state where it was once commonly found (Patterson et al. 2003; See figure 3.2). Gompper and Hackett (2005) note as a diet generalist with a large geographic range, declines in this species were unexpected, as similar species have maintained stable populations or increased during this time.

Mephitis mephitis, while also experiencing population declines during this period, has maintained secure populations throughout its range (Landholt and Genoways 2000; Patterson et al. 2003; Chapter 3). This is especially interesting, given the degree of similarity in natural history of *S. putorius* and *M. mephitis*. Due to these similarities in natural history and in the timing and duration of the decline of both species, possibly the same factors precipitated the decline in *S. putorius* and *M. mephitis* (Chapter 3).

Despite its conservation status, the cause of the decline of *S. putorius* remains unknown (Gompper and Hackett 2005). One suggestion for the cause of the decline in *S. putorius* is a change in agricultural practices decreased abundance of prey species, which left *S. putorius* with insufficient food to maintain historical population sizes (Choate et al. 1973; Gompper and Hackett 2005).

The transition and maintenance of land to agriculture has deleterious effects on many species and has been shown to affect populations of many of the prey species of *S. putorius* (Crabb 1941; Mankin and Warner 1999; Oleske et al. 1997; Peles et al. 1997; Rattner 2009). Previous research has identified landscape changes that could be responsible for the decline in *S. putorius* (Chapter 2), several of which affect the diet of other mesocarnivores (Caryl et al. 2012; Newsome et al. 2010; Sovada et al. 2001).

I sought to test the premise that change in landscape structure, characterized by the transition from small-extent, low intensity, diverse farms to large-extent, high intensity, monoculture caused a change in the diet of *S. putorius* and *M. mephitis.* Furthermore, this change in diet corresponds with population declines in these species. I tested four primary hypotheses: 1) local landscape structure and composition affected diet composition of *S. putorius* and *M. mephitis,* 2) there have been changes in landscape structure corresponding with the decline of *S. putorius*, 3) there have been changes in the diet of *S. putorius* corresponding to the decline of *S. putorius* and these same changes will not be observed in the same magnitude or direction in *M. mephitis* specimens, and 4.) states in which populations of *S. putorius* have remained stable either did not change in diet composition over time or changes differed in magnitude or direction of dietary change.

MATERIALS AND METHODS

For stable isotope and landscape analyses, I sampled 544 *Mephitis mephitis* and 315 *Spilogale putorius* specimens from the National Museum of Natural History (Washington, D.C.), the Museum of Vertebrate Zoology (Berkeley, California), the Texas Cooperative Wildlife Collection (College Station, Texas), the Sternberg Museum of Natural History (Hays, Kansas), the University of Kansas Natural History Museum (Lawrence, Kansas), and the University of Michigan Museum of Zoology (Ann Arbor, Michigan) (Appendix III). I limited *M. mephitis* specimens sampled to states within the range of *S. putorius*. Collection year for specimens ranged from 1852 to 2012. Samples consisted of 4 hairs from each *M. mephitis* individual or 14 hairs from each *S. putorius* individual. When possible, I sampled white hair, in the same growth phase, from the dorsal region immediately anterior to the pelvic girdle. From 2011 to 2012, I opportunistically collected 8 additional *M. mephitis* samples from Kansas road kills. I obtained voucher data for all specimens from the Mammal Networked Information System (MANIS). If locality data were available, I georeferenced specimens without latitude and longitude data with GeoLocate software (Rios and Bart 2010). If only county name was available, I used latitude and longitude for the center of the county.

To remove surface oils, I soaked hair in chloroform for 24 hours and rinsed 3 times (Keith and Leonard 2008, pers. comm.). I then cut samples into 5 mm sections, weighed to 0.5 mg, and placed into tin capsules. A GV Instruments Isoprime mass spectrometer with a Costech elemental analyzer was used to analyze samples for $\delta^{13}C$ and $\delta^{15}N$. All stable isotope data were reported in per mil notation ($\delta X = [R_{sample}/R_{standard}) -1] \times 1000$, where R is the stable isotope ratio $^{13}C/^{12}C$ or $^{15}N/^{14}N$). Repeated analysis of standards indicated measurement error of approximately 0.5‰ for $\delta^{13}C$ and 0.3‰ for $\delta^{15}N$.

The decrease in atmospheric $\delta^{13}C$ values, caused by the input of fossil fuel emissions, known as the Suess effect (Keeling et al. 1979), also decreases the $\delta^{13}C$ values of animal samples. Temporal changes in $\delta^{13}C$ values of animal samples due to the Suess effect are highly predictable, and correcting for this effect has been shown to increase comparability of $\delta^{13}C$ data in long-term datasets (Hilton et al. 2006; Long et al. 2005; Verburg 2006). I corrected for the Suess effect in this dataset by 0‰ to 1.77‰ (Francey et al. 1999; Keeling et al. 2001; Long et al. 2005).

Tanning of skins depletes $\delta^{13}C$ and $\delta^{15}N$ values of hair (Chapter 4), and thus, I did not include tanned specimens in analyses (Chapter 4). Studies have shown juvenile and sub-adult mammals have enriched $\delta^{15}N$ values compared to adult mammals due to additional $^{15}N/^{14}N$ fractionation associated with nursing (Newsome et al. 2006). As such, I also did not include juveniles and sub-adults in analyses.

Effects of Melanin— In studies of birds, Michalik et al. (2010) indicated colored feathers were significantly depleted in $\delta^{13}C$ when compared to white feathers, presumably due to the presence of melanin in black feathers. As the effect of melanin has not been tested in mammals, I examined the effect of coloration in mammalian hair on $\delta^{13}C$ and $\delta^{15}N$ values of mammalian hair.

There are 2 types of melanin in mammal hair: eumelanin, responsible for black and brown coloration in hair, and pheomelanin, responsible for red coloration in hair (Simon and Peles 2010). I selected 8 species, which had distinct areas of eumelanin or pheomelanin containing hair (i.e., colored hair) and melanin-lacking hair (i.e., white hair). I sampled approximately 0.5 mg of white hair and of colored hair from the base of the tail on 5 black-tailed jackrabbit (*Lepus californicus*), and 4 eastern cottontail (*Sylvilagus floridanus*), the ventral region of 5 Canadian lynx (*Lynx rufus*), dorsal immediately anterior to the pelvic girdle of 15 *M. mephitis* and 5 *S. putorius*, and the chest of 5 gray fox (*Urocyon cinereoargenteus*), 5 swift fox (*Vulpes velox*), and 4 red fox (*V. vulpes*). I obtained specimens from the Fort Hays State University teaching collection, the Sternberg Museum of Natural History, the University of Kansas Natural History Museum, and from road kill (Appendix IV). When possible, I sampled white and colored hair in the same growth phase and in close proximity to other sampled hairs from the same specimen. Preparation and analysis of stable isotope samples followed that described above for *S. putorius* and *M. mephitis*.

I first analyzed data irrespective of species to determine the effects of melanin-containing versus melanin-lacking hair on $\delta^{13}C$ and $\delta^{15}N$ values. I also used paired sample t-tests to examine the data by species for interspecific differences in the effects of melanin content on $\delta^{13}C$ and $\delta^{15}N$ values by species. I applied the modified false discovery rate (FDR) developed by Benjamini and Yekutieli to correct for multiple comparisons. As there were 16 comparisons, I adjusted the significance level from $\alpha=0.05$ to $\alpha=0.015$ (Narum 2006). I performed statistical analyses in program R (ver. 2.14.1; R Core Development Team).

Landscape effects—I limited specimens of *S. putorius* and *M. mephitis* to Kansas specimens with locality data for fine-extent analysis of landscape structure on diet as determined by $\delta^{13}C$ and $\delta^{15}N$. I obtained historical and current aerial imagery for Kansas specimens within 10 years of the specimen collection date by using the Kansas Geospatial Data Library and United States Geological Survey Earth Explorer. I obtained imagery for 26 *M. mephitis* individuals from 14 counties dating from 1936 to 2011 and 28 *S. putorius* specimens from 12 counties dating from 1941 to 2010 (Appendix V). I aligned landscape imagery to 2010 National Aerial Imagery Program (NAIP) imagery and created 10 km buffers around the latitude and longitude coordinates for each specimen. I visually determined and classified land cover types to 10 x 10 m resolution into cropland, grassland/pasture, woodland, residential, bare ground, water, roads, and road ditches. I selected these classifications based on ecological relevance and the ability to distinguish between classification types. I created 5 buffers based on home range size, and specimen location accuracy for landscape analysis 1.5 km, 2.5 km, 3.5 km, 4.5 km, and 5.5 km (Greenwood et al. 1997; Lesmeister et al. 2009; Rosatte et al. 2011; Weissinger et al. 2009).

Using FRAGSTATS, I calculated ecologically relevant metrics thought to have biological meaning according to the literature (McGarigal et al. 2012). Data on maize harvested was from the United States Department of Agriculture Census of Agriculture data. I eliminated highly correlated variables ($R^2 \geq 0.80$) from simultaneous consideration in models. I created multiple linear regression models by using combinations of the following variables; percent of land in woodland, percent of land in grassland, percent of land in residential, patch richness density, edge density and interspersion and juxtaposition, for $\delta^{15}N$ and amount of maize in the habitat also was included for $\delta^{13}C$. I used Akaike Information Criterion (AIC) to compare model performance. I examined the suite of R^2, Akaike model weights, and *F*-statistics for top models across buffer sizes, and based final selection of buffer size on model performance and home range size (Lesmeister et al. 2008; Rosatte et al. 2011). Additionally, these models served to assess the impact of locality error on model assignment.

Finally, landscape variables that models suggested influence $\delta^{13}C$ and $\delta^{15}N$ were substituted with comparable state level metrics, if available. These state level metrics were then incorporated into a global models containing trapping effort to explain the Kansas population trends in *M. mephitis* and *S. putorius* described in Chapter 2. I again created a number of multiple linear regression models containing parameters from the global model thought to explain population trends and used AIC to determine the best model. I performed statistical analyses in R and Microsoft Excel.

Mixing models—I collected potential diet sources in the summer of 2011 from Hays, Kansas (38.87917, -99.32639). As Mephitidae use numerous habitat types, I set traps in a variety of habitat types common to Kansas including agricultural fields (5 sites), riparian habitat (1 site), native grassland (1 site), reclaimed grassland (1 site), and hayed grassland (1 site). I trapped potential mammalian prey species over approximately 160 trap nights in each of the 9 sites. Samples consisted of hair clipped from the rump of each individual. I released individuals after sampling. I used shaved patches to identify recaptures, thereby assuring independent samples. I opportunistically obtained additional samples of prairie vole (*Microtus ochrogaster*) from roadside trapping, and eastern cottontail (*Sylvilagus floridanus*) and black-tailed jackrabbit (*Lepus californicus*) from incidental road kills. Preparation and analysis of mammalian stable isotope samples followed that described above for *S. putorius* and *M. mephitis*.

I took 20 sweep net samples and 20 pit fall trap samples for potential arthropod prey sources at each site. After sampling, I promptly froze arthropod samples until they could be dried for 72 hours and identified to family. Using the literature, I determined feeding guilds of each arthropod family (Table 5.1; Daly et al. 1998; Jackman 1997; Triplehorn et al. 2005). If available, I selected 15 members of each feeding guild for stable isotope analysis (10 from agricultural habitats and 5 from grassland habitats). Arthropods for which a specific diet type could not be assigned were not considered for stable isotope analysis. Prior to homogenizing samples indigestible chitinous material from selected arthropods was removed. I then weighed samples to 0.5 mg and placed them into tin capsules for analysis. I obtained $\delta^{13}C$ and $\delta^{15}N$ values for maize grain from Rossi et al. (2007), for consideration in mixing model analysis ($\delta^{13}C$ values of maize corrected for the Suess effect: -10.77 ± 0.24, and $\delta^{15}N$ values of maize: 8.19 ± 0.13).

I assumed $\delta^{13}C$ and $\delta^{15}N$ values of sampled prey species were consistent representations of the $\delta^{13}C$ and $\delta^{15}N$ values of these species through time and across the landscape. To reduce the probability that collected food items sampled were not a representation of those found in other regions; I used only samples from 90 *M. mephitis* and 89 *S. putorius* specimens collected in Kansas for mixing model analysis (Appendix VI). I made an effort to sample prey species in a variety of habitats in Kansas in an attempt to encompass the natural variability in prey diets across Kansas. Variability in diet across the state and over time was possible, and such variability would introduce error into the models. Additionally, I assumed diets of mammalian prey items were comparable between period of time for hair growth and the time they were sampled.

Using a MANOVA followed by a Tukey's honestly significant difference (HSD) test, I examined $\delta^{13}C$ and $\delta^{15}N$ values to assess the validity of assigned feeding guilds for mammals and arthropods (Cameron and Spencer 1981; Chapman et al. 1980; Daly et al. 1998; Jackman 1997; Lackey et al. 1985; Mccarty 1978; Stalling 1990; Streubel and Fitzgerald 1978; Triplehorn et al. 2005; Webster and Jones 1982; Wilkins 1986; Wolff et al. 1985). The most common diet components from the literature were included in mixing model analyses (Crabb 1941; Dixon 1925; Greenwood et al. 1999; Hamilton 1936; Kelker 1937; Llewellyn and Uhler 1952; Selko 1937). I used Stable Isotope Analysis in R (SIAR) software to conduct mixing model analyses with $\delta^{13}C$ and $\delta^{15}N$, incorporating the most common diet components by guild if applicable. I corrected for $^{15}N/^{14}N$ fractionation between trophic levels, and differences in $^{13}C/^{12}C$ between digestible mammalian muscle tissue and the sampled indigestible mammalian hair by incorporating correction factors in mixing model analysis (Codron et al. 2006). As the variance of δ^{15}N had increased significantly over time in *M. mephitis* and *S. putorius*, I used the single data points command to analyze individual diets. I ran 500,000 iterations of the model with a burnin of 50,000. Comparing inter-quartile ranges of individuals over time, which represents high probabilities of a specific solution occurring, I examined temporal diet trends. I used program R to perform statistical analyses.

State level changes—In total, 401 *M. mephitis* and 269 *S. putorius* specimens from 24 and 20 states, respectively, were used to examine state-level changes in diet (Appendix VII). At the coarsest level, I employed multiple linear regression analysis to examine the effects of latitude, longitude, and collection year on δ^{13}C and δ^{15}N values over the sampled range of *M. mephitis* and *S. putorius*. I tested for violations of the assumptions of normality and heterogeneity with a quartile-quartile plot and a residual plot for the multiple regression models. If 10 samples or greater were available, I tested for changes in δ^{13}C and δ^{15}N over time at the state level with Pearson correlations. I used the modified FDR developed by Benjamini and Yekutieli to correct for multiple comparisons while running correlation analyses. As there were 26 comparisons, I adjusted the significance level from $\alpha=0.05$ to $\alpha=0.013$ for correlations (Narum 2006). δ^{15}N for *M. mephitis* and *S. putorius* from Kansas displayed an obvious increase in variance over time that could not be attributed to sample size. I used quantile regression analysis to examine temporal trends in δ^{15}N for these species. I also graphically examined trends in δ^{13}C and δ^{15}N over time by state. I ran statistical analyses in program R.

While I made an effort to sample evenly in space and time, sampling was constrained almost entirely to specimens collected and housed in museums. Thus, sampling was subject to many of the limitations of these collections. For example, specimens are often collected near large museums or in areas where annual sampling is conducted. In addition, museums display fluctuations over time in the type and number of animals collected. These fluctuations are probably because of funding availability and differences in museum personnel. Therefore, samples might violate assumptions of independence both in space and time, despite efforts otherwise.

In addition, specimen locality data were assumed to be exact for these analyses. This was a problematic assumption given many localities were georeferenced from locality data on museum specimens. While specimens with large locality errors were discarded from fine-extent landscape analysis, common locality errors were about 1 km. As there was little variation in top models for the effect of fine-extent landscape structure on diet, I feel this was an appropriate assumption.

RESULTS

Effects of melanin—There was no significant difference between colored and white hair for either $\delta^{13}C$ (t=-1.178, df=47, P=0.245) or $\delta^{15}N$ (t=0.126, df=47, P=0.901) values across species. Similarly, there were no significant differences for either $\delta^{13}C$ or $\delta^{15}N$ values of hair within species (Table 5.2).

Landscape effects—All landscape buffer levels had similar model performance and yielded top models with similar variables. As the buffer size did not appear to affect model performance, I selected a 1.5 km buffer for $\delta^{13}C$ and $\delta^{15}N$ values for *M. mephitis*

(Table 5.3, Table 5.4) and *S. putorius* (Table 5.5, Table 5.6) as it most closely resembles the level at which these species use the landscape based on home range size (Greenwood et al. 1997; Lesmeister et al. 2009; Rosatte et al. 2011; Weissinger et al. 2009).

There was 1 model with considerable support for explaining δ^{13}C values of *M. mephitis*. The top model included maize harvested in the county (AIC_c=110.521, W_i=0.41, adjusted R^2=0.199, F=6.952, df=1, 23, P=0.015), larger amounts of maize in the habitat was positively related to δ^{13}C. Eight models had considerable support for explaining δ^{15}N. The top model included percent of land in woodland and interspersion and juxtaposition (AIC_c=93.495, W_i=0.13, adjusted R^2=0.243, F=4.852, df=2, 22, P=0.018). Percent woodland was negatively related to δ^{15}N values, but interspersion and juxtaposition was positively related to δ^{15}N.

Four models had considerable support for explaining δ^{13}C values of *S. putorius*. All 4 models with considerable support included edge density. The top-ranking model contained solely edge density (AIC_c=132.676, W_i=0.27, adjusted R^2=0.381, F=12.97, df=2, 25, $P<0.001$), which was negatively related to δ^{13}C values. The model containing interspersion and juxtaposition, percent of grassland, and percent of residential was first of 2 models with considerable support for explaining δ^{15}N values of *S. putorius* (AIC_c=114.524, W_i=0.58, adjusted R^2=0.544, F=11.75 ,df=3,24, $P<0.001$). Increased interspersion and juxtaposition and percent grassland cover was positively related to δ^{15}N values, while percent residential cover in the landscape was negatively related to δ^{15}N.

Hectares of maize and woodland in Kansas were the only metrics available that could be compared to population trends in *M. mephitis* and *S. putorius*. Number of farms in Kansas was inversely related to average farm size and might be an indicator of agricultural intensification. As such, number of farms also was included in models to explain population trends. Trapping effort was highly correlated with hectares of maize harvested in the landscape and so was excluded from consideration with hectares of maize in the models. There were 2 models with considerable support for explaining *M. mephitis* harvested per year. The top-ranking model included number of farms and the amount of maize harvested in Kansas (AIC_c=335.611, W_i=0.57, adjusted R^2=0.893, F = 55.190, df = 2, 11, $P < 0.001$), while the second model contained the number of farms and trapping effort (AIC_c = 336.209, W_i = 0.42, adjusted R^2 = 0.888, F = 52.650, df=2, 11, $P < 0.001$) (Table 5.7). Maize, the number of farms, and trapping effort all positively related to the number of *M. mephitis* harvested. *Spilogale putorius* had 3 models with considerable support; the top model contained maize as the only variable (AIC_c = 231.455, W_i = 0.35, adjusted R^2 = 0.818, F = 41.570, df = 1, 8, P <0.001, Table 5.8). The amount of maize in the landscape positively related to the number of *S. putorius* harvested. While it should be noted sample size for these models was small because the census occurred every 5 years, observed trends in maize and number of farms displayed little variation from the general trend observed in maize and number of farms over time.

Mixing models— Mean δ^{15}N values of *M. mephitis* were lower than δ^{15}N values of *S. putorius* (t=-5.076, df=508.529, P<0.001), the difference in the means being approximately 0.9‰ (7.8‰ and 8.7‰, respectively). δ^{13}C values were not significantly different between the 2 species (t=-0.706, df=595.928, P=0.480).

