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SELENIUM STATUS OF WHITE-TAILED DEER IN SOUTHERN FLORIDA

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ABSTRACT: Samples of serum, liver, kidney, and heart were collected for selenium analysis from 174 white-tailed deer (*Odocoileus virginianus*) in southern Florida (USA), 1984 to 1988, to determine the selenium status of these animals. Deer were obtained from eight sites and classified by five age-class groups. For serum and the three tissues analyzed, selenium concentrations varied significantly ($P < 0.001$) among sites. Differences between years ($P < 0.0004$) were found for heart and kidney, age-class ($P < 0.004$) for kidney and season ($P < 0.02$) for liver. Low selenium concentrations were evident, in that 75% of all serum samples analyzed contained less than the critical concentration (<0.06 ppm) by livestock standards, with 50% of serum samples less than 0.03 ppm, evidence of a severe deficiency. Likewise, tissue selenium concentrations (dry basis) were below critical livestock concentrations in 13% of the liver samples (<0.25 ppm), 36% in kidney (<3.0 ppm) and 19% in heart (<0.15 ppm). Based on serum and tissue data, selenium dietary intake was low and may have been deficient for white-tailed deer in southern Florida.

Key words: Florida, selenium status, serum, tissues, deficiencies, white-tailed deer, *Odocoileus virginianus*.

INTRODUCTION

Mineral deficiencies or imbalances in soils and forages long have been held responsible for low production and reproduction among beef cattle in Florida (USA) (McDowell et al., 1993). Soils of subtropical Florida are dominated by spodosols and entisols; most soils in Florida are acid, infertile and sandy in texture (Fiskell and Zelazny, 1972). Native Florida pastures are low in dry matter yield and deficient in a number of minerals, including selenium (McDowell et al., 1982; Espinoza et al., 1991). Forages in all regions of Florida provide very little selenium to herbivores (McDowell et al., 1982). McDowell et al. (1982) reported that all forages analyzed from four regions of Florida were selenium deficient, containing less than the National Research Council (1984) estimated requirement of 0.2 ppm. Eighty-four percent and 90% of total forages contained less than 0.1 ppm during the summer and winter collection periods, respectively; 0.1 ppm is one-half the selenium requirement for beef cattle (National Research Council, 1984). Similarly, low forage selenium also has been reported from north and central Florida by Merkel et al. (1990) and Espinoza et al. (1991), respectively.

Trace mineral status of deer (*Odocoileus* spp.) and other grazing ungulates generally is unknown. Estimates of mineral status can be assessed by measuring mineral concentrations of blood and tissues and making comparisons to livestock standards (McDowell, 1987). Selenium status of white-tailed deer in Michigan (USA) was evaluated by selenium concentrations in muscle (Ullrey et al., 1981) and in whole blood, plasma and the selenium-dependent enzyme glutathione peroxidase (Brady et al., 1978). Ros-McGauran (1989) and Flueck (1991) determined the relationship between whole blood selenium and erythrocyte glutathione peroxidase activity in black-tailed deer (*Odocoileus hemionus columbianus*) in California (USA). Schultz (1990) provided baseline mineral composition data of bone, liver and antlers col-

lected from free-ranging white-tailed deer of central Louisiana (USA). From various regions of Florida analysis of serum, liver, hair and milk have confirmed deficiencies of selenium for cattle (McDowell et al., 1982, 1990). Selenium deficiency is a serious problem for grazing livestock in Florida and many other regions of the world. Our objective was to measure the total selenium content of tissues and serum of white-tailed deer (*Odocoileus virginianus*) of southern Florida to determine the likelihood of selenium deficiency.

