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ISOTOPE VARIATIONS IN WHITE-TAILED KITES FROM VARIOUS HABITATS IN CALIFORNIA: POSSIBLE LIMITATIONS IN ASSESSING PREY UTILIZATION AND POPULATION DYNAMICS

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White-tailed kite (*Elanus leucurus*) populations in the 1930s were close to extirpation in the United States. But by the 1940s, an upward trend towards recovery was apparent and continued to their current stable population levels. These dramatic fluctuations in kite numbers may have been related to changes in rodent prey populations due to the conversion of native habitats to agriculture. To address this question, we evaluated the use of stable isotope analysis in determining if a shift in diet could be isotopically differentiated in current and historic kite populations. We first compared $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ values from present-day kite flight feathers and prey fur samples from four locations in California. The total ranges of isotope values for kite and their rodent prey were similar within each site. Carbon isotope values ranged from −27.1 to −22.2‰ in Arcata, −26.1 to −16.9‰ in Davis, −27.0 to −15.0‰ in Cosumnes, and −28.2 to −11.6‰ in Santa Barbara. Nitrogen isotope values ranged from 3.2 to 15.7‰ in Arcata, 2.8 to 12.7‰ in Davis, 4.0 to 15.7‰ in Cosumnes, and 1.7 to 20.0‰ in Santa Barbara. Sulfur isotope values ranged from −7.8 to 12.4‰ in Arcata, −1.1 to 9.2‰ in Davis, 0.7 to 10.9‰ in Cosumnes, and −8.6 to 15.6‰ in Santa Barbara. Carbon, nitrogen, and sulfur isotope values at each site reflect typical trophic enrichments due to physiological processes. At each site, $\delta^{13}C$ and $\delta^{15}N$ values reflected the influence of a predominantly C_3 or a mixed C_3/C_4 plant community. Sulfur isotope values reflect the influence of predominant marine or terrestrial sulfur sources at each site. However, variability in isotope values may limit the usefulness of such analyses for addressing prey utilization and population dynamics.

Keywords: California; Carbon 13; *Elanus leucurus*; Food web dynamics; Natural variations; Nitrogen 15; Sulfur 34; White-tailed kite

INTRODUCTION

White-tailed kite (*Elanus leucurus*) populations have undergone dramatic fluctuations over the last 150 years. Common during early explorations of the western United States [1–3], by the 1900s the white-tailed kite was considered rare and close to extinction [4, 5]. By the 1930s, it had been extirpated from the southeastern U.S. and was considered nearly extinct in California [4]. However, by the 1940s an upward trend towards recovery was apparent, and

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has continued to their present-day stable population levels [6–8]. One possible cause for these dramatic kite population fluctuations may have been the impact of land use practices and habitat alteration on prey availability [6–9]. White-tailed kites feed on small rodents in grasslands, agricultural fields, and wetlands in California [8–10]. Stendell [9] and Dunk and Cooper [10] noted the dependence of kite populations on the California vole (*Microtus californicus*) and that localized fluctuations in kite numbers may be related to the population dynamics of their microtine rodent prey. Since vole populations are cyclic and can undergo great fluctuations in abundance, they may in turn influence the occurrence and reproductive success of white-tailed kites [8–14]. Conversion of native grassland and wetland habitats to agriculture may also have increased the overall abundance and diversity of rodent prey populations, especially after the introduction of the non-native house mouse (*Mus musculus*) to North America in the early 1900s [7, 13]. Increases in the abundance and diversity of rodent prey may have likewise increased the overall success and survival of white-tailed kites, allowing them to attain their current stable population levels.

To assess whether changes in rodent prey diversity and/or abundance over time may have influenced fluctuations in kite numbers, we evaluated the use of stable isotope analysis in determining the diet of current and historic white-tailed kite populations in California. Our first objective was to determine whether rodent prey species could be differentiated in present-day kite tissue samples. If successful, these techniques could then be applied to historic kite tissue samples from museum specimens for comparison with present-day kite diets. We also assessed the influence of variation in stable isotope values for selected tissues, particularly among flight feathers, as such variation may affect our ability to compare stable isotope measurements between locations and/or time periods.