Nine potential mammalian prey species were sampled for mixed model analysis; 1 thirteen-lined ground squirrel (*Ictidomys tridecemlineatus*), 4 *Lepus californicus*, 1 prairie vole (*Microtus ochrogaster*), 7 house mouse (*Mus musculus*), 3 northern grasshopper mouse (*Onychomys leucogaster*), 51 deer mouse (*Peromyscus maniculatus*), 7 *Reithrodontomys* sp., 4 hispid cotton rat (*Sigmodon hispidus*), and 2 *Sylvilagus floridanus*. The literature defined 3 major diet categories for these species as herbivorous, herbivorous bordering on omnivorous and omnivorous bordering on carnivorous (Table 5.9; Cameron and Spencer 1981; Chapman et al. 1980; Lackey et al. 1985; Mccarty 1978; Stalling 1990; Streubel and Fitzgerald 1978; Webster and Jones 1982; Wilkins 1986; Wolff et al. 1985). Multiple analysis of variance tests followed by Tukey's HSD indicated these groups had different $\delta^{13}C$ and $\delta^{15}N$ values (F=14.099, df=2, 77, P<0.001) and this difference was significant among all groups (Table 5.10, Table 5.11).

I collected 54 arthropod families and separated them into 5 feeding guilds (fluid feeding, herbivore, omnivore, carnivore, and spider) according to Daly et al. (1998), Jackman (1997), and Triplehorn et al. (2005). Fifty five individuals from 33 families were selected randomly for stable isotope analysis, based on feeding guild association. There was a significant difference among diet guilds for arthropods (MANOVA: F=2.308, df=8, 49, P=0.026); however, post-hoc Tukey's HSD test indicated no significant difference among groups for $\delta^{13}C$ or $\delta^{15}N$ (Table 5.12, Table 5.13).

Mammalian species composing the diet guilds herbivorous and omnivorous - carnivorous make up a majority of the mammalian diet of *M. mephitis* and *S. putorius*

(Crabb 1941; Dixon 1925; Greenwood et al. 1999; Hamilton 1936; Kelker 1937; Llewellyn and Uhler 1952; Selko 1937). For this reason and because of the degree of overlap in stable isotope values between omnivorous-herbivorous and herbivorous species and omnivorous-herbivorous and omnivorous-carnivorous species, only herbivorous species and omnivorous-carnivorous species (hereafter termed omnivorous) were included in mixing model analyses. As δ^{13}C and δ^{15}N stable isotope values could not distinguish between diet groups in insects, the commonly consumed families Acrididae and Carabidae were used in the analysis. Maize was the only plant source commonly identified in the diet of *S. putorius* and *M. mephitis* (Crab 1941, Hamilton 1936), and therefore, was the only plant species included in mixing model analyses.

Likely solutions from mixed model analyses, as inferred from individual inter-quartile ranges, suggested *S. putorius* and *M. mephitis* displayed a large range of possible proportions for each tested diet source. They also suggested maize grain was the most common diet component for *M. mephitis* and *S. putorius* (Fig. 5.1, Fig. 5.2). The possible proportion of maize in the diet of *M. mephitis* had remained high but variable over time. The potential proportion of maize in the diet of *S. putorius* appeared to have decreased in the early 1900s. Although there was a great degree of individual variation after the early 1900s, the potential proportion of maize in the diet of *S. putorius* might have increased after 1970.

Inter-quartile range solutions of omnivorous mammals, suggested proportion of omnivorous mammals in the diet had remained relatively stable in *M. mephitis* (Fig. 5.3). Prior to 1940, the proportion of omnivorous mammals in the diet of *S. putorius* was relatively stable (Fig. 5.4). In the 1940s, proportion of omnivorous mammals in the diet of *S. putorius* increased considerably, and afterward, the proportion of omnivorous mammals varied highly by individual. A large degree of individual variation was evident in the inter-quartile range solutions for proportions of herbivorous mammals to the diets of *M. Mephitis* and *S. putorius* (Fig. 5.5, Fig. 5.6), although variability was greater in *S. putorius* and appeared to be cyclic. Relative importance of herbivorous mammals to the diet of *M. mephitis* appeared to have increased in some *M. mephitis* individuals in the last decade. Dietary contribution of Acrididae, as determined from the inter-quartile range, had remained low in *M. mephitis* and *S. putorius*, only displaying considerable dietary importance in a few *M. mephitis* and *S. putorius* individuals in 1889 to 1890 and again in from 2007 to 2008 (Fig. 5.7, Fig. 5.8). *S*olutions for Carabidae in the diet for both *M. mephitis* and *S. putoriu*s showed no temporal trends (Fig. 5.9, Fig. 5.10).

State Level changes—Models including latitude, longitude, and year were significant for both δ^{13}C (multiple linear regression: adjusted R^2=0.123, F= 18.8, df =3, 378, P<0.001) and δ^{15}N (multiple linear regression: adjusted R^2=0.159, F=25.11, df=3,380, P<0.001) values of *M. mephitis* and *S. putorius* (adjusted R^2=0.215, F= 25.12, df =3, 260, P<0.001 and adjusted R^2=0.361, F=50.43, df=3, 260, P<0.001, respectively). Latitude (P<0.001), longitude (δ^{15}N: P<0.001, δ^{13}C: P=0.006) and year (δ^{15}N: P=0.003, δ^{13}C: P< 0.001), affected δ^{15}N and δ^{13}C values of *M. mephitis*. For *M. mephitis*, δ^{15}N and δ^{13}C values of specimens decreased northward and increased westward and over collection year (Fig. 5.11). For *S. putorius,* longitude (P<0.001) and year (P=0.011) explained variation in δ^{13}C, while only longitude explained variation in δ^{15}N (P<0.001).

δ^{13}C values increased with collection year and both δ^{13}C and δ^{15}N values increased westward (Fig. 5.12).

State-by-state examination indicated δ^{15}N decreased over collection year in Florida for *M. mephitis* (r=-0.515, F=-2.879, N=25, P=0.008; Fig. 5.13) and *S. putorius* (r=-0.444, F=-2.845, N=35, P=0.008; Fig. 5.14). *Spilogale putorius* increased in δ^{15}N over collection year in Oklahoma (r=0.690, F=-3.569, N=16, P=0.003; Fig. 5.14) and displayed a nearly significant increase in δ^{15}N over collection year in Iowa (r_s=0.7164, F=3.080, N=11, P=0.013; Fig. 5.14). No other significant trends were observed in any state for either δ^{13}C or δ^{15}N values of *M. mephitis* (Table 5.14, Fig. 5.14) or *S. putorius* (Table 5.15, Fig 5.16).

Quantile regression analysis of δ^{15}N over collection year for *M. mephitis* indicated significance in the 0.5 and 0.75 quantiles, with the highest quantiles showing the greatest slopes (Fig. 5.17, Table 5.16). Quantiles 0.5, 0.75, and 0.95 showed significant relationships between δ^{15}N and collection year for *S. putorius*, displaying progressively steeper slopes as the quantiles increased from 0.5 (Fig. 5.18, Table 5.17).

DISCUSSION

There was no difference between melanin-containing and melanin-lacking hair for both δ^{13}C and δ^{15}N values. It was unclear if significance was not detected because melanin-containing hair was not significantly different in δ^{13}C and δ^{15}N values compared to melanin-lacking hair, measurement error was too large to detect small differences, or differences were masked by greater variability in the δ^{13}C and δ^{15}N values Regardless, if a small difference exists; it was unlikely to affect interpretation of results. As such, I did not eliminate samples from future analyses based on hair color.

$\delta^{13}C$ and $\delta^{15}N$ results supported the literature indicating *S. putorius* and *M. mephitis* are generalists (Crabb 1941; Dixon 1925; Greenwood et al. 1999; Hamilton 1936; Kelker 1937; Llewellyn and Uhler 1952; Selko 1937). Results also supported historical studies indicating *S. putorius* was the more carnivorous species (Selko 1937). There was no difference in the $\delta^{13}C$ between the species, suggesting they, or their prey base, similarly rely on C_3 and C_4 plants.

Fine-extent analysis indicated that edge density was highly associated with depleted $\delta^{13}C$ woodland edge habitat, and the negative relationship between $\delta^{13}C$ and edge density observed in *S. putorius* probably reflected increased foraging in or near woodland habitats where they were available. While woodland edge habitat was not included in the models due to its high positive correlation with edge density, percentage of woodland habitat was included in the model. Interestingly, percentage of woodland habitat was not the best predictor variable for $\delta^{13}C$ values of *S. putorius*. This suggested, in Kansas, *S. putorius* targeted woodland edges for foraging areas rather than interior woodland, when woodland habitat was available in the landscape. Other mesocarnivores, such as raccoons (*Procyon lotor*) use woodland edge habitat more frequently than interior woodland (Dijak and Thompson 2000), but this trend has not been identified in *S. putorius*.

Agricultural crops are enriched in $\delta^{15}N$ compared to local vegetation, potentially a result of increased use of fertilizers (White et al. 2012). As a result, species that feed on agricultural crops are likely to be enriched in $\delta^{15}N$ compared to species inhabiting natural areas. Therefore, increased $\delta^{15}N$ with increased interspersion and juxtaposition of landscape elements, for *M. mephitis* and *S. putorius*, might suggest these species increasingly forage in cropland when cropland was near suitable habitat.

If true, modern agricultural practices involving large scale monoculture, even when comprised of suitable crop types for foraging, might not provide suitable foraging habitat due to the reduced proximity to and altered arrangement of suitable habitat types. In this manner, *M. mephitis* and *S. putorius* could be excluded from large portions of extant cropland historically used as foraging grounds.

Higher amounts of maize in the landscape increased $\delta^{13}C$ values of *M. mephitis*. As maize was enriched in $\delta^{13}C$, results suggested *M. mephitis* or its prey used maize as a food source more often when maize was more abundant in the landscape. Altering diet to take advantage of more abundant food resources is consistent with the categorization of *M. mephitis* as a diet generalist.

Percent grassland cover was inversely correlated with the percent of cropland in the landscape. As such, increased $\delta^{15}N$ values of *S. putorius* associated with percentage of grassland might indicate an increase in $\delta^{15}N$ values associated with the percent of cropland. This was likely considering the enrichment in $\delta^{15}N$ in cropland habitats versus grassland habitats (White et al. 2012). Furthermore, *M. mephitis* displayed the opposite trend, decreased $\delta^{15}N$ values with increased percent of grassland.

Alternatively, cropland contains lower insect diversity and biomass and probably a less complex trophic structure than grassland due to anthropogenic application of pesticides (Barrett 1968). Possibly, *S. putorius* fed at a higher trophic level in grassland habitats, thereby increasing the $\delta^{15}N$ values of this species in grassland rich areas. In addition, higher trophic enrichment factors have been observed in grassland habitat than in cropland (White et al. 2012). A higher trophic enrichment factor when foraging in grassland habitats, combined with a more complex trophic structure in grassland habitats, could potentially cause higher $\delta^{15}N$ values when foraging in grassland versus cropland.

Lower $\delta^{15}N$ values associated with higher amounts of woodland habitat probably reflects a change from $\delta^{15}N$ enriched crops (White et al. 2012) to potentially $\delta^{15}N$ depleted woodland vegetation. Alternatively, lower $\delta^{15}N$ values associated with woodland habitat could indicate a shift to lower tropic level mammals and insects in woodland rich habitats.

Spilogale putorius uses outbuildings associated with farms as hunting areas, due to the abundance of mammalian pest species that serve as a food source for *S. putorius* (Choate et al. 1973). Contrary to this hypothesis, common prey species such as *M. musculus* and *P. maniculatus* had relatively high $\delta^{15}N$ values. Instead, the observed decrease in $\delta^{15}N$ values of *S. putorius* associated with residential areas might reflect shifts in prey diet or increased consumption of herbivorous mammals in these habitats. Alternatively, decreased $\delta^{15}N$ values of *S. putorius* in residential areas could indicate consumption of low $\delta^{15}N$ containing human food waste (Newsome et al. 2010).

At the distribution level, stable isotope values indicated both species were responding to landscape change in approximately the same way. Increased $\delta^{13}C$ indicated there had been a shift from C_3 to C_4 plants in *M. mephitis* and *S. putorius* or their diet components over time. This change might result from exchange of woodland with C_4 cropland throughout much of the range of *S. putorius.* Additionally, this trend might indicate an increased reliance on human food waste or C_4 crops, such as maize, by *M. mephitis* and *S. putorius* over time.

Increases in $\delta^{15}N$ values of *M. mephitis* over time were observed over the sampled range. Similar significant or near significant increases in $\delta^{15}N$ values over time also were observed in states where *S. putorius* was listed as vulnerable, imperiled, or critically imperiled (Iowa, Oklahoma, and Kansas), although this trend was only observed above the 0.5 quantile in Kansas. Florida, one of the few states where *S. putorius* was reportedly common (Kinlaw 1995), was the only state to display a significant negative trend in $\delta^{15}N$ over collection year in both *M. mephitis* and *S. putorius.*

Enrichment in $\delta^{15}N$ values of *S. putorius* and *M. mephitis* might indicate a higher degree of foraging in cropland habitats these species or their prey. This explanation is also consistent with the observed increase in $\delta^{13}C$ values of *M. mephitis* and *S. putorius* over time. However, increased $\delta^{15}N$ values also could reflect an increase in anthropogenic use of fertilizers by over time.

As state trends in $\delta^{15}N$ values corresponded with the conservation status of *S. putorius,* dietary change could be associated with the decline of *S. putorius* and *M. mephitis*. Lack of significance in many states, except perhaps Kansas and Texas, might be a result of small sample size and a small temporal range within those samples and not necessarily indicative of a lack of change in those states.

Changes in diet across the landscape were also observed. Increased reliance on C_4 plants westward in *M. mephitis* and *S.putorius* and C_3 plants northward in *M. mephitis* probably reflected the change in average plant $\delta^{13}C$ across the United States (Keith and Leonard 2008). Latitudinal trends were probably driven primarily by *M. mephitis* collected from Texas. For *M. mephitis* and *S. putorius*, $\delta^{15}N$ values increased westward, possibly indicating a higher trophic level in western portions of the range of *S. putorius* and corresponding *M. mephitis*. Increased $\delta^{15}N$ values westward could also indicate increased foraging in croplands in the Midwest.

$\delta^{13}C$ and $\delta^{15}N$ values of *M. mephitis* and *S. putorius* increased disproportionately west of 95° W, and correspond with geographical changes in annual precipitation. As such, longitudinal trends in $\delta^{15}N$ and $\delta^{13}C$ values of *M. mephitis* and *S. putorius* could be explained in part by a reduction in precipitation, reported to increase both stable isotopes in animal samples (Cormie and Schwarcz 1996; Gideon 2011).

The number of farms in Kansas over time was inversely related to the size of farms in Kansas over time (Chapter 2). This transition from many small farms to a few large farms is characteristic of agricultural intensification (Benton et al. 2003). The agglomeration of many small farms into few large farms is thought to have reduced rural buildings used as den sites for *S. putorius* and *M. mephitis* (Choate et al. 1973; Crabb 1948; Lariviere et al. 1999). This practice previously has been identified as a potential cause of decline for *S. putorius* (Choate et al. 1973). Results indicating the importance of number of farms in explaining the decline of *M. mephitis* and *S. putorius* supported former hypotheses that agricultural intensification could have been a factor in the decline of these species

The proportion of herbivorous mammals, such as *M. ochrogaster* and *S. floridanus,* in the diet of *S. putorius* appeared to be cyclic, with herbivorous mammals comprising a considerable portion of the diet in some years and negligible proportions in others. Cyclic proportions of herbivorous mammals in the diet of generalist predators such as *S. putorius* might reflect increased reliance on these species when they were abundant. Cyclic populations are known to occur in *M. ochrogaster* and *S. floridanus*, with a periodicity of 2 to 4 years and 7 to 8 years, respectively (Fedy and Doherty 2011, Stalling 1990). Neither periodicity was clear in the data; however, trends were probably confounded for *M. mephitis* and *S. putorius* by the uneven sampling of skunks through time and space.

Increased proportions of omnivorous mammals in the diet of *S. putorius* during the 1940s might be a result of the decrease in the availability of maize during this time. Peak contribution of Acrididae to the diet of *S. putorius* and *M. mephitis* coincided in time, and probably reflected a temporary abundance of Acrididae available for consumption.

As the primary diet source, maize appeared to comprise a considerable proportion of the diet of *S. putorius* and *M. mephitis*. While the proportion of maize in the diet of *M. mephitis* was variable, there did not appear to be any temporal trends. This was unexpected given maize had declined in the Kansas landscape. This suggested that *M.*

mephitis might select maize as a food source, and use it disproportionately to its availability in the landscape.

There was a noticeable decline in the proportion of maize in the diet of *S. putorius* prior to the decline of this species. This was likely due to the decline of maize in Kansas beginning in the early 1900s (Chapter 2). Maize appeared to have increased in the diet after the 1970s and corresponded to the increase in hectares of maize harvested in Kansas (Chapter 2). Interestingly, the proportion of maize consumed by many *S. putorius* after 1970 was similar to the proportion of maize consumed prior to 1900, though the amount of maize in the landscape had substantially decreased (Chapter 2). While a decrease in maize was noted in the diet of *S. putorius* over time, maize still comprised a considerable proportion of the diet in many individuals. Again this might suggest that *S. putorius* was consuming maize disproportionally to its abundance in the landscape.

As maize, was a common food source for both *S. putorius* and *M. mephitis* its removal might have negatively impacted these species. Indeed, maize was a factor in explaining the decline in harvest for *M. mephitis* and *S. putorius*. Interestingly, harvest of *M. mephitis* increased in recent years corresponding to the increase in the amount of maize harvested in Kansas (Chapter 2).

Abundance of maize grain is high in fall following harvest, and possibly *S. putorius* and *M .mephitis* relied on maize as a high calorie dietary supplement preceding winter. In *S. putorius* and non-hibernating populations of *M. mephitis*, maize also might have provided a needed diet supplement during food scarcity in winter. Indeed, maize has been identified historically as a fall and winter diet component of *S. putorius* in agricultural landscapes (Crabb 1941). Because *S. putorius* might have relied on maize in the fall and winter, as opposed to only the fall in hibernating populations of *M. mephitis,* removal of maize from the landscape would have had a larger effect on populations of *S. putorius*.

Additionally, cropland maintains high levels of prey rodents compared to native habitats (White et al. 2012). Maize fields might have provided abundant prey and suitable cover for foraging for *M. mephitis* and *S. putorius.* A reduction in maize, or the alteration of agricultural practices, such that maize fields no longer provided suitable foraging habitat, might have contributed population collapses in *M. Mephitis* and *S. putorius* through a decreased small mammal prey base. Again, *S. putorius* relies more on small mammals as a diet component than *M. mephitis,* and this difference could feasibly explain the difference in magnitude of decline between *M. Mephitis* and *S. putorius.*

Spilogale putorius and *M. mephitis* have experienced population declines during the last century. During this time the diet of *S. putorius* and *M. mephitis* had also changed. The use of maize, and abundance of rodents occupying maize fields, as diet supplement in agriculture intensive landscapes, might have allowed these species to overcome habitat loss experienced during the transition from natural habitat to agriculture. If this was true, than the subsequent removal of maize from the landscape, could feasibly explain differences in the population declines for *M. Mephitis* and *S. putorius,* as natural habitat was not replaced during this time. In addition, this study supported prior claims that agricultural intensification contributed to the decline of *S. putorius*.

However, there is evidence for range expansion of *S. putorius* in the 1800s, and increased food availability due to increase in agriculture could have been a factor in this expansion (Van Gelder 1959, Chapter 2). Available fur harvest records did not date prior to the hypothesized range expansion of *S. putorius* or stabilization of agriculture in the landscape. As such, it was not possible to use these records to determine natural historical population sizes (Chapter 3). It is possible, *S. putorius* and *M. mephitis* populations were inflated by increased agriculture, allowing them to expand their range. In this case, observed declines could reflect this species returning to historical levels as has been suggested (Choate et al. 1973).

Maize alone did not provide an adequate explanation for the decline of *S. putorius* and *M. mephitis*. I suggest maize might have provided a diet substitute for a declining natural prey base, maintaining or temporarily increasing *S. putorius* and *M. mephitis* populations that would have otherwise experienced declines until its removal from the landscape.