MATERIALS AND METHODS

White-tailed deer were collected from eight locations within Collier (26°0′N, 81°20′W), Monroe (25°45′N, 80°0′W), and Dade (25°27′N, 80°47′W) counties in southern Florida. Sites in Collier County included the Bear Island Unit (BIU) and Corn Dance Unit (CDU) of the Big Cypress National Reserve (BCNP), Fakahatchee Strand State Preserve (FSSP), Florida Panther National Wildlife Refuge (FPNWR), and private land owned by Collier Enterprises (CE). In addition, the Stairsteps Unit (SSU) and the Loop Road Unit (LRU) of BCNP in Collier and Monroe counties and Everglades National Park (ENP) in Monroe and Dade counties were sampled. The SSU, LRU, and ENP are located in sawgrass habitats in the Everglades physiographic region. The other collection sites were composed of various mosaics of cypress swamps, hardwood hammocks, pine-oak forests, saw palmetto-wiregrass prairies, freshwater marshes, and agricultural lands in the Big Cypress physiographic region. These areas have been described by Davis (1943), Duever et al. (1986), and McPherson (1973).

Samples were collected between 1984 and 1988 from deer shot by personnel of the Florida Game and Fish Commission and the U.S. National Park Service. Additional details on these deer have been presented by Atkinsin et al. (1993). Blood samples were obtained by cardiac puncture within minutes after the animals were killed. These were collected in tubes without anticoagulant and refrigerated for 8 to 10 hr, at which time serum samples were stored at −20 C until analyzed. Liver, kidney, and heart samples usually were obtained within 10 hr of death during which time the carcasses had been stored at 2 C and frozen at −20 C in plastic bags until analyzed. The age of each deer was estimated by the patterns of tooth wear and replacement in the lower jaw (Harlow and DeFoor, 1962).

Selenium data were compared on the basis of location site, year, season, sex and age-class. Animals were grouped into five age-classes: ≤12 (n = 35), 13 to 24 (n = 46), 25 to 36 (n = 42), 37 to 48 (n = 19), and greater than 48 mo old (n = 22). Samples were not collected at all eight sites each year. As an example, samples were collected from ENP only in 1988. Date of collection was recorded by month and categorized by traditional seasons (winter, spring, summer and autumn).

All samples were prepared for analysis according to procedures of Fick et al. (1979). Selenium was determined by a modification of the fluorimetric method (Whetter and Ullrey, 1978). Selenium levels in tissues are reported as ppm (μg/g) on a dry basis and serum as ppm (μg/ml).

An important underlying assumption in the analysis of variance (ANOVA) is homogeneity of variance. That is, it is assumed that the variability of the data does not depend on its expected value. However, it often appears that the variance of data is proportional to its expected value raised to a power. In order to evaluate whether the variance-mean relationship followed this form, and to obtain candidate power transformations to induce homogeneity of variance where it apparently did follow this form, the following procedure was followed. For each tissue, the mean (μ) and standard deviation (σ) of selenium concentration for each site-year-season-sex-age class combination with more than one observation was obtained. Using these μ and σ values, a scatterplot and regression of $\log(\sigma)$ vs. $\log(\mu)$ were obtained for each tissue. A slope of zero in this regression implied homogeneity of variance, and a non-zero slope, or a pattern in the scatterplot, implied heterogeneity of variance. If $\log(\sigma)$ appeared linear in $\log(\mu)$, then the variance stabilizing transformation was obtained by raising the data to the $(1 - \beta)$ power, where β was the slope obtained in the $\log(\sigma)$ vs. $\log(\mu)$ regression, and $\beta = 1$ implied using the log transformation.

For each tissue, an initial ANOVA was performed on power transformed selenium concentration. The initial model contained all main effects and two-way interaction terms for the factors site, year, season, sex, and age-class. For each tissue, the plot of residual versus predicted values from the initial ANOVA was examined to evaluate effectiveness of transformation in stabilizing the variance.

In general, whenever interactions among factors are significant, it is undesirable to examine main effects for those factors. However, these data were too sparse to meaningfully interpret interactions. Therefore, in order to usefully explore the data, only main effect models were used. The results of this analysis must be interpreted with caution, keeping in mind that sig-

nificant interactions may have existed, but were ignored.