MATERIALS AND METHODS

Four kite populations in California were selected: Arcata (Humboldt County), a coastal estuarine grassland-coniferous forest habitat; Davis (Yolo County), a mixed urban-agricultural habitat; the Cosumnes River Preserve (Sacramento County), a mixed riparian grassland-agricultural habitat; and Santa Barbara (Santa Barbara, Ventura, and San Luis Obispo Counties), a coastal estuarine grassland-upland chaparral habitat. These areas were selected because of their relatively stable year-round kite populations and potentially isotopically distinct habitats. The Santa Barbara site was also subdivided into six microhabitats to address isotope variability within a study area. Because kites are non-migratory and year-round residents, isotopic measurements from kite tissues should be comparable to rodent prey from the same location. To reduce annual variability, we collected kite feathers and rodent prey samples during the same time of the year when adult kites molt their flight feathers (breeding and post-fledging periods). We collected kite feather samples from nestlings, or from adult and fledged young, that were captured using various raptor trapping methods [15]. During these kite trapping efforts, samples of the kite's main rodent prey (California vole, house mouse, and western harvest mouse, *Reithrodontomys megalotis*) were also collected using snap traps in known kite feeding locations. Molted flight feathers were opportunistically collected from the ground under nest sites and communal roosts. The significance of variability among opportunistically collected feathers is best understood when compared to the variability within an individual bird. To address this issue of isotopic variation among flight feathers within an individual, we obtained four kite carcasses from Santa Barbara and collected feather samples for isotopic analysis from the distal and proximal ends of each of the ten primaries from the right wing of each specimen.

All kite feather and rodent fur samples were cleaned in a 2:1 chloroform:methanol solution, dried, and weighed prior to analysis. Samples were analyzed for their isotopic composition by continuous flow methods using a Carlo Erba NC2500 elemental analyzer coupled to either a Micromass Optima mass spectrometer or a Finnigan Delta Plus XL mass spectrometer [16, 17]. Isotopic compositions of $\delta^{13}C$ and $\delta^{15}N$ are reported in delta notation (‰) relative to PDB and Air, respectively, using internal laboratory standards calibrated against ANU sucrose ($\delta^{13}C = -10.4$‰), NBS 22 ($\delta^{13}C = -29.6$‰), USGS 25 ($\delta^{15}N = -30.4$‰), and USGS 26 ($\delta^{15}N = 53.7$‰). Isotopic compositions of $\delta^{34}S$ are reported in delta notation (‰) relative to CDT using internal laboratory standards calibrated against NBS 127 and IAEA-S-1 ($\delta^{34}S = 21.1$‰ and -0.3‰, respectively). Analytical error was ± 0.2‰ for C, N, and S values.

To assess whether there was a significant effect on feather isotope compositions related to study area, or microhabitat, we performed a MANOVA on our C, N, and S values. Because of the sensitivity of MANOVA to outlier effects, we also performed a one-way ANOVA for each isotope to determine which of these contributed to any significant effects found in our MANOVA results, and a Tukey's pairwise means comparison test to assess how study areas, or microhabitats, differed from each other. To assess the effect of variation among individual kites, we performed MANOVA for C, N, and S values, and a repeated measures ANOVA to assess whether C, N, and S values varied significantly among feathers from the same individual kite. All analyses were performed with Systat 8.0 statistical program, with a significance level of $\alpha = 0.05$ [18].

ANALYTICAL RESULTS AND DISCUSSION

The total range of isotope values was similar within each location for kite feathers and rodent prey samples (Tab. I). Carbon, nitrogen, and sulfur isotope values at each site reflected typical trophic enrichments due to physiological processes between primary consumers and their predators. Within each site, $\delta^{13}C$ and $\delta^{15}N$ values reflected the influence of a predominantly C_3 or a mixed C_3/C_4 plant community. The variability in $\delta^{34}S$ values may be related to the influence of marine versus terrestrial sulfur sources at each site, depending on the study location's proximity to oceanic and estuarine influences. Although isotope values reflect typical trophic enrichments, values for each rodent species within a given study location show a high degree of overlap (Tab. I).