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Table 5.1. List of sampled arthropod classes, orders, and families and associated feeding guilds. Feeding guilds divided into general fluid, herbivore, predator, spider, and scavenger guilds based on expected $\delta^{15}N$ values and existing literature.

Class	Order	Family	Feeding Guild
Arachnida	Araneae	Lycosidae	Predator
		Oxyopidae	Predator
		Salticidae	Predator
		Tetragnathidae	Predator
		Thomisidae	Predator
	Opiliones	Opiliones	Spider
Malacostraca	Isopoda	Armadillidiidae	Scavenger
Insecta	Coleoptera	Cantharidae	Predator
		Carabidae	Predator
		Chrysomelidae	Herbivore
		Cicindelidae	Predator
		Coccinellidae	Predator
		Curculionidae	Herbivore
		Elateridae	Herbivore
		Lampyridae	Predator
	Diptera	Dolichopodidae	Predator
	Hemiptera	Berytidae	Herbivore

	Coreidae	Herbivore
	Cydnidae	Scavenger
	Issidae	Fluid
	Membracidae	Herbivore
	Reduviidae	Predator
	Rhopalidae	Herbivore
Hymenoptera	Apidae	Fluid
	Chrysididae	Fluid
	Halictidae	Fluid
	Megachilidae	Fluid
	Mutillidae	Predator
	Tiphiidae	Predator
Mantodea	Mantidae	Predator
Microcoryphia	Meinertellidae	Scavenger
Orthoptera	Acrididae	Herbivore

Table 5.2. Results from paired sample t-tests comparing colored (melanin-containing) hair to white (melanin-lacking) hair for 8 mammal species. Values given include *t*, sample size (*N*), and *P*-values for $\delta^{13}C$ and $\delta^{15}N$. Adjusted significance level was set at $\alpha=0.015$.

Species	$\delta^{13}C$			$\delta^{15}N$		
	t	*N*	*P*	*t*	*N*	*P*
Lepus californicus	-2.239	4	0.089	-3.638	4	0.022
Lynx rufus	2.072	4	0.107	1.321	4	0.257
Mephitis mephitis	0.361	14	0.724	1.444	14	0.171
Spilogale putorius	-2.059	4	0.109	-0.583	4	0.592
Sylvilagus floridanus	-1.537	3	0.222	-0.784	3	0.490
Urocyon cinereoargenteus	-1.170	4	0.307	1.584	4	0.188
Vulpes velox	2.500	4	0.067	0.263	4	0.806
Vulpes vulpes	-0.999	3	0.391	-1.426	3	0.249

Table 5.3. Top ranked models for the effect of fine-extent landscape structure on $\delta^{13}C$ values for *Mephitis mephitis*. Table includes the model description, number of model parameters (K), R^2, P-values, AIC adjusted for small sample size (AIC_c), model weights (W_i), and model rank for models with considerable support. Significant values are bolded.

Model Description	K	R^2	P	AIC_c	Δ_i	W_i	Rank
Maize	3	0.199	**0.015**	110.521	0.000	0.41	1
% Woodland + Maize	4	0.175	**0.046**	112.992	2.471	0.12	
% Grassland + Maize	4	0.168	0.051	113.203	2.682	0.11	
Maize + Edge Density	4	0.167	0.051	113.224	2.704	0.11	
Maize + Patch Richness Density	4	0.167	0.052	113.242	2.721	0.10	
% Woodland + % Grassland + Maize	5	0.142	0.104	115.970	5.449	0.03	
Maize + Patch Richness Density + Edge Density	5	0.128	0.121	116.365	5.844	0.02	
Edge Density	3	-0.021	0.485	116.582	6.061	0.02	
Edge Density + % Residential	4	0.043	0.236	116.696	6.176	0.02	
Patch Richness Density	3	-0.039	0.743	117.003	6.483	0.02	
% Woodland	3	-0.041	0.832	117.073	6.552	0.02	

% Grassland	3	-0.042	0.837	117.076	6.555	0.02
% Grassland + % Residential	4	0.023	0.296	117.214	6.693	0.01
Patch Richness Density + % Residential	4	0.018	0.315	117.356	6.835	0.01

Table 5.4. Top ranked models for the effect of fine-extent landscape structure on δ^{15}N values for *Mephitis mephitis*. Table includes the model description, number of model parameters (K), R^2, P-values, AIC adjusted for small sample size (AIC$_c$), model weights (W_i), and model rank for models with considerable support. Significant values are bolded.

Model Description	K	R^2	P	AIC$_c$	Δ_i	W_i	Rank
% Woodland + Interspersion and Juxtaposition	4	0.243	**0.018**	93.495	0.000	0.13	1
% Woodland + % Grassland	4	0.241	**0.019**	93.578	0.083	0.12	2
% Woodland + % Grassland + Interspersion and Juxtaposition	5	0.264	**0.024**	94.789	1.294	0.07	3
Edge Density + Interspersion and Juxtaposition	4	0.201	**0.033**	94.848	1.354	0.07	4
% Grassland + Interspersion and Juxtaposition	4	0.193	**0.036**	95.088	1.593	0.06	5
Interspersion and Juxtaposition	3	0.134	**0.041**	95.124	1.629	0.06	6
% Grassland + % Residential	4	0.184	**0.041**	95.375	1.880	0.05	7
% Grassland + Edge Density	4	0.183	**0.042**	95.407	1.912	0.05	8
% Grassland + Patch Richness Density	4	0.175	**0.046**	95.647	2.152	0.04	
Interspersion and Juxtaposition + % Woodland + Edge Density	5	0.220	**0.042**	96.233	2.739	0.03	
% Woodland + % Grassland + % Residential	5	0.218	**0.043**	96.310	2.816	0.03	

Interspersion and Juxtaposition + % Woodland + Patch Richness Density	5	0.217	**0.044**	96.333	2.839	0.03
% Woodland + % Grassland + Edge Density	5	0.215	**0.045**	96.401	2.906	0.03
Interspersion and Juxtaposition + % Woodland + % Residential	5	0.208	**0.049**	96.621	3.127	0.03
% Woodland + % Grassland + Patch Richness Density	5	0.206	0.050	96.668	3.174	0.03
Interspersion and Juxtaposition + % Grassland + Edge Density	5	0.201	0.053	96.834	3.339	0.02
Patch Richness Density + Interspersion and Juxtaposition	4	0.098	0.117	97.347	3.853	0.02
Interspersion and Juxtaposition + Patch Richness Density + Edge Density	5	0.167	0.079	97.872	4.377	0.01
% Residential + Interspersion and Juxtaposition	4	0.095	0.128	97.951	4.457	0.01
Interspersion and Juxtaposition + % Grassland + Patch Richness Density	5	0.165	0.081	97.954	4.459	0.01
% Residential + % Grassland + Edge Density	5	0.162	0.084	98.043	4.548	0.01
% Woodland	3	0.021	0.231	98.179	4.684	0.01
Interspersion and Juxtaposition + % Grassland + % Residential	5	0.155	0.090	98.227	4.732	0.01

% Woodland + % Residential	4	0.082	0.151	98.325	4.830	0.01
% Grassland + Patch Richness Density + Edge Density	5	0.148	0.097	98.437	4.942	0.01
Edge Density + % Residential	4	0.042	0.238	99.369	5.875	0.01
Edge Density	3	-0.032	0.623	99.503	6.009	0.01
Patch Richness Density	3	-0.038	0.739	99.648	6.154	0.01
Patch Richness Density + % Residential	4	0.005	0.362	100.316	6.822	0.00

Table 5.5. Top ranked models for the effect of fine-extent landscape structure on $\delta^{13}C$ values for *Spilogale putorius*. Table includes the model description, number of model parameters (*K*), R^2, *P*-values, AIC adjusted for small sample size (AIC_c), model weights (W_i), and model rank for models with considerable support. Significant values are bolded.

Model Description	*K*	R^2	*P*	AIC_c	Δ_i	W_i	Rank
Edge Density	3	0.381	**<0.001**	132.676	0.000	0.27	1
Maize + Edge Density	4	0.380	**0.001**	134.377	1.701	0.11	2
Patch Richness Density + Edge Density	4	0.376	**0.001**	134.557	1.881	0.10	3
% Woodland + Edge Density	4	0.375	**0.001**	134.612	1.936	0.10	4
Edge Density + % Residential	4	0.372	**0.001**	134.750	2.074	0.10	
% Grassland + Edge Density	4	0.360	**0.001**	135.264	2.588	0.07	
% Residential + Patch Richness Density + Edge Density	5	0.377	**0.002**	136.369	3.693	0.04	
% Woodland + % Residential + Edge Density	5	0.373	**0.003**	136.516	3.839	0.04	
Maize + Patch Richness Density + Edge Density	5	0.369	**0.003**	136.722	4.046	0.04	
% Woodland + Patch Richness Density + Edge Density	5	0.357	**0.003**	137.247	4.571	0.03	
% Grassland + Patch Richness Density + Edge Density	5	0.352	**0.004**	137.443	4.767	0.02	

% Woodland + % Grassland + Edge Density	5	0.350	**0.004**	137.542	4.866	0.02
% Residential + % Grassland + Edge Density	5	0.346	**0.004**	137.737	5.060	0.02
% Woodland	3	0.238	**0.005**	138.499	5.823	0.01
% Woodland + Maize	4	0.277	**0.007**	138.696	6.020	0.01

Table 5.6. Top ranked models for the effect of fine-extent landscape structure on $\delta^{15}N$ values for *Spilogale putorius*. Table includes the model description, number of model parameters (K), R^2, P-values, AIC adjusted for small sample size (AIC_c),model weights (W_i), and model rank for models with considerable support. Significant values are bolded.

Model Description	K	R^2	P	AIC_c	Δ_i	W_i	Rank
Interspersion and Juxtaposition + % Grassland + % Residential	5	0.544	**<0.001**	114.524	0.000	0.58	1
Interspersion and Juxtaposition + % Residential	4	0.490	**<0.001**	115.841	1.318	0.30	2
Interspersion and Juxtaposition + % Grassland + % Residential	5	0.469	**<0.001**	118.797	4.274	0.07	
Interspersion and Juxtaposition	3	0.383	**<0.001**	119.509	4.986	0.05	

Table 5.7. Top ranked models for the effect of trapping effort and landscape structure on *Mephitis mephitis* pelts sold (1928 to 1969, 1971, 1972, 1974, 1975) or individuals harvested (1970, 1973, 1976 to 2010) in Kansas. Table includes the model description, number of model parameters (K), R^2, P-values, AIC adjusted for small sample size (AIC_c),model weights (W_i), and model rank for models with considerable support. Significant values are bolded.

Model Description	K	R^2	P	AIC_c	Δ_i	W_i	Rank
Maize + Number of Farms	4	0.893	**<0.001**	335.611	0.000	0.57	1
Number of Farms + Trapping Effort	4	0.888	**<0.001**	336.209	0.600	0.42	2

Table 5.8. Top ranked models for the effect of trapping effort and landscape structure on *Spilogale putorius* pelts sold in Kansas. Table includes the model description, number of model parameters (K), R^2, P-values, AIC adjusted for small sample size (AIC$_c$), model weights (W_i), and model rank for models with considerable support. Significant values are bolded.

Model Description	K	R^2	P	AIC$_c$	Δ_i	W_i	Rank
Maize	3	0.818	**<0.001**	231.455	0.000	0.35	1
Trapping Effort + Number of Farms	4	0.875	**<0.001**	231.597	0.142	0.33	2
Maize + Number of Farms	4	0.862	**<0.001**	232.643	1.188	0.20	3
Trapping Effort	3	0.712	**0.001**	236.635	4.608	0.04	
Number of Farms	3	0.693	**0.002**	237.287	5.260	0.03	
Woodland + Maize	4	0.797	**0.002**	237.799	5.772	0.02	
Trapping Effort + Maize	4	0.793	**0.002**	238.023	5.997	0.02	

Table 5.9. List of sampled mammal species and their associated feeding guilds. Feeding guilds were determined according to expected $\delta^{15}N$ and existing literature and include herbivore, herbivore bordering on omnivore, and omnivore bordering on carnivore.

Species	Feeding Guild
Lepus californicus	Herbivore
Ictidomys tridecemlineatus	Omnivore/Carnivore
Microtus Ochrogaster	Herbivore
Sigmodon hispidus	Herbivore/Omnivore
Mus musculus	Omnivore/Carnivore
Onychomys leucogaster	Herbivore/Omnivore
Peromyscus leucopus	Herbivore/Omnivore
Peromyscus maniculatus	Omnivore/Carnivore
Reithrodontomys sp.	Herbivore/Omnivore

Table 5.10. Tukey's HSD for MANOVA comparing $\delta^{13}C$ values over 3 mammal diet groupings: herbivore, herbivore bordering on omnivore and omnivore bordering on carnivore as determined by expected $\delta^{13}C$ and existing literature. Significant are values bolded.

Groups	*P*
Omnivore/Carnivore-Herbivores	**0.045**
Omnivore/Herbivore-Herbivore	**0.001**
Omnivore/Herbivore-Omnivore/Carnivore	**0.026**

Table 5.11. Tukey's HSD for MANOVA comparing $\delta^{15}N$ values over 3 mammal diet groupings: herbivore, herbivore bordering on omnivore and omnivore bordering on carnivore as determined by expected $\delta^{15}N$ and existing literature. Significant are values bolded.

Groups	*P*
Omnivorous/Carnivore-Herbivore	**<0.001**
Omnivore/Herbivore-Herbivore	**<0.001**
Omnivore/Herbivore-Omnivore/Carnivore	**0.037**

Table 5.12. Tukey's HSD for MANOVA comparing δ^{13}C values over 5 arthropod diet groupings: fluid, herbivore, carnivore, spider, and scavenger as determined by expected δ^{13}C and existing literature.

Groups	*P*
Herbivore-Fluid	0.975
Carnivore-Fluid	0.708
Scavenger-Fluid	>0.999
Spider-Fluid	0.634
Carnivore-Herbivore	0.143
Scavenger-Herbivore	0.995
Spider-Herbivore	0.147
Scavenger-Carnivore	0.645
Spider-Carnivore	0.999
Spider-Scavenger	0.574

Table 5.13. Tukey's HSD for MANOVA comparing $\delta^{15}N$ values over 5 arthropod diet groupings: fluid, herbivore, carnivore, spider, and scavenger as determined by expected $\delta^{13}C$ and existing literature.

Groups	*P*
Herbivore-Fluid	0.975
Carnivore-Fluid	0.708
Scavenger-Fluid	>0.999
Spider-Fluid	0.634
Carnivore-Herbivore	0.143
Scavenger-Herbivore	0.995
Spider-Herbivore	0.147
Scavenger-Carnivore	0.645
Spider-Carnivore	0.999
Spider-Scavenger	0.574

Table 5.14. Results from Pearson correlation tests between isotopes δ^{13}C and δ^{15}N values of *Mephitis mephitis* specimens and collection year. Significant values are bolded. Table includes species, isotope, state, *F* statistic*,* sample size (*N*), *P*-values, and correlation coefficient (*r*). Adjusted significance level was set at α=0.013.

Species	Isotope	State	*F*	*N*	*P*	*r*
Mephitis mephitis	δ^{13}C	Colorado	-1.366	19	0.190	-0.315
Mephitis mephitis	δ^{13}C	Florida	0.060	25	0.953	0.012
Mephitis mephitis	δ^{13}C	Kansas	-0.315	90	0.753	-0.034
Mephitis mephitis	δ^{13}C	Nebraska	0.567	10	0.586	0.196
Mephitis mephitis	δ^{13}C	Oklahoma	-2.015	21	0.058	-0.420
Mephitis mephitis	δ^{13}C	Texas	1.421	127	0.158	0.126
Mephitis mephitis	δ^{15}N	Colorado	2.247	20	0.037	0.468
Mephitis mephitis	δ^{15}N	Florida	-2.879	25	**0.008**	-0.515
Mephitis mephitis	δ^{15}N	Nebraska	2.059	10	0.073	0.589
Mephitis mephitis	δ^{15}N	Oklahoma	0.421	21	0.678	0.096
Mephitis mephitis	δ^{15}N	Texas	-0.373	129	0.710	-0.033

Table 5.15. Results from correlations tests between isotopes $\delta^{13}C$ and $\delta^{15}N$ values of *Spilogale putorius* specimens and collection year. Significant values are bolded. Table includes species, isotope, state, *F*-statistic*,* sample size (*N*), *P*-values, and correlation coefficient (*r*). Adjusted significance level was set at α=0.013.

Species	Isotope	State	*F*	*N*	*P*	*r*
Spilogale putorius	$\delta^{13}C$	Alabama	1.096	21	0.287	0.244
Spilogale putorius	$\delta^{13}C$	Florida	1.5506,	35	0.131	0.261
Spilogale putorius	$\delta^{13}C$	Georgia	0.485	11	0.639	0.160
Spilogale putorius	$\delta^{13}C$	Iowa	1.033	11	0.329	0.326
Spilogale putorius	$\delta^{13}C$	Kansas	0.153	89	0.879	0.016
Spilogale putorius	$\delta^{13}C$	North Carolina	-1.266	12	0.234	-0.372
Spilogale putorius	$\delta^{13}C$	Oklahoma	0.491	16	0.631	0.130
Spilogale putorius	$\delta^{13}C$	Texas	1.620	35	0.115	0.271
Spilogale putorius	$\delta^{15}N$	Alabama	1.081	21	0.293	0.241
Spilogale putorius	$\delta^{15}N$	Florida	-2.845	35	**0.008**	-0.444
Spilogale putorius	$\delta^{15}N$	Georgia	-0.267	11	0.795	-0.089

Spilogale putorius	$\delta^{15}N$	Iowa	3.080	11	0.013	0.716
Spilogale putorius	$\delta^{15}N$	North Carolina	-1.340	12	0.210	-0.390
Spilogale putorius	$\delta^{15}N$	Oklahoma	3.569	16	**0.003**	0.690
Spilogale putorius	$\delta^{15}N$	Texas	0.618	35	0.541	0.107

Table 5.16. Table including 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from quantile regression analysis of $\delta^{15}N$ values of *Mephitis mephitis* specimens over collection year. Table depicting *P*-values, *t*-statistics, and slope for tested quantiles. Significant values are bolded.

Quantile	*t*	Slope	*P*
0.05	-1.274	-0.009	0.206
0.25	-0.190	0.005	0.413
0.50	-1.056	0.008	**0.025**
0.75	-1.505	0.015	**0.028**
0.95	1.728	0.015	0.087

Table 5.17. Table including 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from quantile regression analysis of δ^{15}N values of *Spilogale putorius* over collection year. Table depicting *P*-values, *t*-statistics, and slope for tested quantiles. Significant values are bolded.

Quantile	*t*	Slope	*P*
0.05	-1.055	-0.012	0.435
0.25	0.455	0.004	0.294
0.50	2.136	0.018	**0.035**
0.75	3.623	0.031	**<0.001**
0.90	6.704	0.038	**<0.001**

Fig. 5.1. Box plots displaying the proportions of maize in the diet of individual *Mephitis mephitis* specimens collected in Kansas from 1887 to 2012. Boxes represent the inter-quartile range and the whiskers indicate the range of potential solutions as given by SIAR.