Because of severe imbalance in the data, an iterative model-fitting procedure was followed, starting with a model containing main effects terms for the factors site, year, season, sex, and age class. At each iteration, the term that was nonsignificant and had the largest P-value, according to a type III hypothesis test, was deleted from the model, and then the reduced model was fitted. Iteration ceased when all terms were significant in the current model. Using the final model, least squares means and pairwise comparisons between least squares means were obtained. All model fitting was performed using PROC GLM in the SAS System (SAS Institute Inc., 1988).

The iterative model-fitting procedure used was similar to the backward elimination model-selection method in regression (Draper and Smith, 1981). In backward elimination in regression, the one regressor with the smallest non-significant Type II F-test value is removed from the model at each iteration; in the iterative ANOVA method used in this study, the group of indicator variables associated with the term with the largest non-significant P value for the Type II test was removed from the model at each iteration.

RESULTS

Selenium concentrations in serum and tissues varied (Table 1). Homogeneity of variance in serum was induced by the log transformation of observed selenium concentrations. Inferences reported are from the analysis of log (selenium). For serum selenium concentrations (Table 2), site differences ($P = 0.0007$) were found, but no differences were observed for year ($P = 0.063$), age-class ($P = 0.13$, season ($P = 0.070$), or sex ($P = 0.62$). Most sites did not differ ($P > 0.05$ for each pairwise comparison) in serum selenium.

Homogeneity of variance in liver was induced by the log transformation of observed selenium concentrations. Inferences reported below are from the analysis of log (selenium). For liver selenium, significant effects for site ($P < 0.0001$) and season ($P = 0.014$) were found; but year ($P = 0.53$), sex ($P = 0.43$) and age-class ($P = 0.069$) were without effect. Liver selenium was highest in sites ENP (1.12 ppm), BIU (0.95 ppm), and SSU (1.37 ppm); these sites had significantly higher ($P < 0.05$ for each pairwise contrast) levels than the sites CE, FPNWR, and CDU. Liver concentrations were higher in spring (1.29 ppm) than in autumn (0.64 ppm, $P = 0.019$), winter (0.63 ppm, $P = 0.0034$) or summer (0.56 ppm, $P = 0.0074$).

Homogeneity of variance in kidney samples was induced by the log transformation of observed selenium concentrations. Inferences reported below are from the analysis of log (selenium). Kidney selenium concentrations were affected by site ($P = 0.0008$), year ($P = 0.0004$), and age-class ($P = 0.004$), but not by season ($P = 0.94$) or sex ($P = 0.27$). Site BIU had the highest kidney selenium (4.74 ppm), being significantly higher than CE (3.44 ppm, $P < 0.0001$), FPNWR (3.81 ppm, $P = 0.0043$), and CDU (4.28 ppm, $P = 0.032$). Kidney selenium was higher ($P < 0.0004$) in 1988 compared to all other years, with a mean value of 8.21 ppm. Younger animals ($\leq$12 mo) had the lowest kidney selenium (3.20 ppm) concentrations, being lower ($P < 0.008$ for each pairwise contrast) than all other age classes except animals over 48 mo old ($P = 0.0927$).

Homogeneity of variance of heart samples was improved by raising observed selenium values to the 0.33 power. Inferences reported below are from the analysis of $(\text{selenium})^{1/3}$. There were significant site ($P < 0.0001$), season ($P = 0.043$), and year ($P = 0.0001$) effects for heart selenium concentrations, but sex ($P = 0.43$) and age class ($P = 0.17$) differences were not significant. Site SSU had the highest mean heart selenium (0.891 ppm) and the site CE had the lowest (0.278 ppm), being lower ($P < 0.0001$ for each pairwise contrast) than all other sites. For the 3 yr where comparisons were made, 1987 was lower ($P < 0.0003$) than 1985 and 1986; selenium levels were 0.331, 0.583 and 0.564, respectively.