In order to determine the influence of variation on our ability to compare stable isotope measurements between locations, we assessed the effect of study location on kite flight feather isotope values. A comparison of mean isotope values between study areas shows a high degree of overlap (Fig. 1). However, we found a significant influence on our isotope values related to study area (MANOVA, $F_{9,226} = 2.1$, $P = 0.03$). Of the three isotopes analyzed, carbon (one-way ANOVA, $F_{3,97} = 2.88$, $P = 0.04$) and sulfur (one-way ANOVA, $F_{3,98} = 3.09$, $P = 0.03$) had the greatest effect on the MANOVA results, with the Arcata and Davis sites differing the most from each other ($P < 0.05$, Fig. 1). These results may be related to the fact that Davis is the most inland of our study sites and furthest from marine and estuarine influences, while Arcata, located on Humboldt Bay, is one of the closest to these oceanic influences.

To assess the effect of microhabitats on the variation in feather isotope compositions, we subdivided the Santa Barbara location into six microhabitats (Fig. 2). Santa Barbara is unique among the four study locations as kites were sampled in habitats varying from upland chaparral to transitional foothills, coastal grassland, and estuarine environments. We found

TABLE I Mean (±SD) and Minimum (min) and Maximum (max) δ Values for Stable-Carbon, Nitrogen, and Sulfur Isotopes for White-Tailed Kite Flight Feathers and Rodent Prey Fur Samples from Four Study Locations in California.

Location	*Sample*	*n*	$\delta^{13}C$(‰) *Mean ± SD (min, max)*	*n*	$\delta^{15}N$(‰) *Mean ± SD (min, max)*	*n*	$\delta^{34}S$(‰) *Mean ± SD (min, max)*
Arcata	White-tailed kite	10	−25.4 ± 0.7 (−26.0, −24.2)	10	8.9 ± 1.3 (7.2, 10.9)	11	7.7 ± 4.1 (1.6, 12.4)
	California vole	19	−25.2 ± 1.9 (−27.1, −22.2)	19	7.1 ± 2.7 (3.2, 15.7)	19	0.2 ± 2.7 (−5.4, 4.7)
	House mouse	2	−24.1 ± 0.0 (−24.1, −24.1)	2	7.9 ± 0.1 (7.8, 7.9)	2	−0.4 ± 10.6 (−7.8, 7.1)
Davis	White-tailed kite	22	−23.2 ± 1.3 (−25.0, −19.6)	22	10.3 ± 1.3 (8.3, 12.7)	23	3.8 ± 3.0 (−1.1, 9.2)
	California vole	10	−24.9 ± 0.6 (−25.8, −24.0)	10	4.1 ± 0.9 (2.8, 5.6)	10	2.9 ± 1.2 (1.4, 5.0)
	House mouse	14	−24.1 ± 1.1 (−25.8, −21.7)	13	6.7 ± 1.6 (4.1, 8.9)	14	2.9 ± 1.9 (0.0, 6.8)
	Western harvest mouse	11	−23.9 ± 0.7 (−25.5, −23.1)	11	6.4 ± 0.9 (4.9, 8.2)	11	2.1 ± 1.4 (0.3, 4.1)
Cosumes	White-tailed kite	30	−23.5 ± 1.9 (−26.0, −15.0)	30	9.9 ± 2.3 (5.4, 15.7)	29	5.8 ± 2.5 (0.7, 10.9)
	California vole	12	−25.7 ± 1.7 (−27.0, −20.9)	12	6.6 ± 1.9 (4.0, 10.0)	12	3.6 ± 0.9 (2.3, 5.3)
Santa Barbara	White-tailed kite	39	−23.6 ± 2.5 (−26.1, −11.6)	39	10.9 ± 3.0 (5.2, 20.0)	39	4.8 ± 4.6 (−8.6, 14.6)
	California vole	6	−26.3 ± 1.5 (−28.2, −24.7)	6	6.2 ± 2.0 (2.5, 8.1)	6	6.3 ± 7.9 (−4.6, 15.6)
	House mouse	4	−25.0 ± 0.4 (−25.5, −24.7)	4	7.9 ± 0.7 (6.9, 8.4)	4	5.6 ± 5.7 (−2.7, 9.6)