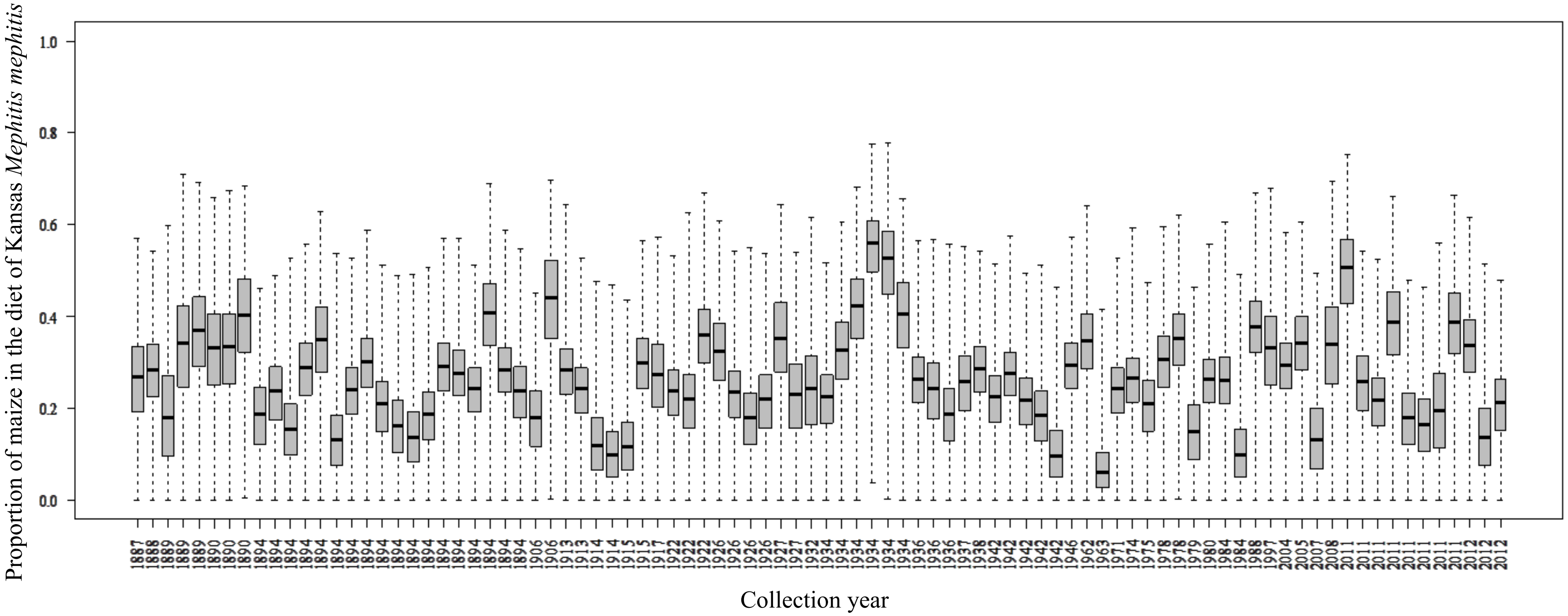
Proportion of maize in the diet of Kansas *Mephitis mephitis*
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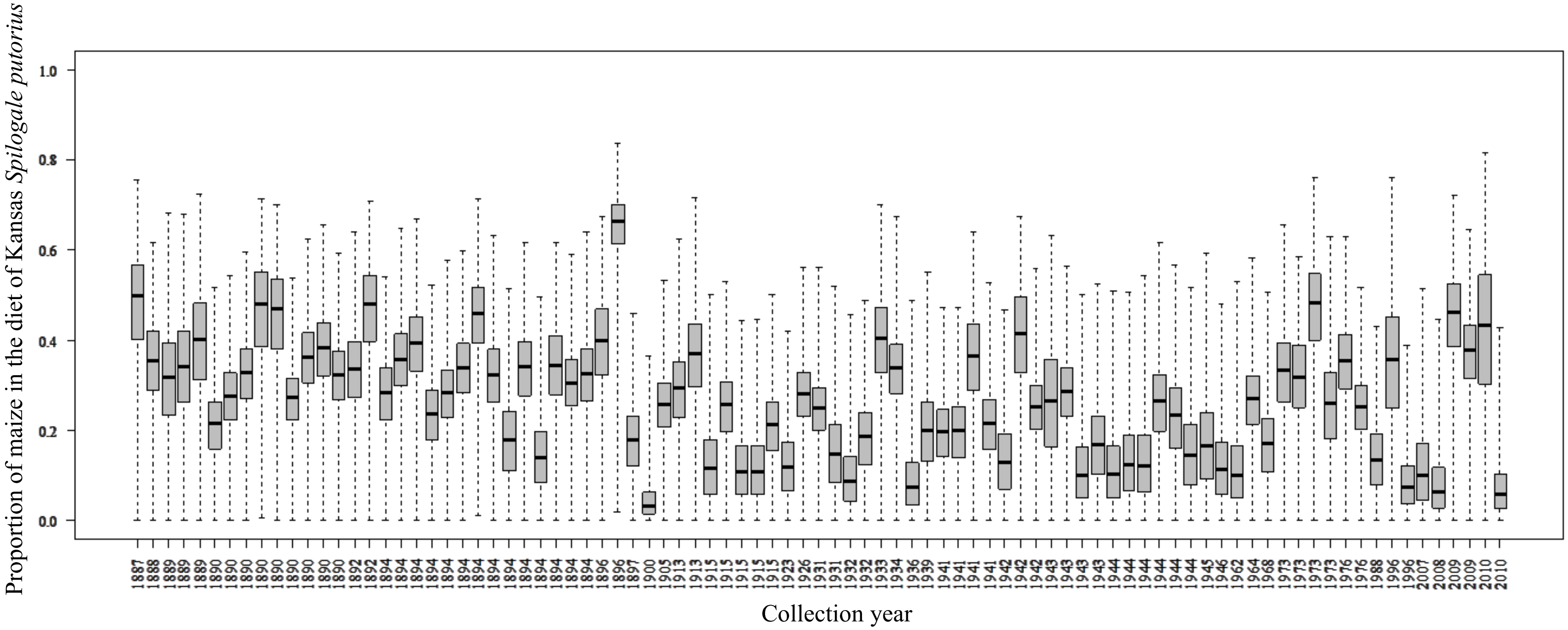
Fig. 5.2. Box plots displaying the proportions of maize in the diet of individual *Spilogale putorius* specimens collected in Kansas from 1887 to 2010. Boxes represent the inter-quartile range and the whiskers indicate the range of potential solutions as given by SIAR.


Proportion of maize in the diet of Kansas *Spilogale putorius*
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2008
2009
2009
2010
2010
Collection year

Fig. 5.3. Box plots displaying the proportions of omnivorous mammals in the diet of individual *Mephitis mephitis* specimens collected in Kansas from 1887 to 2012. Boxes represent the inter-quartile range and the whiskers indicate the range of potential solutions as given by SIAR.

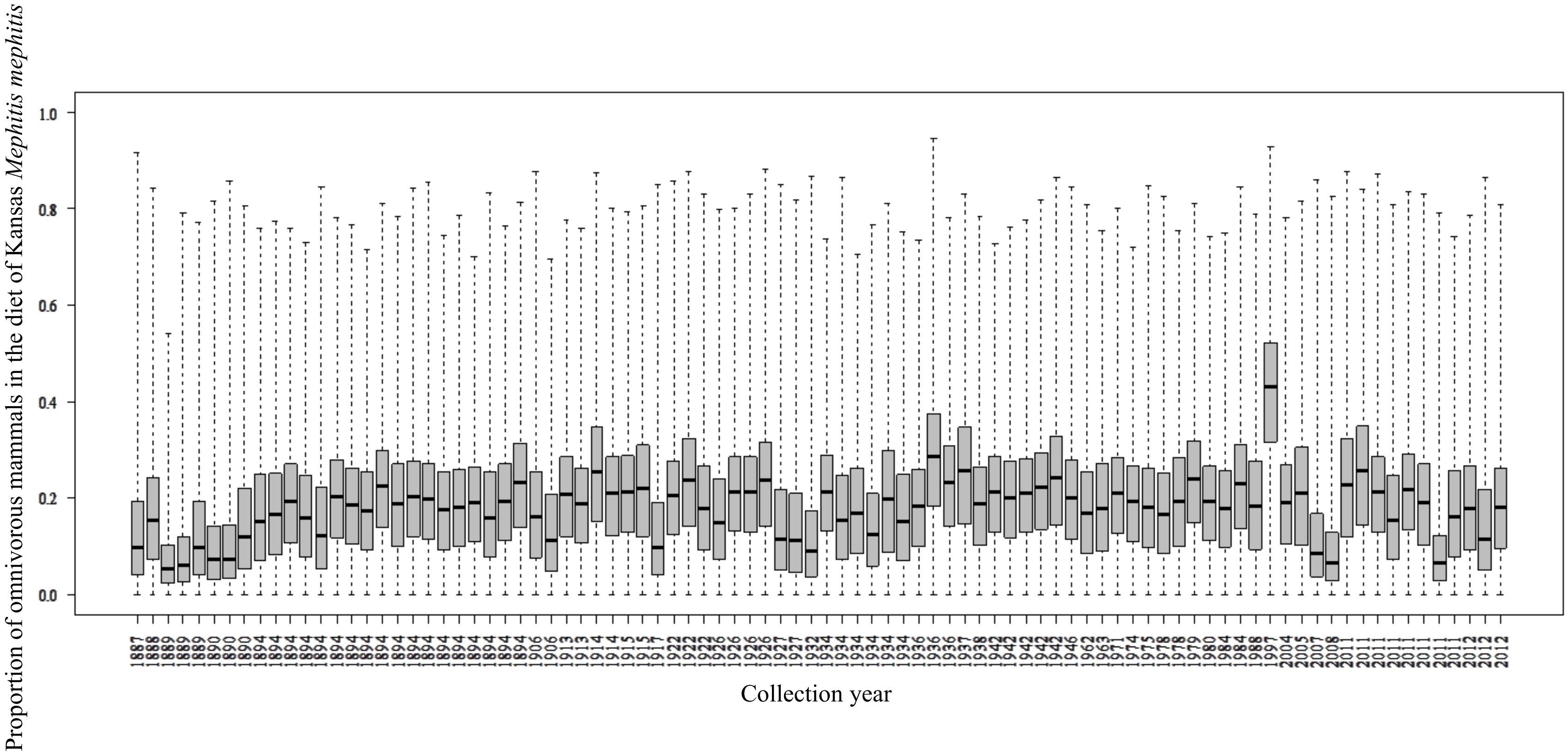

Proportion of omnivorous mammals in the diet of Kansas *Mephitis mephitis*
1.0
0.8
0.6
0.4
0.2
0.0
1887 1888 1889 1889 1889 1890 1890 1890 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1906 1906 1913 1913 1914 1914 1915 1915 1917 1922 1922 1922 1926 1926 1926 1926 1927 1927 1932 1934 1934 1934 1934 1934 1934 1936 1936 1936 1937 1938 1942 1942 1942 1942 1942 1946 1962 1963 1971 1974 1975 1978 1978 1979 1980 1984 1984 1988 1997 2004 2005 2007 2008 2011 2011 2011 2011 2011 2011 2011 2012 2012 2012
Collection year

Fig.5.4. Box plots displaying the proportions of omnivorous/carnivorous mammals in the diet of individual *Spilogale putorius* specimens collected in Kansas from 1887 to 2010. Boxes represent the inter-quartile range and the whiskers indicate the range of potential solutions as given by SIAR.

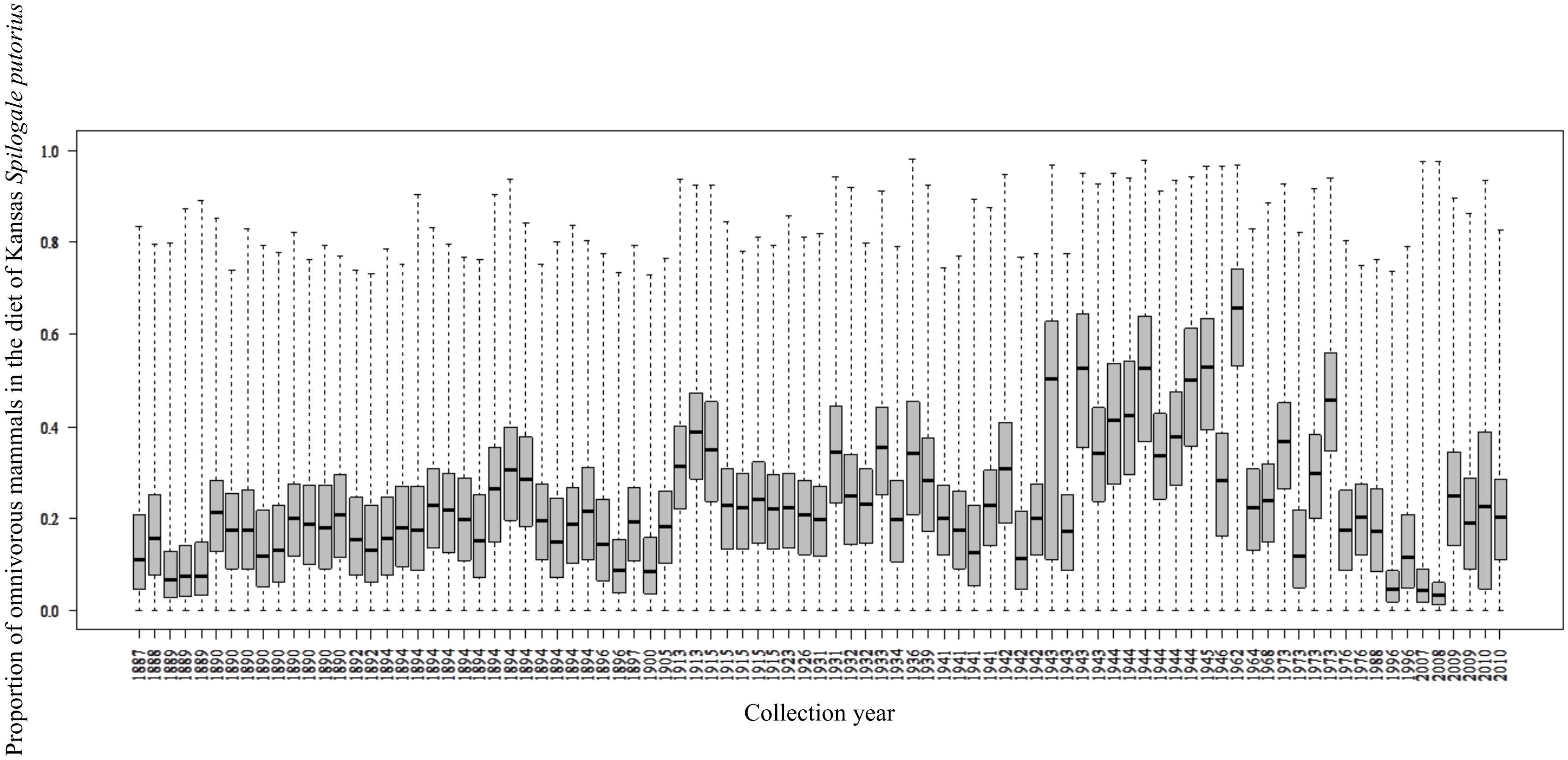
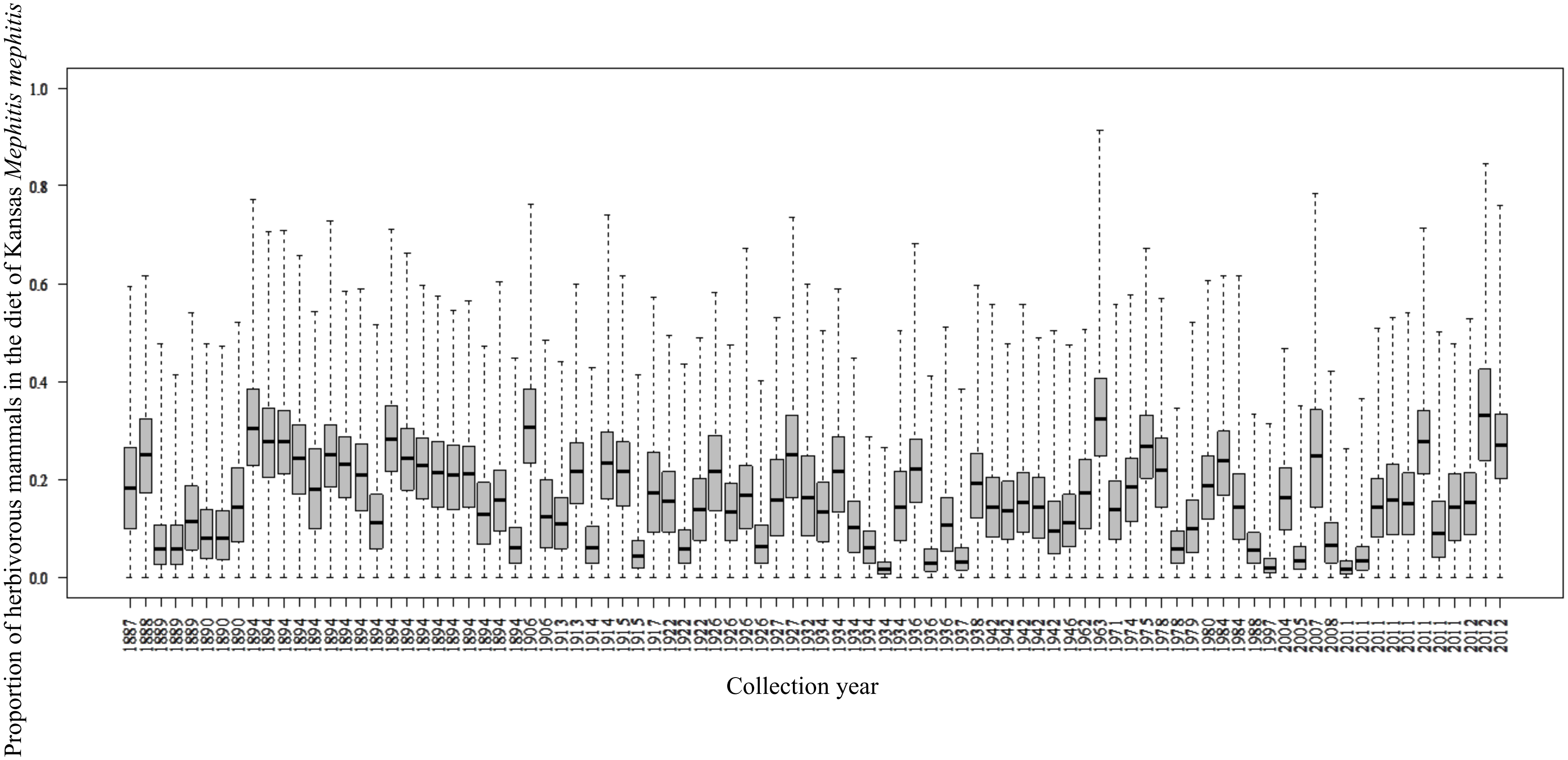

Proportion of omnivorous mammals in the diet of Kansas *Spilogale putorius*
1.0
0.8
0.6
0.4
0.2
0.0
1887 1888 1889 1889 1889 1890 1890 1890 1890 1890 1890 1890 1890 1892 1892 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1896 1896 1897 1900 1905 1913 1913 1915 1915 1915 1915 1915 1923 1926 1931 1931 1932 1932 1933 1934 1936 1939 1941 1941 1941 1941 1942 1942 1942 1943 1943 1943 1943 1944 1944 1944 1944 1944 1944 1945 1946 1962 1964 1968 1973 1973 1973 1973 1976 1976 1988 1996 1996 2007 2008 2009 2009 2010 2010
Collection year

Fig. 5.5. Box plots displaying the proportions of herbivorous mammals in the diet of individual *Mephitis mephitis* specimens collected in Kansas from 1887 to 2012. Boxes represent the inter-quartile range and the whiskers indicate the range of potential solutions as given by SIAR.