DISCUSSION

Based on livestock standards, white-tailed deer serum selenium concentrations

TABLE 1. Selenium concentration (ppm) in serum and tissues (dry basis) of white-tailed deer in Florida, 1984 to 1988.[a]

Sample	Number of samples	Range	Mean	SE
Serum	174	0.01 to 0.45	0.051	0.004
Liver	139	0.14 to 4.28	0.676	0.055
Kidney	137	1.21 to 11.34	3.66	0.140
Heart	87	0.01 to 1.02	0.372	0.026

[a] Represents all samples collected at eight different sites.

considered to be deficient range from 0.007 to 0.060 ppm (Puls, 1988). McDowell (1985) proposed that serum is a good indicator of selenium status, with less than 0.03 to 0.04 ppm considered a critical level for cattle. However, more recently Swecker et al. (1989) observed that serum selenium concentrations of ≥0.10 ppm were associated with optimal antibody production.

Comparing serum selenium concentrations of white-tailed deer to those established as deficient for livestock, we believe there is a deficiency in deer. Using a livestock standard of ≤0.06 ppm selenium as a critical concentration, 130 (75%) of 174 deer were deficient; if a lower critical concentation of ≤0.03 ppm selenium was used, 87 (50%) of the deer would be considered severely deficient. From the raw data of site CDU, which had the greatest number of serum samples, 47 (84%) of 56 deer contained ≤0.06 ppm selenium and 34 (61%) contained ≤0.03 ppm. We also reported low serum concentrations from cattle originating in selenium-deficient regions (McDowell et al., 1982, 1990).

Liver tissue also is a good indicator of selenium status; 0.25 ppm (dry basis) is considered a critical concentration for cattle (McDowell et al., 1993). Of the 139 livers analyzed, 18 (13%) were at the critical concentration of 0.25 ppm or less, evidence for a selenium deficiency. Likewise, 76 (55%) were ≤0.50 ppm, evidence for low to deficient concentrations. Brady et al. (1978) reported that supplemental dietary selenium significantly increased liver selenium in white-tailed deer in Michigan (USA). Low liver selenium concentrations occur in Florida cattle originating in selenium-deficient regions (McDowell et al., 1982).

Selenium concentrations were higher in kidneys than in livers (Table 1). When the dietary intake of selenium was very low, the kidneys of lambs had higher concentrations of selenium than did liver, but when the dietary intake of selenium was increased, liver concentrations usually were higher than those of kidneys (Oh et al., 1976b).

Assuming kidney samples contained 30% dry matter, when receiving adequate di-

TABLE 2. Adjusted mean selenium concentrations of serum, liver, kidney and heart (ppm dry basis) compared by sites in southern Florida, 1984 to 1988.[a,b]

Site	Serum (n = 174)	Liver (n = 139)	Kidney (n = 137)	Heart (n = 87)
Bear Island Unit	0.087 (67)[c]	0.953 (53)	4.74 (57)	0.443 (39)
Collier Enterprises	0.0227 (11)	0.414 (11)	3.44 (11)	0.278 (11)
Everglades National Park	0.1320 (5)	1.12 (8)	3.05 (8)	ND[d]
Florida Panther Wildlife Refuge	0.0310 (6)	0.508 (6)	3.81 (6)	0.448 (6)
Fakahatchee Strand State Preserve	0.0469 (7)	0.587 (7)	4.04 (7)	0.510 (7)
Loop Road Unit	0.030 (6)	ND	ND	ND
Corn Dance Unit	0.0389 (53)	0.506 (41)	4.28 (41)	0.386 (23)
Stairsteps Unit	0.0914 (8)	1.373 (7)	3.21 (7)	0.891 (1)

[a] Total sample sizes were as follows: serum (174), liver (139), kidney (137), and heart (87).
[b] The site P values were: serum (0.0007), liver (0.0001), kidney (0.0008), and heart (0.0001).
[c] Mean selenium concentraitons (sample size).
[d] No values determined.

etary selenium, kidney selenium concentrations ranged from 3.3 to 5.0 ppm in cattle and 3.0 to 10.0 ppm in sheep (Puls, 1988). In lambs with white muscle disease, Allaway et al. (1966) reported kidney selenium concentrations ranged from 0.52 to 0.83 ppm. Using the value of 3.0 ppm selenium in kidney as a measure of a low to deficient selenium status, 50 (36%) of 139 deer samples had less than this value.