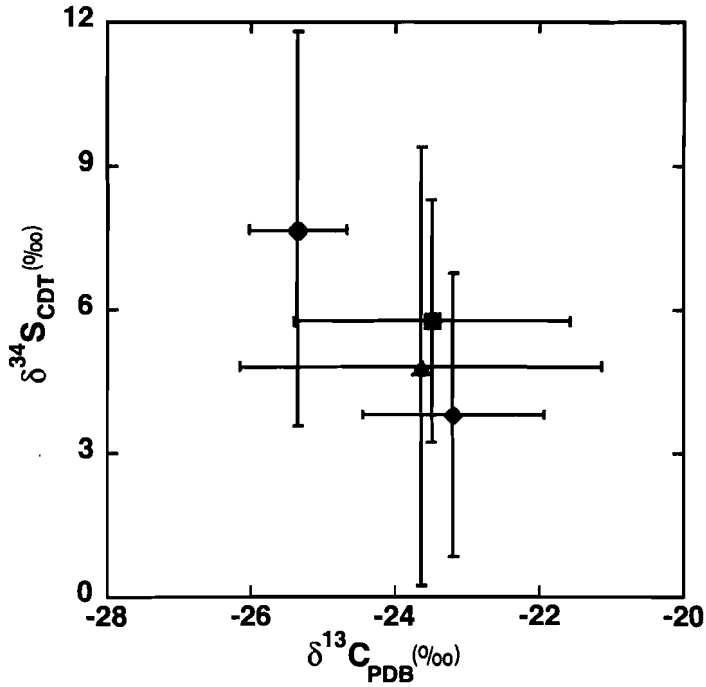

FIGURE 1 Distribution ($\bar{x} \pm$ SD) of δ^{13}C (‰) and δ^{34}S (‰) values for white-tailed kite flight feathers from four study locations in California: Arcata (●); Cosumnes (■); Davis (◆); and Santa Barbara (▲).

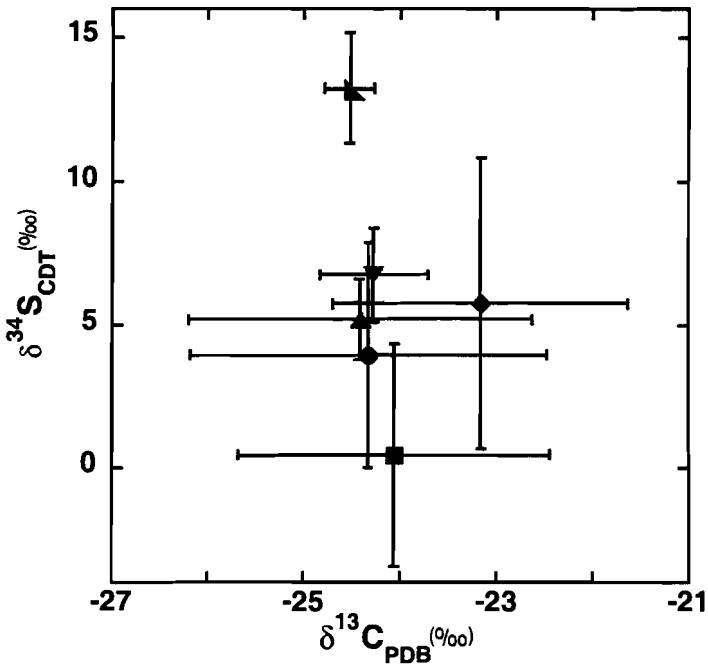

FIGURE 2 Distribution ($\bar{x} \pm$ SD) of δ^{13}C (‰) and δ^{34}S (‰) values for white-tailed kite flight feathers from six microhabitats within the Santa Barbara study area: Microhabitat 1 = San Marcos Pass area (●); Microhabitat 2 = Santa Barbara foothills (■); Microhabitat 3 = Coal Oil Point Reserve (◆); Microhabitat 4 = More Mesa (▲); Microhabitat 5 = Carpinteria (▼); and Microhabitat 6 = Vandenberg AFB (◣).