Proportion of herbivorous mammals in the diet of Kansas *Mephitis mephitis*
1.0
0.8
0.6
0.4
0.2
0.0
1887
1888
1889
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1894
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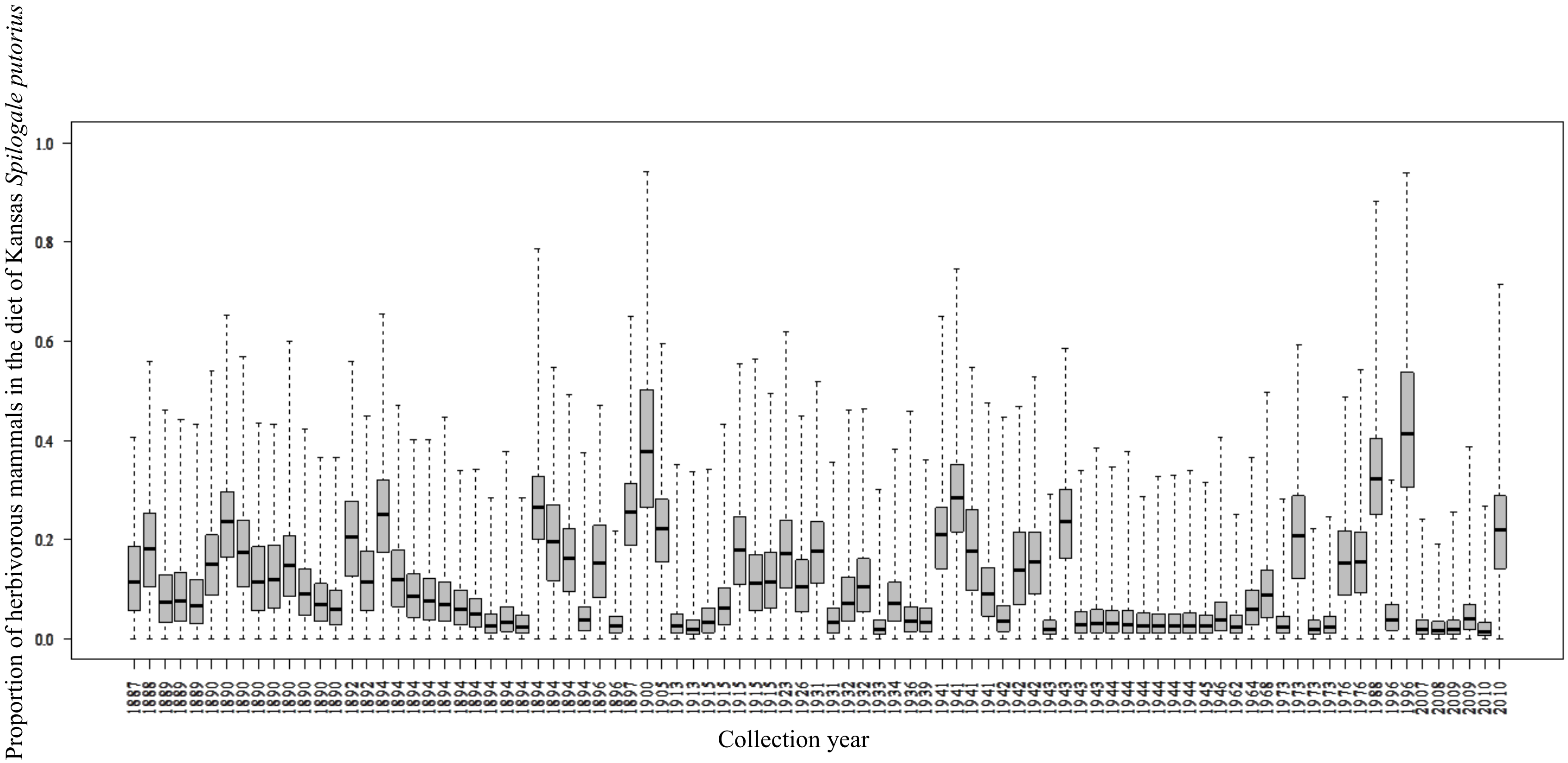
2011
2012
2012
2012
Collection year

Fig. 5.6. Box plots displaying the proportions of herbivorous mammals in the diet of individual *Spilogale putorius* specimens collected in Kansas from 1887 to 2010. Boxes represent the inter-quartile range and the whiskers indicate the range of potential solutions as given by SIAR.



Proportion of herbivorous mammals in the diet of Kansas *Spilogale putorius*
1.0
0.8
0.6
0.4
0.2
0.0
1887
1888
1889
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1890
1890
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2010
Collection year

Fig. 5.7. Box plots displaying the proportions of Acrididae in the diet of individual *Mephitis mephitis* specimens collected in Kansas from 1887 to 2012. Boxes represent the inter-quartile range and the whiskers indicate the range of potential solutions as given by SIAR.

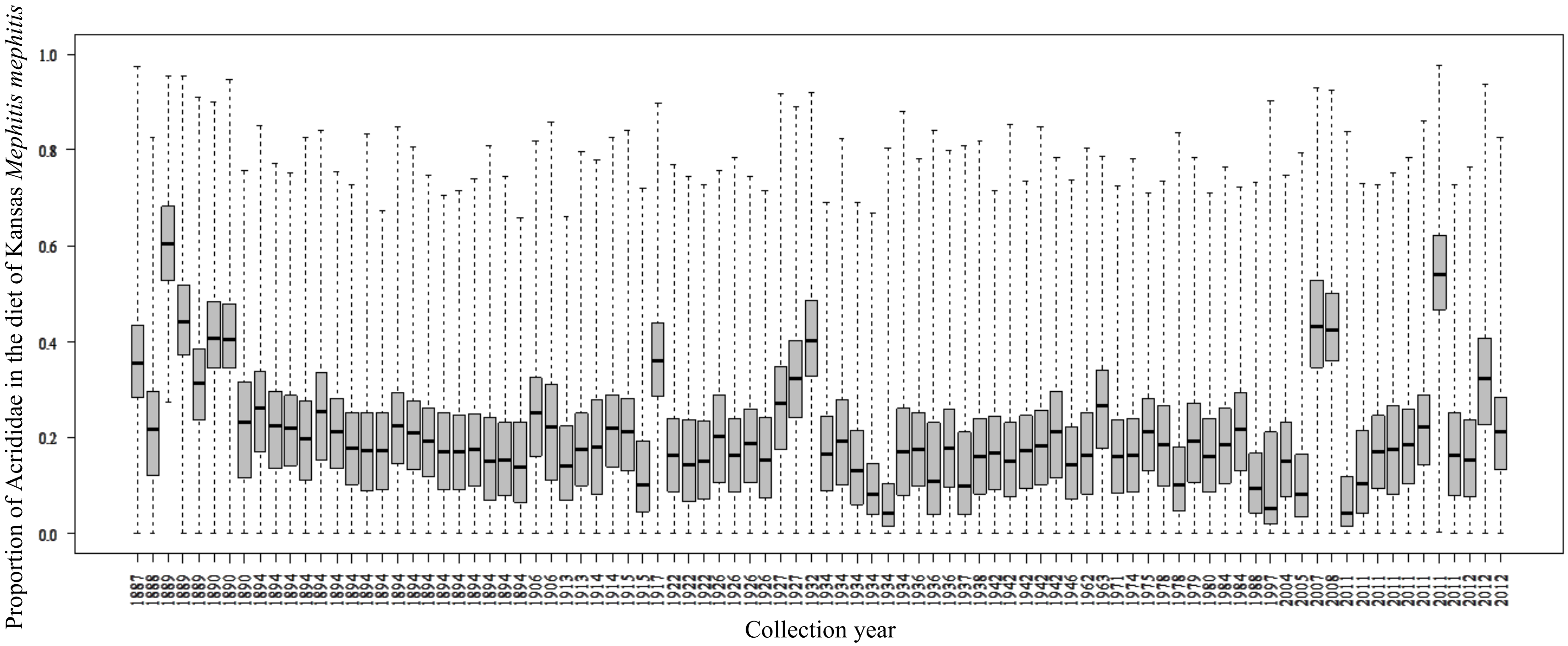
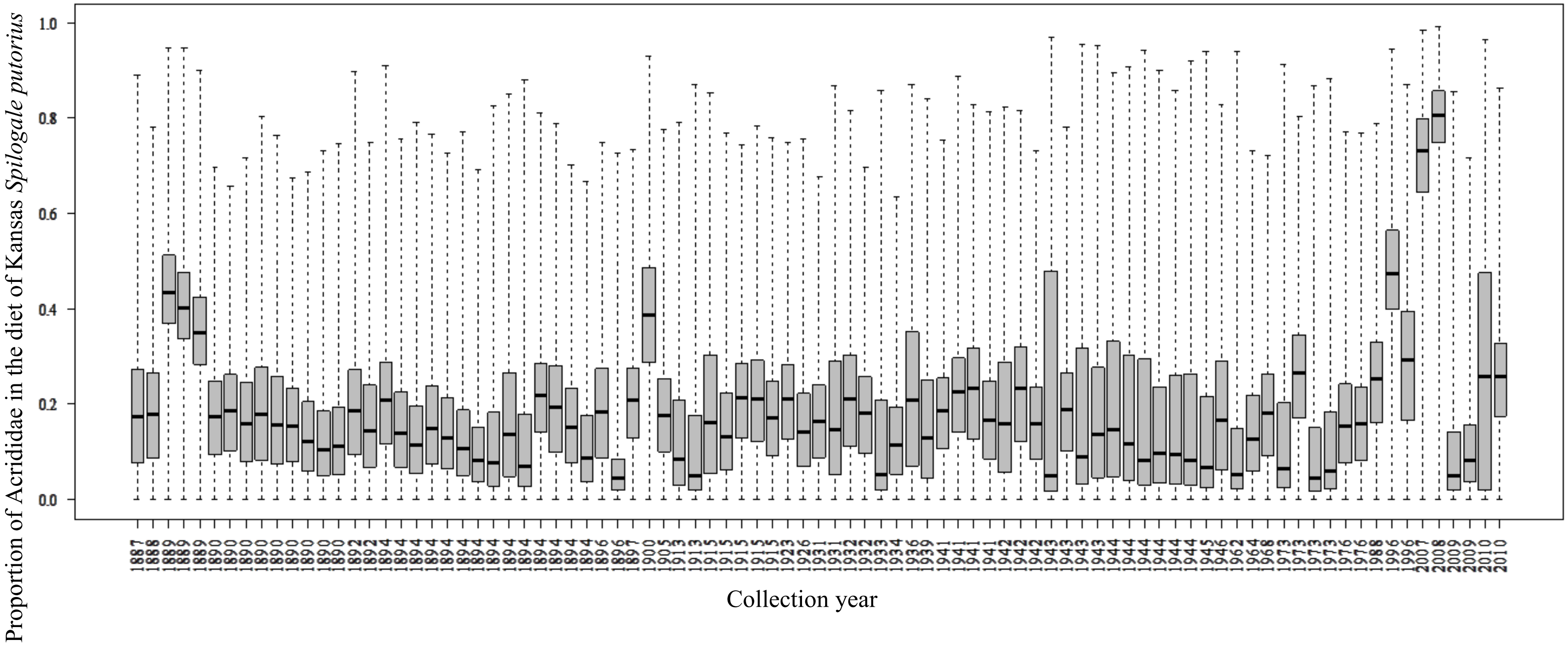

Proportion of Acrididae in the diet of Kansas *Mephitis mephitis*
1.0
0.8
0.6
0.4
0.2
0.0
1887 1888 1889 1889 1889 1890 1890 1890 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1894 1906 1906 1913 1913 1914 1914 1915 1915 1917 1922 1922 1922 1926 1926 1926 1926 1927 1927 1932 1934 1934 1934 1934 1934 1936 1936 1936 1937 1938 1942 1942 1942 1942 1942 1946 1962 1963 1971 1974 1975 1978 1978 1979 1980 1984 1984 1988 1997 2004 2005 2007 2008 2011 2011 2011 2011 2011 2011 2011 2011 2012 2012 2012
Collection year

Fig. 5.8. Box plots displaying the proportions of Acrididae in the diet of individual *Spilogale putorius* specimens collected in Kansas from 1887 to 2010. Boxes represent the inter-quartile range and the whiskers indicate the range of potential solutions as given by SIAR.


Proportion of Acrididae in the diet of Kansas *Spilogale putorius*
1.0
0.8
0.6
0.4
0.2
0.0
1887
1888
1889
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1890
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1890
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2008
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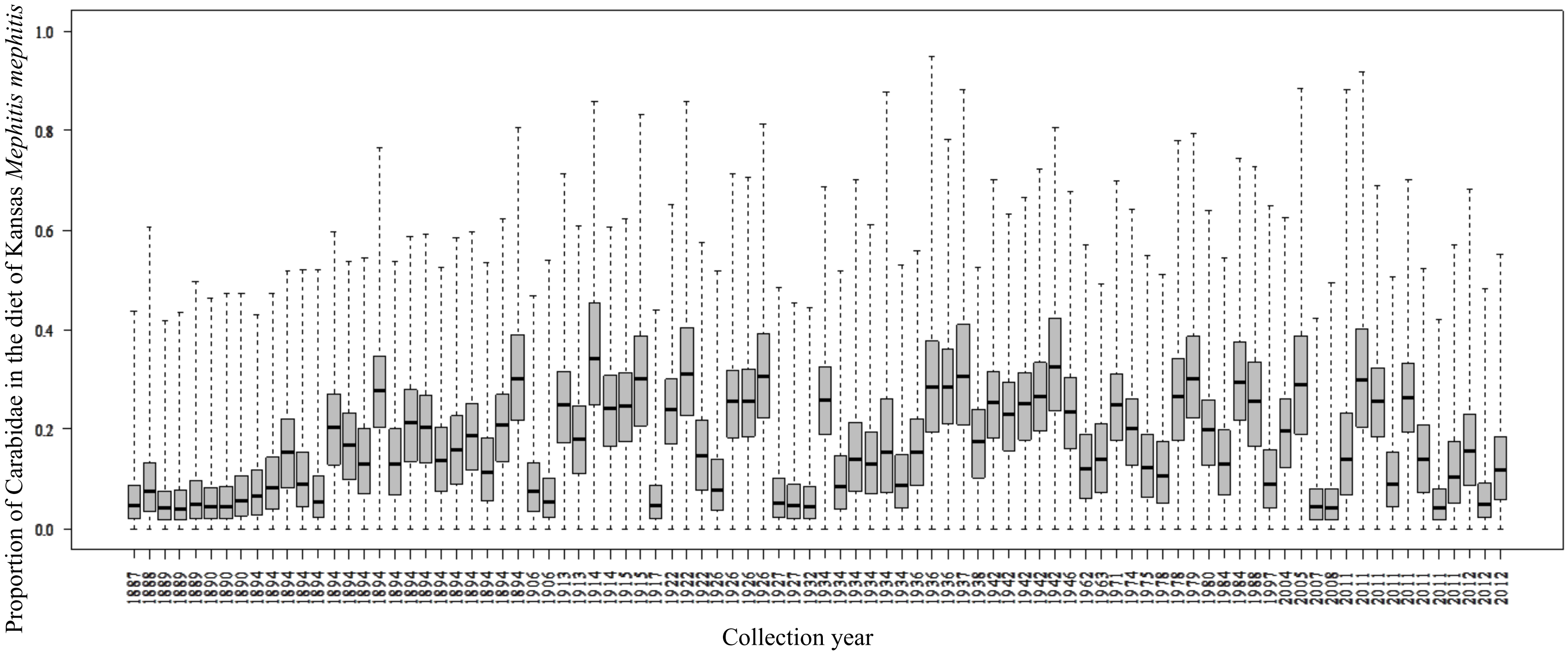
2009
2010
2010
Collection year

Fig. 5.9. Box plots displaying the proportions of Carabidae in the diet of individual *Mephitis mephitis* specimens collected in Kansas from 1887 to 2012. Boxes represent the inter-quartile range and the whiskers indicate the range of potential solutions as given by SIAR.


Proportion of Carabidae in the diet of Kansas *Mephitis mephitis*
1.0
0.8
0.6
0.4
0.2
0.0
1887
1888
1889
1889
1889
1890
1890
1890
1894
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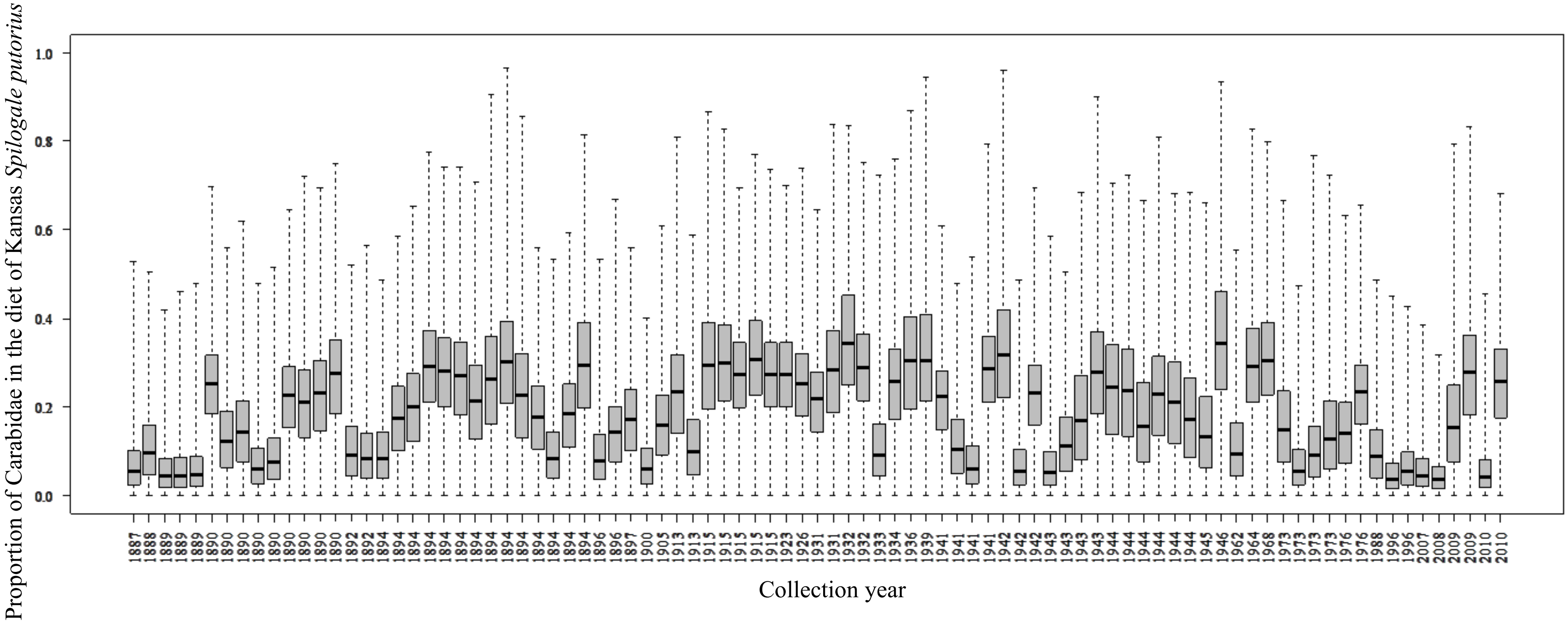
2011
2011
2012
2012
2012
Collection year

Fig. 5.10. Box plots displaying the proportions of Carabidae in the diet of individual *Spilogale putorius* specimens collected in Kansas from 1887 to 2010. Boxes represent the inter-quartile range and the whiskers indicate the range of potential solutions as given by SIAR.