Few data are available with respect to a critical concentration of heart selenium levels that reflect a deficiency in livestock. However, in lambs from ewes fed adequate selenium (0.45 to 0.57 ppm, dry basis), heart selenium averaged 1.53 ppm, while heart selenium was 0.03 ppm in lambs exhibiting white muscle disease (Allaway et al., 1966). Adequate heart selenium concentrations for swine have been reported to be 0.23 to 0.43 ppm wet weight (Puls, 1988). Assuming that 0.15 ppm (dry basis) selenium is a low heart concentration, 17 (19%) of the 90 samples were at or below this value. Site CE had low heart selenium concentrations, with 9 of the 11 deer samples containing ≤0.05 ppm selenium.

Based on available evidence, dietary supplies of selenium are inadequate for grazing Florida beef cattle. For example, forage mineral analyses from nine ranches in southeastern, southwestern, central and northwestern regions of Florida all were reported to be deficient in selenium, with an overall average of 0.05 ppm during the winter and 0.07 ppm during the summer (McDowell et al., 1982). From central Florida (Espinoza et al., 1991), all mean forage selenium values were below the proposed requirement concentration of 0.2 ppm (National Research Council, 1984) for cattle, ranging from 0.05 to 0.09 ppm. Mean forage analyses from northern Florida (Merkel et al., 1990) were 0.05 ppm, with 65% less than 0.1 ppm selenium; this is half of the proposed beef cattle selenium requirement. From the previously noted Florida experiments, selenium concentrations of serum, liver, hair, and milk were low, providing further evidence for selenium deficiencies. Clinical cases of white muscle disease in Florida (Mason et al., 1985) also are evidence of selenium deficiency in cattle. A case of white muscle disease in white-tailed deer occurred in east-central Florida (Forrester, 1992).

The wide range of selenium concentrations in wild unsupplemented white-tailed deer was not surprising due to reports of variations in other free-ranging species, such as free-ranging mountain goats (*Oreamnos americanus*) (Robbins et al., 1985). Apparently some deer either live in pockets of habitat that supply substantially more selenium through plants, or they may exhibit different feeding behavior. Another possibility is that some deer may have had access to a selenium containing free-choice mineral supplement intended for beef cattle, especially in BIU where range cattle are common.

The most meaningful interpretation of the data is by comparing the selenium concentrations in the raw data of serum and tissues to known critical concentrations associated with selenium deficiency. Contrary to a number of minerals, dietary selenium concentrations ranging from deficient to adequate are readily reflected in selenium concentrations in serum and specific tissues. In studies with practical sheep diets (Paulson et al., 1968; Oh et al., 1976a) various concentrations of selenium as selenite (up to 0.52 ppm) were added to deficient diets, and liver, and kidney concentrations increased respectively from 0.05 to 0.9 ppm, and 0.5 to 3.8 ppm, respectively.

Based on the serum and tissue data, dietary intakes of selenium were low for white-tailed deer in southern Florida. There was some agreement among types of samples as to the severity of selenium deficiency. Selenium concentrations were of the highest magnitude for serum, liver and kidney among deer at site BIU. Site CDU, which had the largest number of samples collected, had more of the lower serum and liver concentrations.

The practice of supplying mineral mixtures to free-ranging deer to supplement nutrient intake on native range is of unproved efficacy. Schultz and Johnson (1992) reported an estimated mean (±SE) monthly mineral consumption for white-tailed deer in south-central Louisiana of 538.0 (±70.8) g/deer. If deer mineral supplementation programs are initiated in Florida, it is apparent from the data reported herein that selenium should be one of the trace minerals provided.

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