a significant effect related to microhabitat in the Santa Barbara study area (MANOVA, $F_{15,83} = 2.0$, $P = 0.02$). Of the three isotopes analyzed, sulfur (one-way ANOVA, $F_{5,33} = 4.48$, $P = 0.003$) had the greatest effect on our MANOVA results, with the Santa Barbara foothills site (Microhabitat 2) differing the most with both the Vandenberg (Microhabitat 6) and Coal Oil Point Reserve (Microhabitat 3) sites ($P < 0.05$, Fig. 2). Our results may be again related to the relative distance of the foothills microhabitat from marine and estuarine sulfur influences, as both the Coal Oil Point and Vandenberg sites were within 500 m of the Pacific Ocean.

Finally, to assess the effect of variation among individual kites on flight feather isotope measurements, we first compared isotope values for the 10 primary feathers from four individual kites for Santa Barbara (Fig. 3). We found a highly significant effect related to variation among individual kites (MANOVA, $F_{9,175} = 7.52$, $P < 0.0005$), with nitrogen (one-way ANOVA, $F_{3,74} = 8.91$, $P < 0.0005$) and sulfur (one-way ANOVA, $F_{3,74} = 16.48$, $P < 0.0005$) having the greatest effect on our MANOVA results. We next wanted to assess the isotopic variation within single feathers from the same individual by analyzing feathers from two sampling locations (basal and distal) on each of the 10 primary feathers. We found a high degree of isotopic variation within and between flight feathers on the same individual, particularly for sulfur (Fig. 4). The mean sulfur values (±SD) for all primary flight feathers from the four kites was 3.5 ± 4.4‰, with minimum and maximum values ranging from −6.4 to 11.7‰. The results of our repeated measures ANOVA show a significant difference for carbon values among feathers from the same individual (flight feather, $F_{9,26} = 3.69$, $P = 0.004$), with the greatest influence on this result related to the sampling location on a given feather (sampling location, $F_{1,26} = 14.16$, $P = 0.001$). The differences in nitrogen values between individuals also seem to be most influenced by the sampling location on a given feather (individual

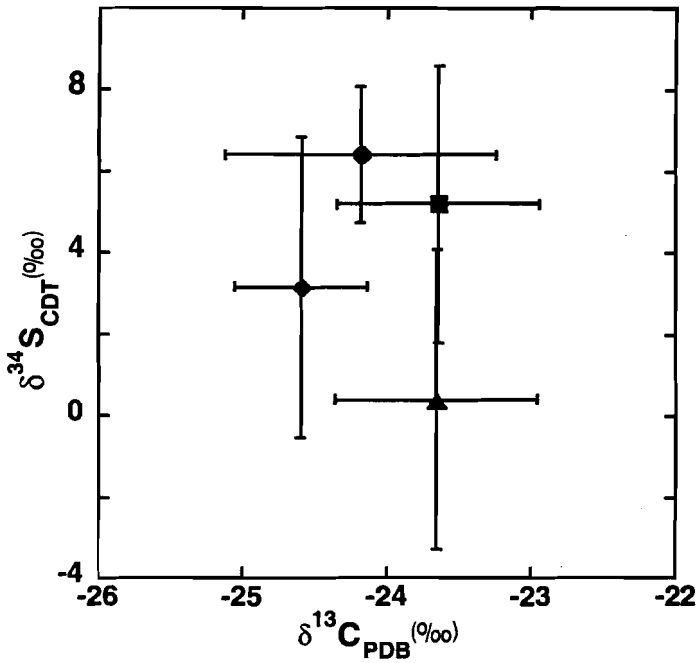

FIGURE 3 Distribution ($\bar{x} \pm$ SD) of $\delta^{13}C$ (‰) and $\delta^{34}S$ (‰) values for white-tailed kite flight feathers from four white-tailed kites from Santa Barbara: Kite #1 (●), Kite #2 (■), Kite #3 (◆), and Kite #4 (▲).