Proportion of Carabidae in the diet of Kansas *Spilogale putorius*
1.0
0.8
0.6
0.4
0.2
0.0
1887
1888
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1890
1890
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1962
1964
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2008
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2009
2010
2010
Collection year

Fig. 5.11. Plots depicting the negative relationship between δ^{13}C values of *Mephitis mephitis* and collection latitude for specimens collected over their United States range. b. Negative relationship between δ^{15}N values of *M. mephitis* and collection latitude for specimens collected over their United States range. c. Positive relationship between δ^{13}C values of *M. mephitis* and collection longitude for specimens collected over their United States range. d. Positive relationship between δ^{15}N values of and *M. mephitis* collection longitude for specimens collected over their United States range. e. Positive relationship between δ^{13}C values of *Mephitis mephitis* and collection year for specimens collected over their United States range. and f. Positive relationship between δ^{15}N values of *M. mephitis* and collection year for specimens collected over their United States range

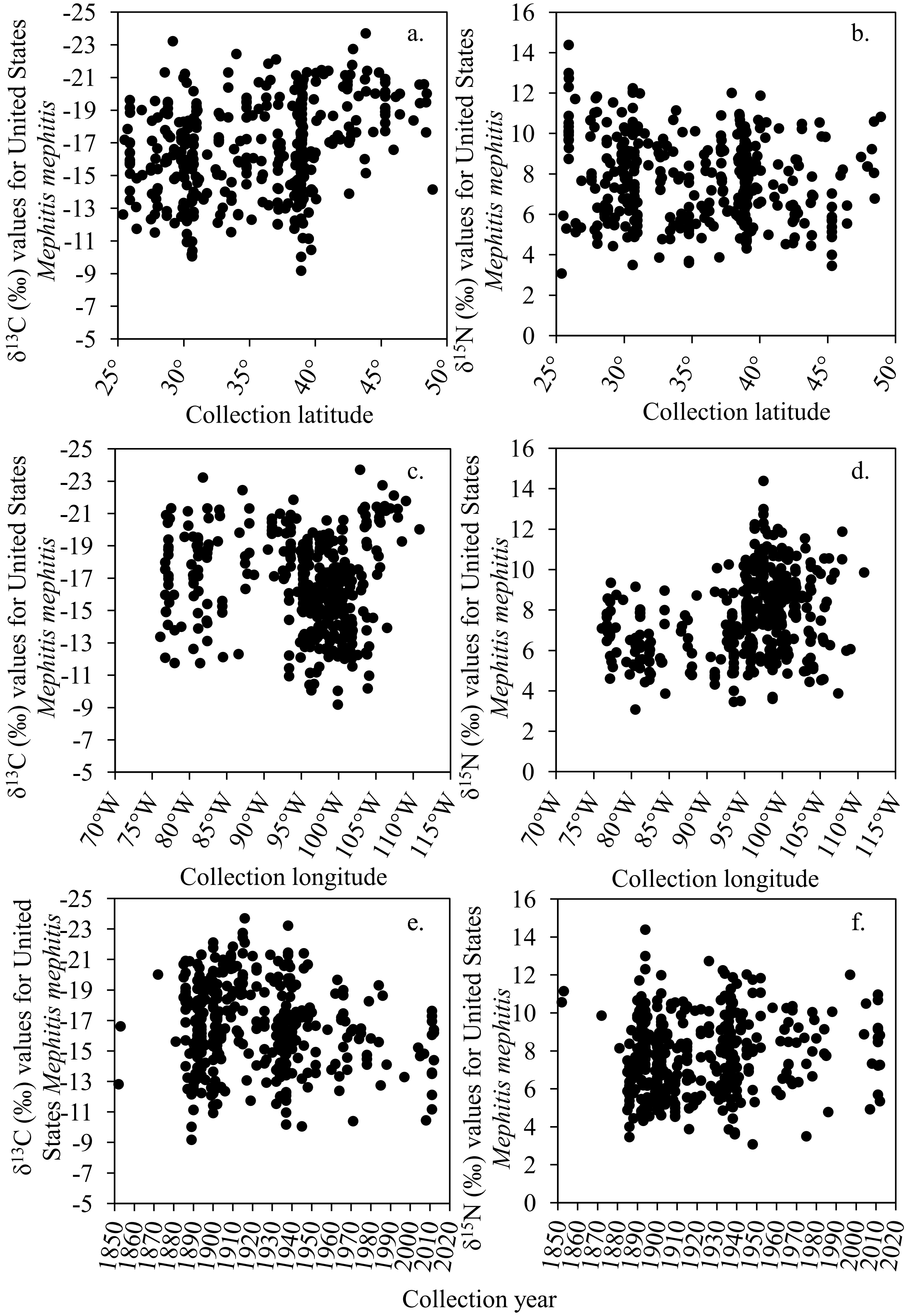
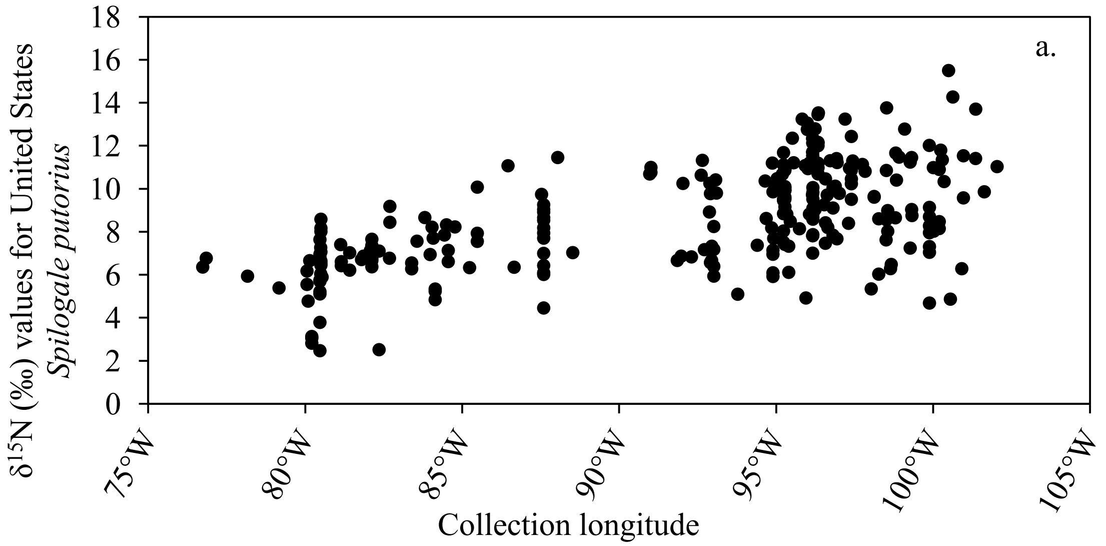
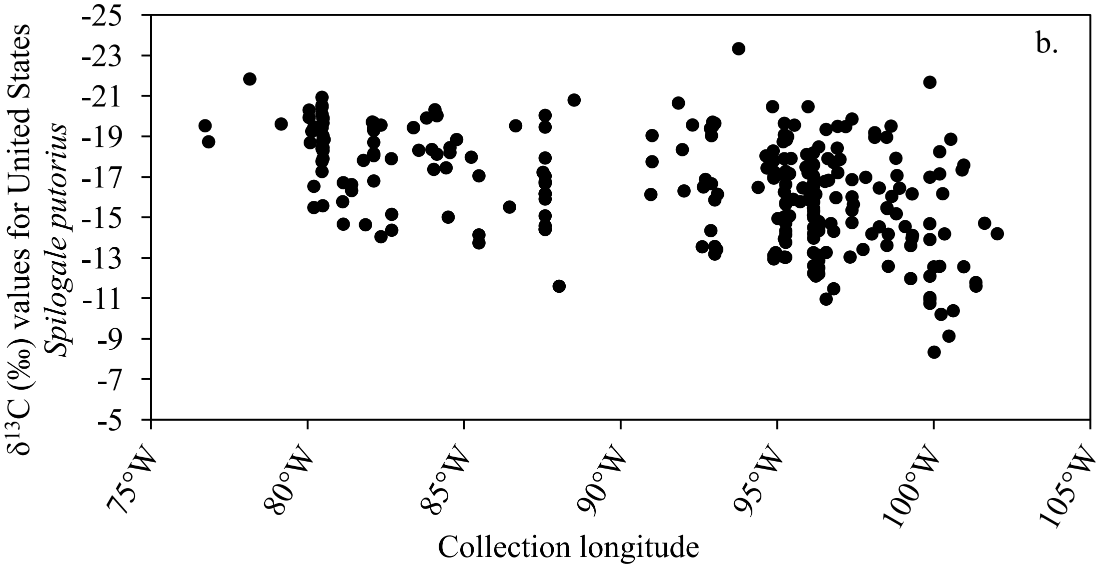

a.
b.
c.
d.
e.
f.
δ13C (‰) values for United States Mephitis mephitis
δ15N (‰) values for United States Mephitis mephitis
-25
-23
-21
-19
-17
-15
-13
-11
-9
-7
-5
16
14
12
10
8
6
4
2
0
25°
30°
35°
40°
45°
50°
Collection latitude
70°W
75°W
80°W
85°W
90°W
95°W
100°W
105°W
110°W
115°W
Collection longitude
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Collection year

Fig. 5.12. a. Plot of the positive relationship between δ^{15}N values of *Spilogale putorius* and collection longitude for specimens collected across their United States range. b. Plot of the positive relationship between δ^{13}C values of *S. putorius* and collection longitude for specimens collected across their United States range. and c. Plot of the positive relationship between δ^{13}C values of *S. putorius* and year for specimens collected across their United States range.


a.
δ15N (‰) values for United States
Spilogale putorius
0
2
4
6
8
10
12
14
16
18
75°W
80°W
85°W
90°W
95°W
100°W
105°W
Collection longitude


b.
δ13C (‰) values for United States
Spilogale putorius
-25
-23
-21
-19
-17
-15
-13
-11
-9
-7
-5
75°W
80°W
85°W
90°W
95°W
100°W
105°W
Collection longitude

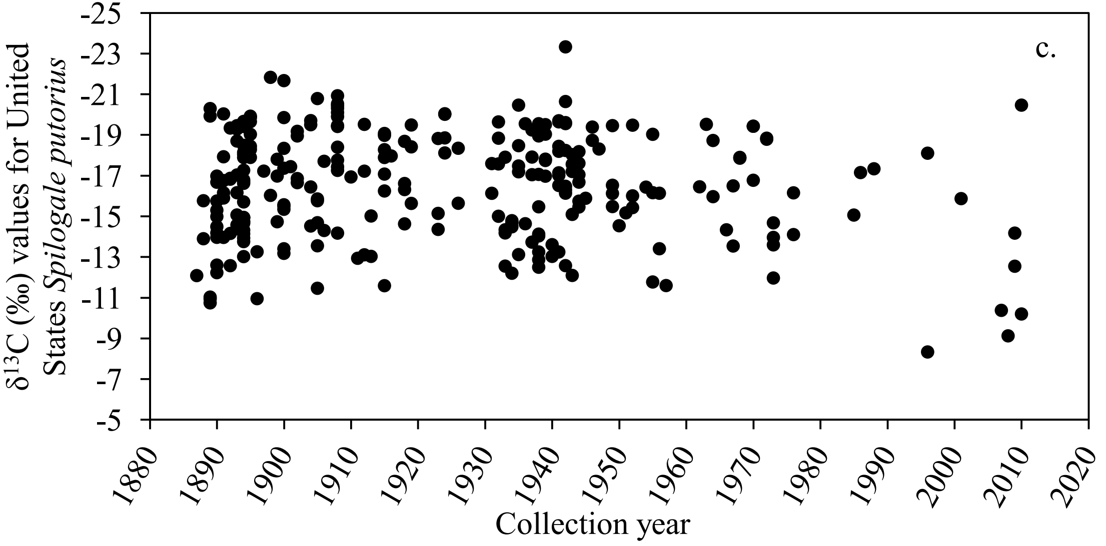

c.
δ13C (‰) values for United
States *Spilogale putorius*
-25
-23
-21
-19
-17
-15
-13
-11
-9
-7
-5
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Collection year

Fig. 5.13. $\delta^{15}N$ values of *Mephitis mephitis* over collection year for states with 10 or greater specimens. From top left: Colorado, Florida, Nebraska, Oklahoma, and Texas. *P*-values embedded in plots for each state.

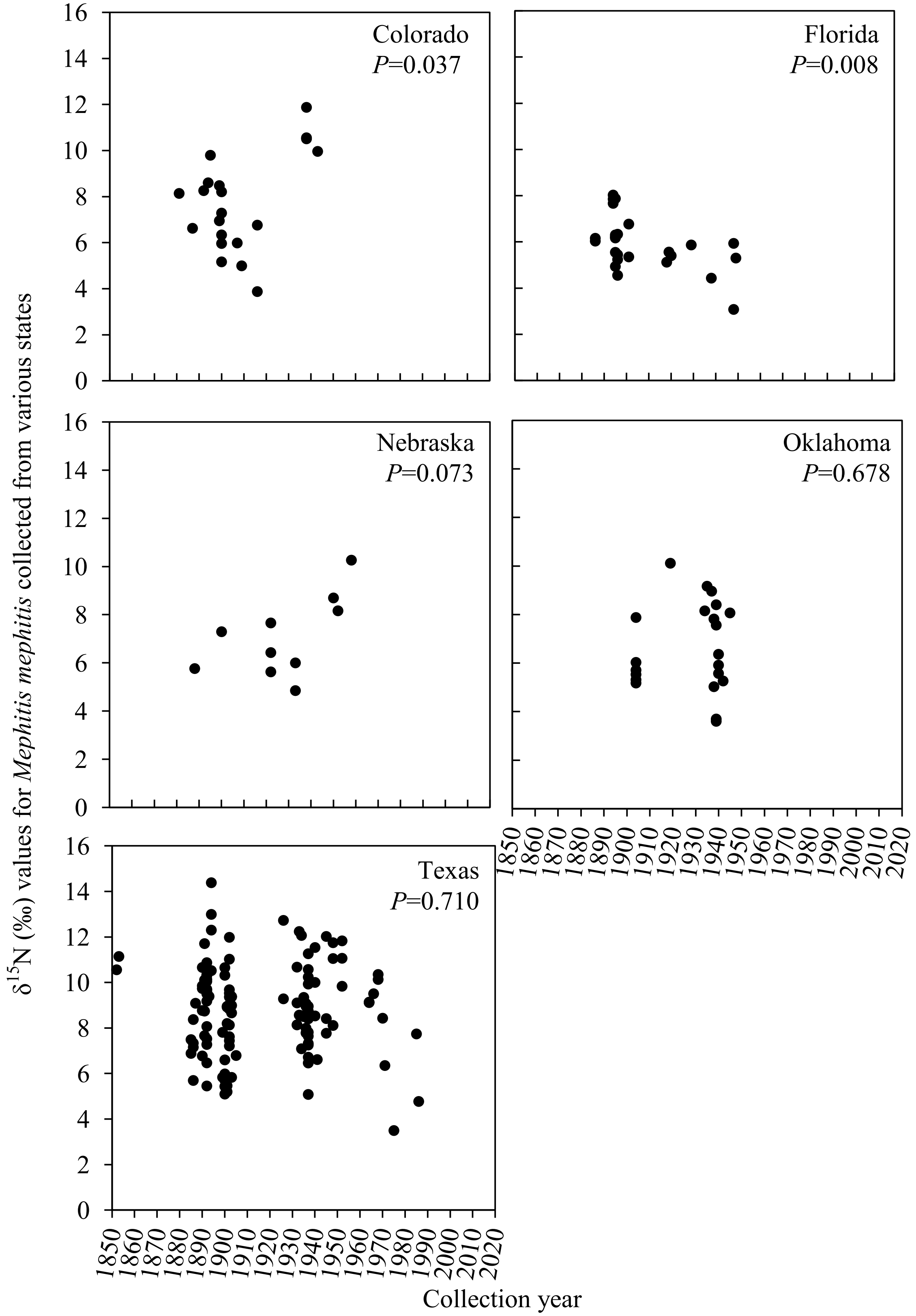

Colorado
P=0.037
Florida
P=0.008
Nebraska
P=0.073
Oklahoma
P=0.678
Texas
P=0.710
0
2
4
6
8
10
12
14
16
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
δ15N (‰) values for Mephitis mephitis collected from various states
Collection year

Fig. 5.14. $\delta^{15}N$ values of *Spilogale putorius* over collection year for states with 10 or greater specimens. From top left: Alabama, Florida, Georgia, Iowa, North Carolina, Oklahoma, and Texas. *P*-values embedded in plots for each state.

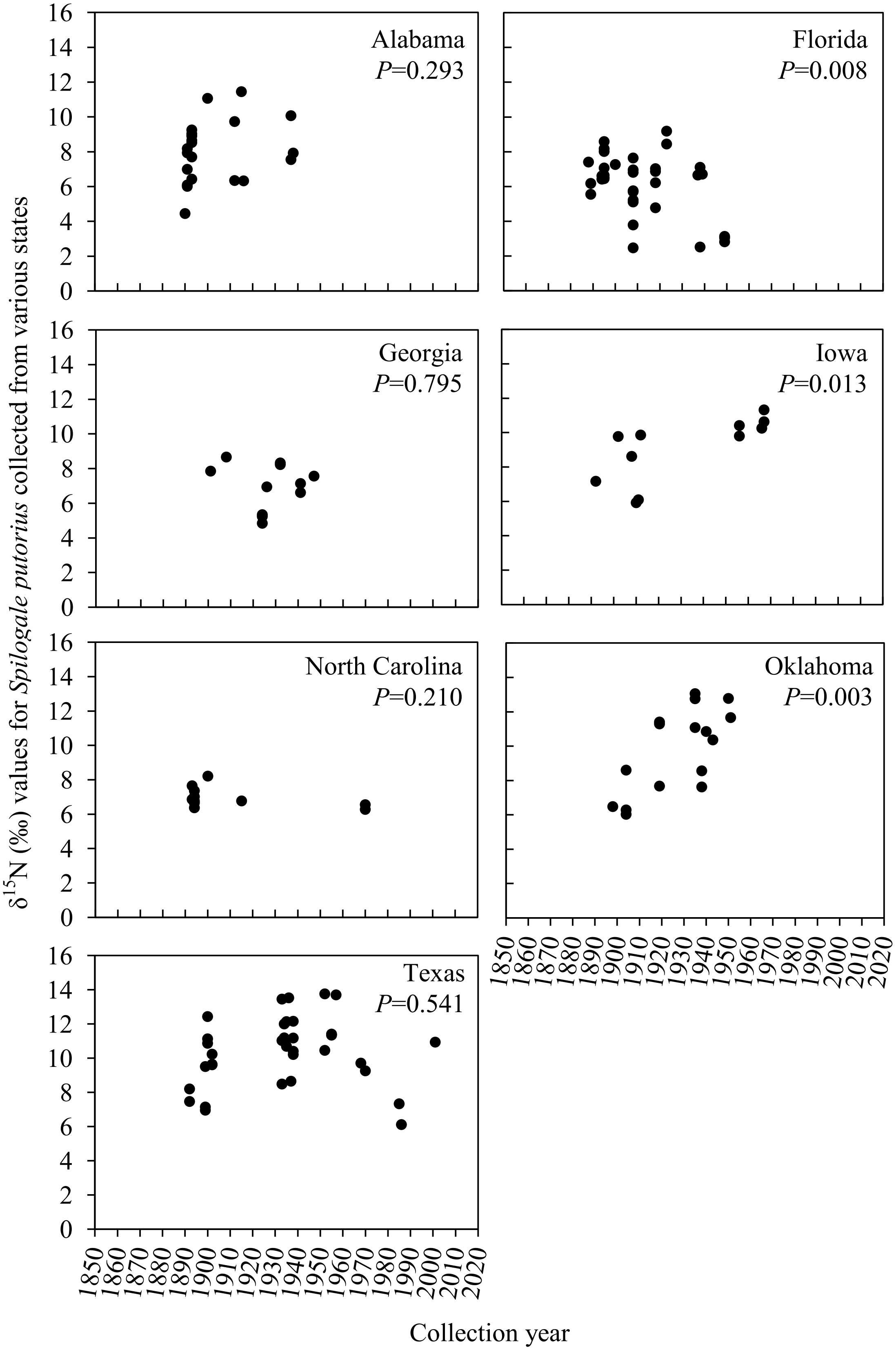

Alabama
P=0.293
Florida
P=0.008
Georgia
P=0.795
Iowa
P=0.013
North Carolina
P=0.210
Oklahoma
P=0.003
Texas
P=0.541
δ15N (‰) values for *Spilogale putorius* collected from various states
0
2
4
6
8
10
12
14
16
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Collection year

Fig.5.15. δ^{13}C values of *Mephitis mephitis* over collection year for states with 10 or greater specimens. From top left: Colorado, Florida, Kansas, Nebraska, Oklahoma, and Texas. *P*-values embedded in plots for each state

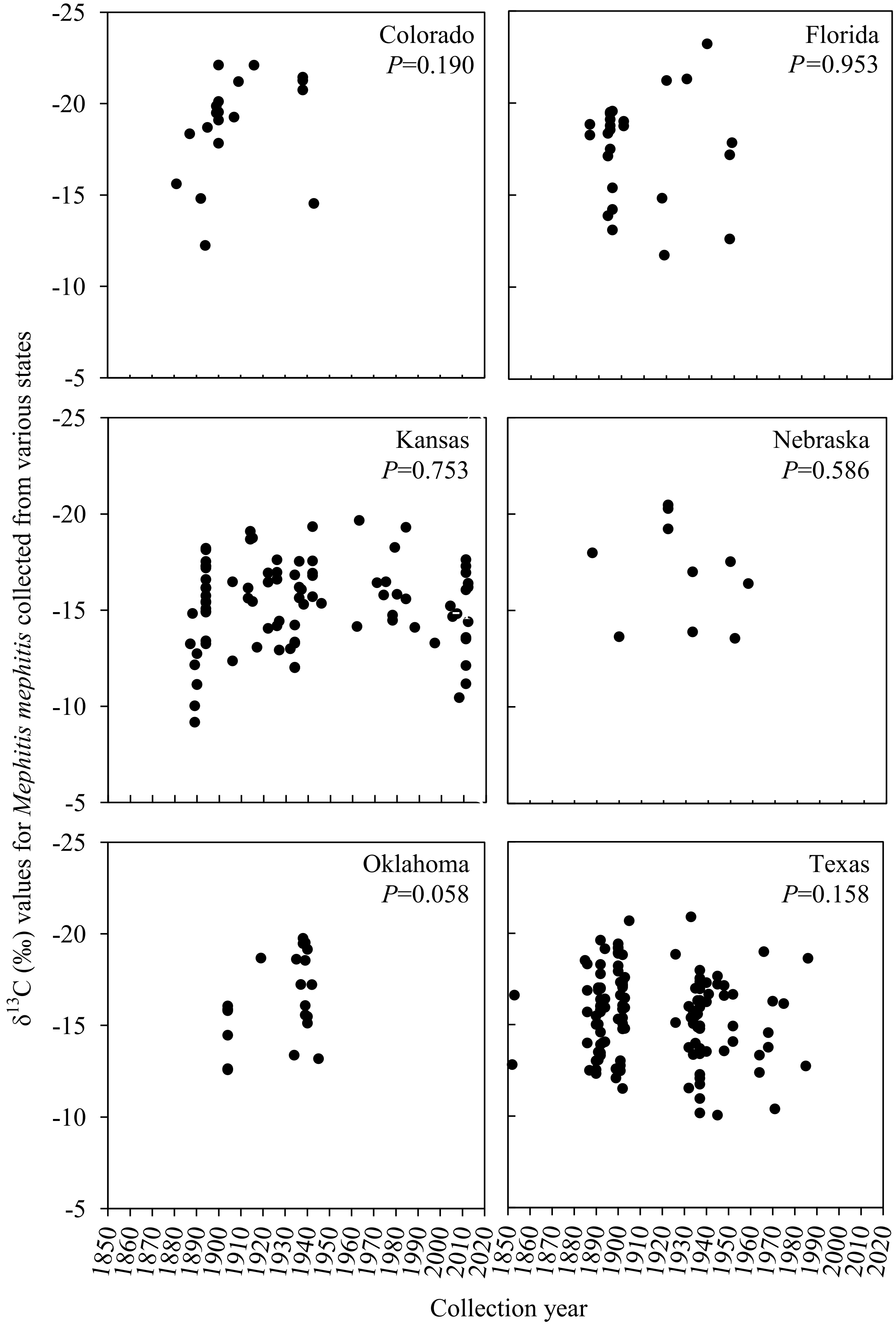

Colorado
P=0.190
Florida
P=0.953
Kansas
P=0.753
Nebraska
P=0.586
Oklahoma
P=0.058
Texas
P=0.158
-25
-20
-15
-10
-5
δ13C (‰) values for Mephitis mephitis collected from various states
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Collection year

Fig. 5.16. $\delta^{13}C$ values of *Spilogale putorius* over collection year for states with 10 or greater specimens. From top left Alabama, Florida, Georgia, Iowa, Kansas, North Carolina, Oklahoma, and Texas. *P*-values embedded in plots for each state.

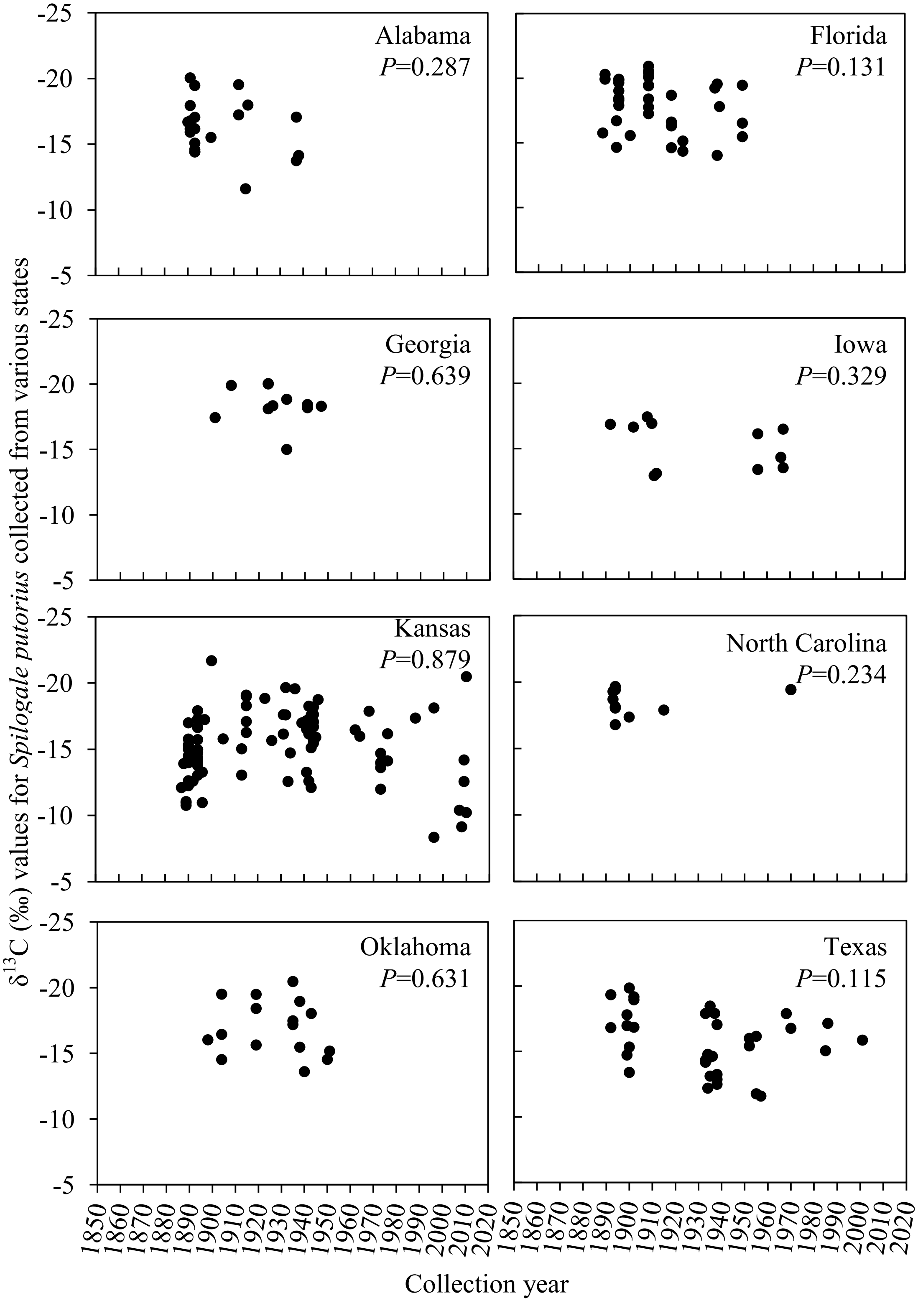
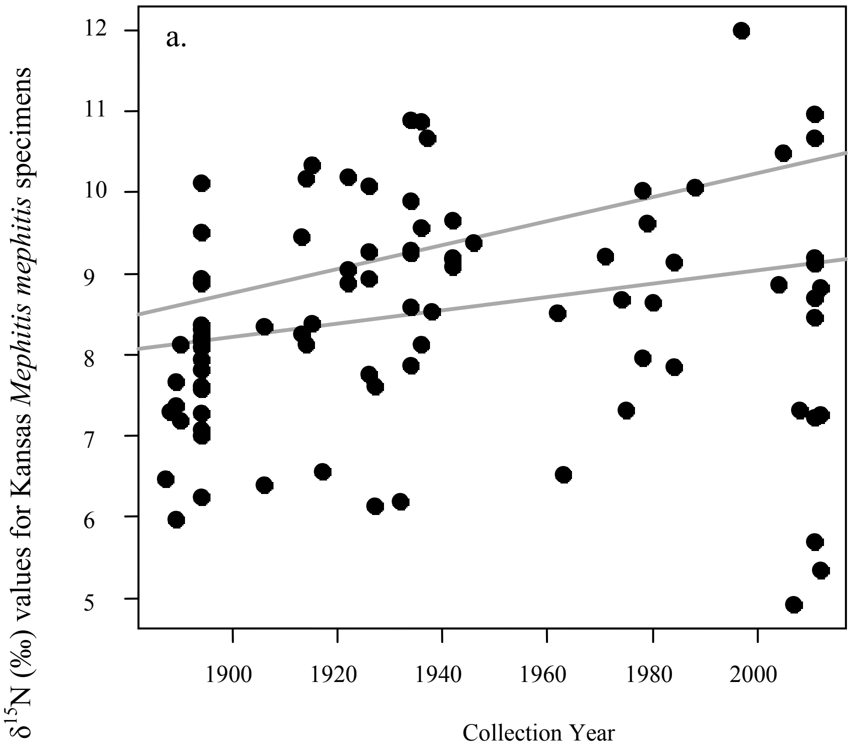
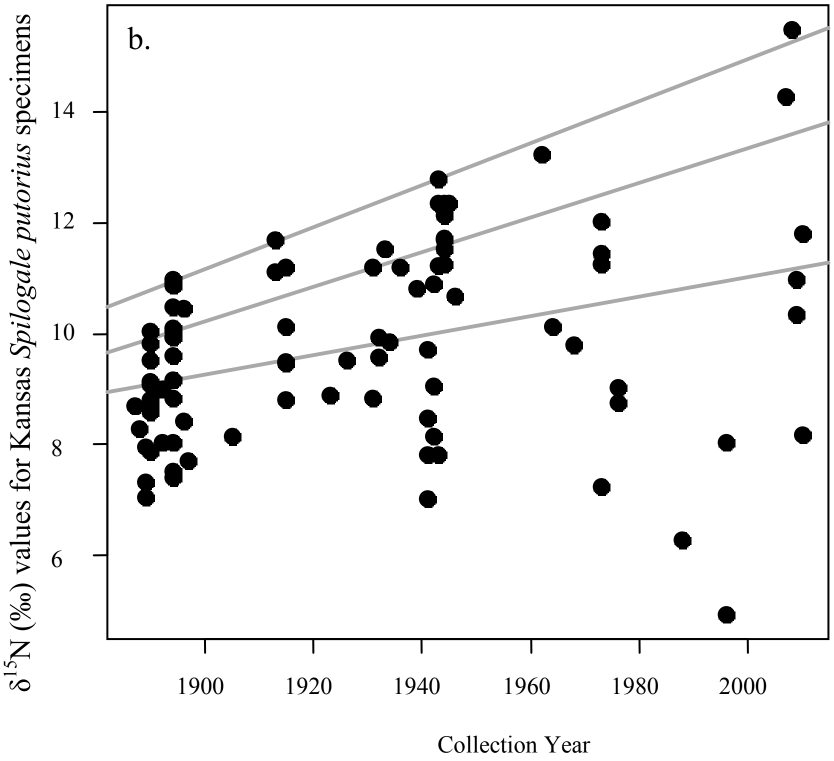

Alabama
P=0.287
Florida
P=0.131
Georgia
P=0.639
Iowa
P=0.329
Kansas
P=0.879
North Carolina
P=0.234
Oklahoma
P=0.631
Texas
P=0.115
-25
-20
-15
-10
-5
δ^{13}C (‰) values for *Spilogale putorius* collected from various states
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Collection year

Fig. 5.17. Graph depicting results from quantile regression for: a. $\delta^{15}N$ values of *Mephitis mephitis* over collection year in Kansas and b. $\delta^{15}N$ values of *Spilogale putorius* over collection year in Kansas. Solid gray lines represent the significant 0.5 and 0.75 quantiles for *M. mephitis* and the significant 0.5, 0.75, and 0.95 quantiles for *S. putorius.*


a.
δ15N (‰) values for Kansas *Mephitis mephitis* specimens
12
11
10
9
8
7
6
5
1900
1920
1940
1960
1980
2000
Collection Year


b.
δ15N (‰) values for Kansas *Spilogale putorius* specimens
14
12
10
8
6
1900
1920
1940
1960
1980
2000
Collection Year

Appendix I. List of specimens used in examination of molting patterns by voucher number. Specimens organized alphabetically by species, museum affiliation, and then voucher number.

Spilogale putorius

University of Kansas Natural History Museum, Lawrence, Kansas: 1281, 1282, 1283, 1285, 1286, 1287, 1288, 1289, 1290, 1291, 1292, 1294, 1295, 1296, 1300, 2040, 2517, 2631, 2635, 4103, 4130, 4131, 4132, 4820, 5100, 8002, 10332, 13003, 14089, 14236, 14237, 14736, 18457, 18745, 39186, 41553, 54330, 54331, 54332, 54333, 54334, 54335, 54336, 54337, 54338, 54339, 54340, 54341, 54342, 72406, 74492, 108074, 109832, 112840, 119637, 134412, 134413, 151913, 156041, 156042, 160311. Sternberg Museum of Natural History, Hays, Kansas: 2448, 10450, 10480, 10481, 10482, 12553, 27856, 37522, 39054.

Mephitis mephitis

University of Kansas Natural History Museum, Lawrence, Kansas: 284, 1312, 1316, 1318, 1319, 1320, 1322, 1323, 1324, 1327, 1328, 1330, 1332, 2038, 2468, 2633, 2656, 3473, 3474, 3475, 3476, 3552, 3573, 4127, 4312, 4818, 4819, 5098, 5441, 5497, 6956, 8622, 10057, 10323, 10329, 10330, 10331, 10966, 10967, 11491, 11492, 12391, 12393, 13234, 14165, 14166, 14167, 14168, 14169, 14235, 16550, 18833, 51647, 60565, 72458, 72657, 72658, 76590, 76591, 79182, 79842, 79843, 81849, 92625, 134414, 160168. Sternberg Museum of Natural History, Hays, Kansas: 184, 1269, 11505, 14348, 15690, 18057, 20851, 21889, 22000, 25447, 37288, 38185.

Appendix II. List of *Mephitis mephitis* specimens used in examination of the effects of tanning on $\delta^{13}C$ and $\delta^{15}N$ values by voucher number. Specimens organized alphabetically museum affiliation, then voucher number. Tanned skins are marked with an asterisk.

National Museum of National History, Washington, DC: 127, 292, 13279, 13353, 17051, 17052, 17053, 17054, 17055, 19536, 20114, 21816, 21817, 23037, 23760, 24457, 24837, 24838, 25251, 25277, 25278, 25279, 29025, 29029, 31416, 32537, 32538, 32688, 32946, 33130, 34041, 35703, 36041, 36042, 36043, 36044, 36045, 36185, 36186, 36351, 36352, 55555, 55947, 61768, 64016, 64017, 64018, 70026, 73052, 79118, 79119, 79120, 79121, 79122, 79123, 79124, 79156, 79157, 79158, 83301, 96612, 97718, 99367, 99378, 99649, 99650, 99651, 99670, 99698, 99710, 99711, 99712, 99713, 99714, 99715, 99716, 99764, 99831, 99832, 99833, 99834, 99891, 100116, 108534, 108535, 108785, 109101, 111374, 16016, 116285, 116478, 116479, 116534, 117205, 117206, 118618, 118619, 118620, 118621, 118622, 118623, 119015 ,119016, 119017, 120194, 120906, 126348, 126349, 126350, 126421, 127874, 130366, 136548, 139175, 139176*, 139777, 149717, 149718*, 49719*, 159427, 159428, 159429, 159740, 169003, 177512, 188476, 188477, 188490, 188499, 188500, 188501, 188502, 188503, 188504, 188505, 188506, 188594, 203516, 207187, 209489*, 209490*, 209491*, 209493*, 209500*, 209501*, 209502*, 210206*, 213116*, 213118*, 213696*, 214798*, 214799*, 216294*, 216296*, 216298*, 216299, 221839*, 222681*, 223735*, 224093*, 224196*, 224197*, 224198*, 224200*, 224201*, 224203*, 224204*, 224205*, 224206*, 224225*, 224508, 224544*, 224545*, 224546, 231611, 231612, 234383, 248744, 261646*, 261647*, 261648*, 261649, 263700, 266416*, 266505*, 286588*, 286731*, 286732*, 289396, 506926, 507429*, 507430*, 507431*, 507432*, 511150, 566429, 567897*, 567898*, 567899*, 567900*, 567901*, 567902*, 597644. Museum of Vertebrate Zoology, Berkeley, California: 21991, 21992, 38939*, 51604*, 52095*, 52096*, 52097*, 52098*, 80333*, 80334*, 80335, 80690*, 81377, 81378, 81390, 84150, 84151, 84152, 90775, 90776, 90850. Sternberg Museum of Natural History, Hays, Kansas: 184, 1269. Texas Cooperative Wildlife Collection, College Station, Texas: 222, 232, 430, 720, 721, 853, 922, 1420, 1458, 1459, 1573, 1574, 1575, 1822, 1881, 2236, 2237, 2238, 2239, 2241, 2524, 2674, 2675, 2676, 3597, 3598, 3672*, 3673, 3694*, 3695*, 3696*, 3697*, 3698*, 3699*, 3700*, 3701*, 3702*, 3703*, 3704*, 3705*, 3907*, 3929, 22784, 23517, 28297, 28301, 28304, 36392*. University of Kansas Natural History Museum, Lawrence, Kansas: 284, 1271, 1277, 1278, 1279, 1280, 1312, 1316, 1318, 1319, 1320, 1322, 1323, 1324, 1327, 1328, 1330, 1332, 1334, 1335, 1336, 1337, 1338, 1339, 1340, 1341, 1342, 2038, 2468, 2632, 2633, 2656, 3473, 3474, 3475, 3476, 3496, 3552, 3573, 4038, 4039, 4040, 4818, 4819, 5098, 5441, 5497, 6956, 8622, 10323, 10329, 10330, 10331, 10966, 10967, 11491, 11492, 12391, 12392, 12393, 13234, 14165, 14167, 14168, 14169, 14235, 14672, 14673, 18833, 27336, 51647, 51740, 51741, 51743, 51752*, 60565, 72458*, 72657*, 72658*, 76590*, 76591*, 79182, 79842*, 79843*, 81849*, 134414, 154202, 154206. University of Michigan Museum of Zoology, Ann Arbor, Michigan: 55705, 55706, 58022, 58023, 66803, 66804, 68287, 68288, 75793, 75794, 76969, 79399, 79400, 90449, 90833, 96866, 96867, 98934.

Appendix III. List of specimens sampled by voucher number. Specimens organized alphabetically by species, museum affiliation, and then voucher number. Asterisks indicate specimens in which stable isotope analysis failed and there were not enough samples to redo the analysis.