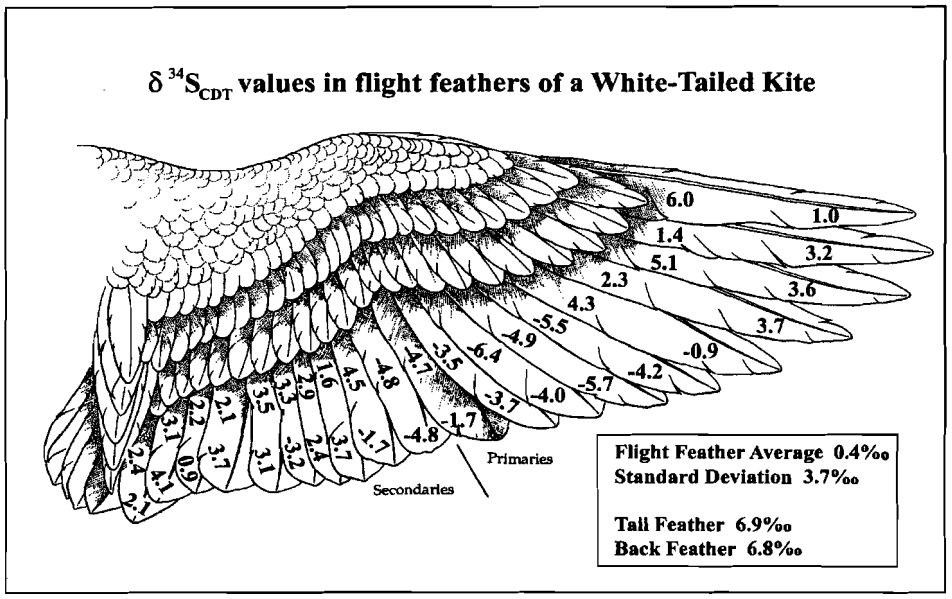

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FIGURE 4 An example of $\delta^{34}S$ (‰) isotope values found both within and between flight feathers from the right wing of an adult white-tailed kite.

vs. sampling location interaction: $F_{3,26} = 3.73$, $P = 0.02$). Interestingly, despite the variation in sulfur values among flight feathers on individual kites and the highly significant difference in sulfur values between individuals, there was only a slight effect due to sampling location on the feather (flight feather *vs.* sampling location interaction: $F_{9,26} = 1.86$, $P = 0.10$). The variability that we observed in our isotope values among kite flight feathers from the same individual may be related to changes in food quality over the feather-growing season, particularly in relation to essential amino acid compounds used in the development of feather keratin [19, 20]. These isotope values may also be influenced by an individual kite's physiology, such as the proportion of food resources versus body reserves used for flight feather development [21]. Other factors, such as the age or sex of the bird, may likewise effect how kites physiologically process and incorporate these isotopes into their body tissues [21, 22].

CONCLUSIONS

Although we found significant differences for kite flight feather isotopic composition between study areas and microhabitats, the variation we observed in isotope values within and between kite flight feathers is a concern. Sampling white-tailed kites tissues is not easy given the difficulty in capturing this particular raptor species (R. Stendell, *pers. comm.*). Although kites molt during the breeding season and communally roost, and a large number of feather samples (particularly wing flight feathers) can be easily obtained from these areas, the variation in isotope values among flight feathers made diminish the usefulness of this particular type of kite tissue in habitat use and prey utilization determinations. The variation we observed in isotope values within and between flight feathers may obscure any subtle isotopic differences between study areas or prey utilization. Similar concerns regarding

isotopic variation among flight feathers have been raised in previous studies assessing dietary changes over time [23, 24]. Because of this variation in isotope values among flight feathers, analyzing other tissues such as body feathers or blood may yield more useful information regarding prey utilization and diet in white-tailed kites. As a result, consideration should be given to seasonal changes in diet and avian physiology, and how these factors may affect the interpretation of stable isotope data. Without taking into account variation in isotope values that may be related to the sex, age, molt pattern, physiology, and diet of a species, opportunistic feather sampling may be of limited use in drawing conclusions regarding avian diet and population dynamics.