Mephitis mephitis

Museum of Vertebrate Zoology, Berkeley, California: 6314, 21991, 21992, 38939, 51604, 52095, 52096, 52097, 52098, 80333, 8033, 80690, 80751, 81377, 81378, 81390, 81782, 84150, 84151, 84152, 90775, 90776, 90850. National Museum of Natural History, Washington, DC: 127, 292*, 292, 11096, 11800, 13279, 13353, 17051, 17052, 17053, 17054, 17055, 19536, 20114, 21816, 21817, 22533, 23037, 23760, 24457, 24837, 24838, 25251, 25251, 25277, 25278, 25279, 29025, 29029, 31416, 31416, 32537, 32538, 32688, 32946, 32946, 33130, 34041, 34539, 34540, 34541, 35703, 36041, 36043, 36044, 36045, 36045, 36185, 36185, 36186, 36351, 36352, 51504, 51505, 53917, 53918*, 53918, 53919, 55555, 55947, 61768, 64016, 64017, 64018, 67372, 70026, 73052, 79118, 79119, 79120, 79121, 79122, 79123, 79124,79156, 79157*, 79158, 83301, 96612, 97718, 99367, 99378, 99649, 99650*, 99651, 99670, 99697, 99698, 99710, 99711*, 99711, 99712, 99713, 99714, 99715, 99716, 99717*, 99764, 99831*, 99832*, 99832, 99833, 99834, 99891, 100116, 108317, 108534, 108535*, 108535, 108785, 109101*, 109101, 111374, 116016, 116285*, 116285, 116478, 116479, 116534, 117205, 117206, 118618*, 118618, 118619, 118620, 118621, 118622, 118623, 119015, 119016, 119017, 120194, 120906, 126348*, 126348, 126349, 126350, 126421, 127874, 130366, 132456, 132457,132458, 132459, 132747, 132748, 136548*, 136548, 139172, 139175*, 139175, 139176, 139777*, 139777, 149717*, 149718, 149719, 158456, 159427, 159428, 159429, 159740*, 160506, 160507, 160508, 166810, 166811, 167488, 169003*, 170637, 172092, 177512, 180252, 180253, 188476, 188477, 188480, 188481*, 188482, 188483*, 188483, 188484*, 188485, 188486, 188487, 188488*, 188488, 188490*, 188496*, 188496, 188499, 188500*, 188501, 188502, 188503, 188504, 188505, 188506, 188594, 203516, 207186*, 207187*, 207187, 207708*, 208152*, 208152, 208153, 208485, 208879, 208880*, 209489, 209490, 209491, 209493, 209500, 209501, 209502, 210206, 213116, 213117*, 213117, 213118, 213696, 214798, 214799, 216294, 216296, 216298, 216299*, 216299, 221839, 222681, 223735, 224093, 224196, 224197, 224198, 224200, 224201, 224203, 224204, 224205, 224206, 224224*, 224225, 224508*, 224544, 224545, 224546*, 231611, 231612, 234383, 248744, 249122, 251417, 251503, 260920, 260921, 261646, 261647, 261648, 261649*, 261649, 262251, 263700, 264618*, 265573, 265944, 265945, 265946, 265947, 265948, 266505, 267308, 267404, 268012, 273408*, 273970*, 273970, 273971, 273972, 273973, 273974, 275125, 282752, 283106, 286588, 286731, 286732, 289396, 506926, 507429, 507430, 507431, 507432, 511150, 530286, 530287, 566429*, 566429, 567897, 567898*, 567898, 567899, 567900, 567901, 567902, 597644. Sternberg Museum of Natural History, Hays, Kansas: 184, 1269, 11505, 14348, 15690, 18057, 20851, 21889, 22000, 23617, 25447, 34736, 37288, 38185. Texas Cooperative Wildlife Collection, College Station, Texas: 222, 232, 430, 720, 721, 853, 922, 1420, 1458, 1459, 1573, 1574, 1575, 1822, 1881, 2236, 2237, 2238, 2239, 2241, 2524, 2674, 2675, 2676, 3597, 3598, 3672, 3673, 3694, 3695, 3696, 3697, 3698, 3699, 3700, 3701, 3702, 3703, 3704, 3705, 3907, 3929, 22784, 23517, 28296, 28297, 28298, 28301, 28304, 28755, 30178, 35562, 36392, 38608, 38609, 57850, 57851. University of Kansas Natural History Museum, Lawrence, Kansas: 284, 1271, 1277, 1278, 1279, 1280, 1312, 1316, 1318, 1319, 1320, 1322, 1323, 1324, 1327, 1328, 1330, 1332, 1334, 1336, 1337, 1338, 1339, 1340, 1341, 1342, 2038, 2468, 2632, 2633, 2656, 3473, 3474, 3475, 3476, 3496, 3552, 3573, 4038, 4039, 4040, 4127, 4818, 4819, 5098, 5441, 5497, 6956, 8622, 10057, 10323, 10329, 10330, 10331, 10966, 10967, 11491, 11492, 12391, 12392, 12393, 13234, 14165, 14167, 14168, 14169, 14235, 14672, 14673, 16550, 18833, 27336, 51647, 51740, 51741, 51743, 51752, 60565, 72458, 72657, 72658, 76590, 76591, 79182, 79842, 79843, 81849, 92625, 104075, 105158, 108075, 108076, 109833, 119640, 119641, 119642,119643, 119644, 119645, 134414, 154202, 154206, 160168. University of Michigan Museum of Zoology, Ann Arbor, Michigan: 32621, 34952, 34953, 53841, 55705, 55706, 58022, 58023, 65803, 66803, 66804, 68287, 68288, 75667, 75793, 75794, 76969, 79399, 79400, 83551, 90449, 90833, 96866, 96867, 98934, 125686.

Spilogale putorius

Museum of Vertebrate Zoology, Berkeley, California: 52093, 52094, 57144, 57145, 63291, 80691, 80750, 81316, 81583, 81584, 90639, 90745, 90746, 90905, 95769, 97347, 97348, 97392, 97393, 97930, 97931, 97932, 9998. National Museum of Natural History, Washington, DC: 3913, 8131, 11136, 17183, 17184, 17185, 19537, 19537, 22534, 22535, 22536, 23170, 24716, 25248, 25248, 25269, 25270, 25271, 25272, 25273, 25274, 25275, 25276, 25484, 25690, 26432, 26433, 26433, 31021, 31022, 31023, 31858, 32421, 32422, 33028, 35228, 35230, 36188, 55794, 56305, 56306, 57039*, 57039, 57040, 57041*, 57041, 57585, 57586, 58115*, 58697, 58698, 58699, 58700*, 58700, 58701*, 64019, 64020, 64021, 66302, 66303, 66304, 70304, 70305, 70306, 70307, 70309, 70310, 70311, 83862, 83863, 86429, 91590, 92171*, 96066, 97032, 97033, 99776, 99892, 100099, 100100, 101332, 101989, 113373, 116348, 118427*, 118428, 120201,132434, 132466, 132806*, 132806, 135488, 135904*, 135904, 135905*, 135906, 140557, 140559, 147751, 147752*, 147752, 148517, 157065, 158875, 159525*, 159525, 178143, 178478, 188460, 188461*, 188464*, 18846*, 188466, 188475, 207188*, 207188, 210795, 223100, 228372, 228382, 231607*, 231608, 231609, 231610, 243510, 243511, 244349*, 244349, 245461, 245462, 245463, 253844, 255388*, 255388, 261650, 261651*, 262214, 263620, 263681, 264642, 265298, 271982*, 273968, 273969, 276013, 286403, 286676*, 286676, 287724, 287736, 287739, 301795, 392846, 392847, 399031*, 530288, 567908, 589250, 589251. Sternberg Museum of Natural History, Hays, Kansas: 2448, 10450, 10480, 10481, 10482, 12553, 27856, 37522, 39054, 39235, 39236, 39237, 39238. Texas Cooperative Wildlife Collection, College Station, Texas: 230, 297, 722, 854, 868, 877, 923, 1031, 1419, 2527, 5623, 5624, 6534, 6554, 26648, 28754, 57879, 57881, 59601, 59800. University of Kansas Natural History Museum, Lawrence, Texas: 219, 1281, 1282, 1283, 1285, 1286, 1287, 1288, 1289, 1290, 1291, 1292, 1293, 1294, 1295, 1296, 1297, 1298, 1299, 1300, 2040, 2517, 2631, 2635, 4103, 4130, 4131, 4132 ,4820, 5100, 8002, 10332, 13003, 14089, 14236, 14237, 14736, 18457, 18745, 39186, 41553, 51739, 54330, 54331, 54332, 54333, 54334, 54335, 54336, 54337, 54338, 54339, 54340, 54341, 54342, 57214, 72406, 108074, 109832, 112840 ,119637, 119638, 119639, 134412, 134413, 151913, 156041, 156042, 160311. University of Michigan Museum of Zoology, Ann Arbor, Michigan: 38429, 41763, 41979, 42533, 75668, 75669, 75670, 76968, 81815, 81816, 81817, 91085, 96868, 96869, 98715, 105473, 107443, 107938, 107939, 107940, 107941, 107942, 107944, 107945, 107946, 107947, 107948, 112375, 123812, 123813.

Appendix IV. List of specimens used in examination of effects of melanin on $\delta^{13}C$ and $\delta^{15}N$ values by voucher number. Specimens organized alphabetically by species, museum affiliation, and then voucher number.

Lepus californicus

Sternberg Museum of Natural History, Hays, Kansas: 18369, 18358, 18366, 620.

Lynx rufus

Sternberg Museum of Natural History, Hays, Kansas: 620.

Mephitis mephitis

Sternberg Museum of Natural History, Hays, Kansas: 1319, 11505, 18057, 23537.

Spilogale putorius

Sternberg Museum of Natural History, Hays, Kansas: 10480, 10481, 12552, 12553, 27856.

Urocyon cinereoargenteus

Sternberg Museum of Natural History, Hays, Kansas: 11081, 12716

Vulpes velox

Sternberg Museum of Natural History, Hays, Kansas: 12991, 14685, 24511.

Vulpes vulpes

Sternberg Museum of Natural History, Hays, Kansas: 32346.

Appendix V. List specimens used in examination of the relationships between $\delta^{13}C$ and $\delta^{15}N$ stable isotope diet analysis and fine-extent landscape patterns by voucher number. Specimens organized alphabetically by species, museum affiliation, and then voucher number.

Mephitis mephitis

Sternberg Museum of Natural History, Hays, Kansas: 184, 1269, 11505, 14348, 15690, 18057, 20851, 21889, 22000, 25447, 34736, 37288, 38185. University of Kansas Natural History Museum, Lawrence, Kansas: 12391,160168.

Spilogale putorius

Sternberg Museum of Natural History, Hays, Kansas: 2448, 10450, 10480, 10481, 10482, 12553, 27856, 37522, 39054, 39236, 39237, 39238. University of Kansas Natural History Museum, Lawrence, Kansas: 14736, 18457, 54330, 54331, 54332, 54333, 54334, 54335, 54336, 54337, 54338, 54339, 156041, 156042, 160311.

Appendix VI. List of specimens used in mixing model analysis by voucher number. Specimens organized alphabetically by species, museum affiliation, and then voucher number.

Mephitis mephitis

Museum of Vertebrate Zoology, Berkeley, California: 21991, 21992. National Museum of Natural History, Washington, DC: 17051, 17052, 17053, 17054, 17055, 25277, 25278, 25279, 203516. Sternberg Museum of Natural History, Hays, Kansas: 184, 1269, 11505, 14348, 15690, 18057, 20851, 21889, 22000, 25447, 34736, 37288, 38185. University of Kansas Natural History Museum, Lawrence, Kansas: 284, 1312, 1316, 1318, 1319, 1320, 1322, 1323, 1324, 1327, 1328, 1330, 1332, 1334, 1335, 1337, 2038, 2468, 2632, 2633, 2656, 3473, 3552, 3573, 4818, 4819, 5098, 5441, 5497, 6956, 8622, 10323, 10329, 10330, 10331, 10966, 10967, 11491, 11492 ,12391, 12393, 13234, 14165, 14167, 14168, 14169, 14235, 18833, 134414, 160168. University of Michigan Museum of Zoology, Ann Arbor, Michigan: 55705, 55706.

Spilogale putorius

Museum of Vertebrate Zoology, Berkeley, California: 57144, 57145, 63291, 95769. Natural Museum of Natural History, Washington, DC: 8131, 19537, 22534, 22535, 22536, 24716, 25269, 25270, 25271, 25272, 25273, 25274, 25275, 25276, 35228, 35230, 83862, 83863, 91590, 188464, 188466. Sternberg Museum of Natural History, Hays, Kansas: 2448, 10450, 10480, 10481, 10482, 12553, 27856, 37522, 39054, 39235, 39236, 39237, 39238. Texas Cooperative Wildlife Collection, College Station, Texas: 5623, 5624. University of Kansas Natural History Museum, Lawrence, Kansas: 1281, 1282, 1283, 1285, 1286, 1288, 1289, 1290, 1291, 1292, 1294, 1295, 1296, 1300, 2040, 2517, 2631, 2635, 4103, 4820, 5100, 8002, 10332, 13003, 14089, 14236, 14237, 14736, 18457, 54330, 54331, 54332, 54333, 54334, 54335, 54336, 54337, 54338, 54339, 54340, 54341, 134412, 134413, 156041, 156042, 160311. University of Michigan Museum of Zoology, Ann Arbor, Michigan: 91085, 112375.

Appendix VII. List of specimens used in examination of state by state relationships between $\delta^{13}C$ and $\delta^{15}N$ values and collection year by voucher number. Specimens organized alphabetically by species, museum affiliation, and then voucher number.

Mephitis mephitis

Museum of Vertebrate Zoology, Berkeley, California: 6314, 21991, 21992, 80335, 80751, 81377, 81378, 81390, 81782, 84150, 84151, 84152, 90775, 90776, 90850, 1335. National Museum of Natural History, Washington, DC: 127, 292, 11096, 11800, 13353, 17051, 17052, 17053, 17054, 17055, 19536, 20114, 21816, 21817, 23037, 24457, 24837, 24838, 25251, 25277, 25278, 25279, 29025, 29029, 31416, 32537, 32538, 32688, 32946, 33130, 34041, 34539, 35703, 36041, 36043, 36045, 36185, 36186, 36351, 36352, 51504, 51505, 53917, 53918, 53919, 55555, 55947, 61768, 64016, 64017, 64018, 67372, 70026, 73052, 79118, 79119, 79120, 79121, 79122, 79123, 79124, 79156, 79157, 79158, 83301, 96612, 97718, 99367, 99378, 99649, 99650, 99651, 99670, 99697, 99698, 99710, 99711, 99712, 99713, 99714, 99715, 99716, 99764, 99831, 99832, 99833, 99834, 99891, 100116, 108317, 108534, 108535, 108785, 109101, 111374, 116016, 116285, 116478, 116479, 116534, 117205, 117206, 118618, 118619, 118620, 118621, 118622, 118623, 119015, 119016, 119017, 120194, 120906, 126348, 126349, 126350, 126421, 127874, 130366, 132456, 132457, 132458, 132459, 132747, 132748, 136548, 139175, 139777, 149717, 158456, 159427, 159428, 159429, 159740, 160506, 160507, 160508, 166810, 166811, 167488, 169003, 170637, 172092, 177512, 180252, 180253, 188476, 188477, 188480, 188481, 188482, 188483, 188484, 188485, 188486, 188487, 188488, 188490, 188496, 188499, 188500, 188501, 188502 , 188503, 188504, 188505, 188506, 188594, 203516, 207186, 207187, 207708, 208152, 208153, 208485, 208879, 208880, 213117, 216299, 224508, 224546, 231611, 231612, 234383, 248744, 249122, 251417, 251503, 260920, 260921, 261649, 262251, 263700, 264618, 265573, 265944, 265945, 265946, 265947, 265948, 267308, 267404, 268012, 273970, 273971, 273972, 273973, 273974, 275125, 283106, 289396, 511150, 530286, 530287, 566429, 597644. Sternberg Museum of Natural History, Hays, Kansas: 184, 1269, 11505, 14348, 15690, 18057, 20851, 21889, 22000, 23617, 25447, 34736, 37288, 38185. Texas Cooperative Wildlife Collection, College Station, Texas: 222, 232, 430, 720, 853, 922, 1420, 1458, 1459, 1573, 1574, 1575, 1822, 1881, 2236, 2237, 2238, 2239, 2241, 2524, 2674, 2675, 2676, 3597, 3598, 3673, 3929, 22784, 23517, 28296, 28298, 28301, 28755, 30178, 35562, 57850, 57851. University of Kansas Natural History Museum, Lawrence, Kansas: 23537, 284, 1271, 1277, 1278, 1279, 1280, 1312, 1316, 1318, 1319, 1320, 1322, 1323, 1324, 1327, 1328, 1330, 1332, 1334, 1337, 2038, 2468, 2632, 2633, 2656, 3473, 3474, 3475, 3476, 3552, 3573, 4127, 4818, 4819, 5098, 5441, 5497, 6956, 8622, 10057, 10323, 10329, 10330, 10331, 10966, 10967, 11491, 11492, 12391, 12393, 13234, 14165, 14167, 14168, 14169, 14235, 14672, 14673, 16550, 18833, 27336, 51647, 51740, 51741, 51743, 60565, 79182, 92625, 104075, 105158, 108075, 108076, 109833, 134414, 154202, 154206, 160168. University of Michigan Museum of Zoology, Ann Arbor, Michigan: 32621, 34952, 34953, 53841, 55705, 55706, 58022, 58023, 65803, 66803, 66804, 68287, 68288, 75667, 75793, 75794, 76969, 79399, 79400, 83551, 90449, 90833, 96866, 96867, 98934, 125686.

Spilogale putorius

Museum of Vertebrate Zoology, Berkeley, California: 52093, 52094, 57144, 57145, 63291, 80691, 80750, 81316, 81583, 81584, 90639, 90745, 90746, 90905, 95769, 97347, 97348, 97392, 97393, 97930, 97931, 97932, 99981. National Museum of Natural History, Washington, DC: 3913, 8131, 17183, 17184, 19537, 22534, 22535, 22536, 23170, 24716, 25248, 25269, 25270, 25271, 25272, 25273, 25274, 25275, 25276, 25484, 25690, 26432, 26433, 31021, 31858, 32421, 32422, 33028, 35228, 35230, 55794, 56305, 56306, 57039, 57040, 57041, 57585, 57586, 58697, 58698, 58699, 58700, 64020, 64021, 66302, 66303, 66304, 70304, 70305, 70306, 70307, 70309, 70310, 83862, 83863, 86429, 91590, 96066, 97032, 97033, 99776, 99892, 100099, 100100, 101332, 101989, 113373, 116348, 118427, 118428, 120201, 132434, 132466, 132806, 135488, 135904, 135906, 140557, 140559, 147751, 147752, 148517, 157065, 158875, 159525, 178143, 178478, 188460, 188464, 188466, 207188, 210795, 223100, 228372, 228382, 231608, 231609, 243510, 243511, 244349, 245461, 245462, 245463, 253844, 262214, 263620, 263681, 265298, 271982, 273968, 273969, 276013, 286403, 286676, 301795, 392846, 392847, 567908, 589250, 589251. Sternberg Museum of Natural History, Hays, Kansas: 2448, 10450, 10480, 10481, 10482, 12553, 27856, 37522, 39054, 39235, 39236, 39237, 39238. Texas Cooperative Wildlife Collection, College Station, Texas: 230, 297, 854, 868, 877, 923, 1031, 1419, 2527, 5623, 5624, 6534, 26648, 28754, 57879, 57881, 59601, 59800. University of Kansas Natural History Museum, Lawrence, Kansas: 219, 1281, 1282, 1283, 1285, 1286, 1288, 1289, 1290, 1291, 1292, 1294, 1295, 1296, 1300, 2040, 2517, 2631, 2635, 4103, 4130, 4131, 4132, 4820, 5100, 8002, 10332, 13003, 14089, 14236, 14237, 14736, 18457, 18745, 39186, 41553, 51739, 54330, 54331, 54332, 54333, 54334, 54335, 54336, 54337, 54338, 54339, 54340, 54341, 54342, 57214, 72406, 108074, 109832, 112840, 119637, 119638, 119639, 134412, 134413, 151913, 156041, 156042, 160311. University of Michigan Museum of Zoology, Ann Arbor, Michigan: 38429, 41763, 41979, 42533, 75668, 75669, 75670, 76968, 81815, 81816, 81817, 91085, 96868, 96869, 98715, 105473, 107443, 107938, 107939, 107940, 107941, 107942, 107944, 107945, 107946, 107947, 107948, 112375, 123812, 123813.