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References

[1] Cooper, J. G. (1870). In: Baird, S. F. (Ed.), *Ornithology, Vol. I. Land Birds*, Geological Survey of California.
[2] Bent, A. C. (1961). *Life Histories of North American Birds of Prey, Part 1*. Dover Publications, New York, p. 409.
[3] Larson, D. (1980). Increase in the white-tailed kite populations of California and Texas-1944–19780. *American Birds*, **34**, 689–690.
[4] Pickwell, G. (1930). The white-tailed kite. *Condor*, **32**, 221–239.
[5] Grinnell, J. and Miller, A. H. (1944). The distribution of the birds of California. *Pacific Coast Avifauna*, **27**, 608.
[6] Eisenmann, E. (1971). Range expansion and population increase in North and Middle America of the white-tailed kite (*Elanus leucurus*). *American Birds*, **25**, 529–536.
[7] Pruett-Jones, S. G., Pruett-Jones, M. A. and Knight, R. L. (1980). The white-tailed kite in North and Middle America: Current status and recent population changes. *American Birds*, **34**, 682–688.
[8] Dunk, J. R. (1995). White-tailed kite (*Elanus leucurus*). In: Poole, A. and Gill, F. (Eds.), *The Birds of North America*, Vol. 178. Academy of Natural Sciences, Philadelphia and The American Ornithologists' Union, Washington, D.C., p. 16.
[9] Stendell, R. C. (1972). The occurrence, food habits, and nesting strategy of white-tailed kites in relation to a fluctuating vole population. *PhD dissertation*, University of California, Berkeley, CA, p. 224.
[10] Dunk, J. R. and Cooper, R. J. (1994). Territory-size regulation in black-shouldered kites. *Auk*, **111**, 588–595.
[11] Hawbecker, A. C. (1942). A life history of the white-tailed kite. *Condor*, **44**, 267–276.
[12] Waian, L. B. and Stendell, R. C. (1970). The white-tailed kite in California with observations on the Santa Barbara population. *Calif. Fish and Game*, **56**, 188–198.
[13] Stendell, R. C. and Myers, P. (1973). White-tailed kite predation on a fluctuating vole population. *Condor*, **75**, 359–360.
[14] Blaustein, A. R. (1980). Behavioral aspects of competition in a three-species rodent guild of coastal southern California. *Behav. Ecol. Sociobiol.*, **6**, 247–255.
[15] McClure, E. (1984). *Bird Banding*. The Boxwood Press, Pacific Grove, CA, p. 340.
[16] Fry, B., Brand, W., Mersch, F. J., Tholke, K., and Garritt, R. (1992). Automated analysis system for coupled $\delta^{13}C$ and $\delta^{15}N$ measurements. *Anal. Chem.*, **64**, 288–291.
[17] Giesemann, A., Jäger, H. J., Norman, A. L., Krouse, H. R. and Brand, W. A. (1994). On-line sulfur-isotope determination using an elemental analyzer coupled to a mass spectrometer. *Anal. Chem.*, **66**, 2816–2819.
[18] SPSS, Inc. (1998). *Systat for Windows*, Version 8.0 ed. Evanston, IL, USA.
[19] Murphy, M. E. and King, J. R. (1984). Dietary sulfur amino acid availability and molt dynamics in white-crowned sparrows. *Auk*, **101**, 164–167.

[20] Murphy, M. E. and King, J. R. (1992). Energy and nutrient use during moult by white-crowned sparrows *Zonotrichia leucophrys gambelii*. *Ornis Scand.*, **23**, 304–313.

[21] Machlin, L. J., Jackson, J. T., Lankenau, A. H. and Pearson, P. B. (1954). Uptake of S^{35} in the feathers, gizzard lining, liver and muscle of young chickens after injection with radioactive methionine or sulfate. *Poutry Sci.*, **33**, 234–238.

[22] Leeming, T. K. and Donaldson, W. E. (1984). Effect of dietary methionine and lysine on the toxicity of ingested lead acetate in the chick. *J. Nutr.*, **114**, 2155–2159.

[23] Hobson, K. and Clark, R. G. (1992). Assessing avian diets using stable isotopes II: Factors influencing diet-tissue fractionation. *Condor*, **94**, 189–197.

[24] Thompson, D. R. and Furness, R. W. (1995). Stable-isotope ratios of carbon and nitrogen in feathers indicate seasonal dietary shifts in northern fulmars. *Auk*, **112**, 493–498.