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Received: 28 October 2025 | Revised: 26 March 2026 | Accepted: 13 April 2026

DOI: 10.1002/jwmg.70223

THE JOURNAL OF WILDLIFE MANAGEMENT | THE WILDLIFE SOCIETY

RESEARCH ARTICLE

Management scale and intensity limit forage availability on properties managed for white-tailed deer

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Funding information

University of Tennessee School of Natural Resources; Tennessee Valley Authority; National Institute of Food and Agriculture, Grant/Award Number: Hatch Project OKLO3519

Abstract

Habitat management for cervids often focuses on increasing the availability of high-quality forage to improve body condition and promote larger morphology. Although previous work has evaluated the effects of various treatments on forage availability, no study has quantified existing forage availability across a wide geographic area or compared the contribution of all available vegetation types to nutrient availability and quality for deer on a property. We sampled selected white-tailed deer (*Odocoileus virginianus*) forages on 43 properties managed for deer across 25 states in the eastern United States to evaluate the limitations of biomass and nutritional carrying capacity using 14% crude protein and 0.3% phosphorus constraints across all major vegetation types on each property. We also calculated a relative forage contribution (RFC) value for each vegetation type to determine which contributed more to the total property-level nutrient availability relative to their coverage. Forage availability was limited on most properties. Row crops, food plots, and early successional vegetation provided the greatest forage availability, whereas closed-canopy hardwood forest and pasture/hay provided the least. Early successional vegetation, food plot, and open-canopy hardwood provided the greatest RFC and closed-canopy hardwood forest provided the least. Closed-canopy forest averaged 62.4% coverage, and open-canopy forest and early successional vegetation averaged only 25.2% and 17% coverage, respectively, across

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all properties where they were present. Extensive coverage of closed-canopy forest with limited forage availability was the primary limitation for deer nutrients on most sites. However, forage estimates in open vegetation types were lower than those reported in the literature, indicating relatively poor management of these vegetation types on most properties. Scenarios where forage production in those vegetation types was increased to correspond with values in the literature led to large increases in property-wide nutrient availability. Even on properties where deer management is a primary objective, our results indicate that most provide relatively poor nutrient availability compared to what is possible with more intensive management. Managers interested in increasing deer forage availability and resulting deer body condition and morphometrics should evaluate available nutrients in the major vegetation types on their property and not only consider more intensive management but also implement management at a greater scale by converting more forest into open woodland and early successional vegetation. Our results can be used by biologists and managers to better understand the potential to influence nutrient availability through more intensive and widespread management.

KEYWORDS

cervid nutrition, deer management, habitat management, nutritional carrying capacity, *Odocoileus virginianus*

Cervid management often focuses on increasing forage availability, as nutrition influences multiple facets of cervid ecology. Improved nutrition can lead to improved animal condition and increased body size (Toïgo et al. 2006, Hewison et al. 2009, McGraw et al. 2022), which can positively affect survival (White et al. 1987; Bender et al. 2007, 2008). Additionally, an improved nutritional plane increases antler growth of males (French et al. 1956, Harmel et al. 1989, Michel et al. 2016), which is an important objective for many managers and hunters. Nutrient availability often is considered at the landscape level, and vegetation types producing greater forage availability tend to increase cervid body and antler size (Strickland and Demarais 2000, 2008; Hefley et al. 2013; Quebedeaux et al. 2019). Meeting deer nutritional requirements to maximize desired morphological traits on a property requires nutrients not to be limited for any individual. Limited nutrition causes deer to shift from luxury to dispersal phenotypes (Geist 1989, Michel et al. 2016), which is counter to the objectives of many deer management programs aimed to produce robust cervid populations with males having greater body mass and larger antlers. Deer management commonly focuses on increasing nutrition through habitat management and reducing competition (i.e., reductions in deer density). Given the interest of managers in producing robust cervid populations, models commonly are used to evaluate the current nutritional plane.

Nutritional carrying capacity (NCC) commonly is used to evaluate forage quantity and quality simultaneously. Mixed-diet NCC models consider the amount of forage available to support some minimum life-history requirement

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(Hobbs and Swift 1985), as nutritional requirements vary throughout the year. For example, white-tailed deer (*Odocoileus virginianus*; hereafter deer) nutritional requirements are elevated for males during antler growth and for females during gestation and lactation (National Research Council 2007, Hewitt 2011). Nutritional carrying capacity models often consider energy, crude protein, or phosphorus requirements (Hobbs et al. 1982, Lashley et al. 2011, Nanney et al. 2018, Turner and Harper 2024), with recent work indicating phosphorus as likely the most-limiting nutrient for deer in the eastern United States during the growing season (Turner et al. 2025). Forage availability estimates based on NCC have been used to assess the effects of habitat management on nutrient availability for deer (Lashley et at. 2011, Nanney et al. 2018, Harper et al. 2021, Powell et al. 2022, Turner and Harper 2024).

Several common practices are implemented to increase deer forage availability. For example, reducing canopy cover in forests increases understory forage production, and disturbance such as prescribed fire can promote nutrient-dense forbs and stump sprouts (Lashley et al. 2011, Nanney et al. 2018, Nichols 2020, Nichols et al. 2021, Turner et al. 2024*a*). Herbicide applications also may be used in forests and fields to control undesirable species and promote selected forages (Edwards et al. 2004, Harper et al. 2021). Agronomic plantings (i.e., food plots) are commonly used to promote deer forage but typically only represent a small percentage of properties planted in highly selected and nutritious forages (Lashley et al. 2011, Harper 2019, Turner et al. 2024*b*). These practices commonly are applied by landowners managing property for deer, but no study has yet quantified site-level forage availability across a broad geographic area on properties where increasing deer body and antler size is an objective.

Scale and intensity of management on properties with deer management as an objective have not been widely considered in the literature despite the number of studies that have identified strategies to increase deer forage availability. Habitat management practices for deer are implemented broadly, yet the cumulative effects of management applied on a property to enhance deer nutrient availability have not been reported. Studies that quantify forage by vegetation type on properties managed for deer are needed to determine how scale and intensity of management may influence nutrient availability. Scale of management may include the proportion of a property being managed. When the relative contribution to forage availability of a vegetation type is considered, the scale of management may be increased by converting that vegetation type to another. For example, closed-canopy hardwood forest may be converted to open-canopy hardwood forest or to an early successional plant community. Intensity of management is the relative amount and quality of management implemented, which influences how much forage a vegetation type provides relative to what is possible based on the literature. Incorporating current forage availability estimates into scenarios where managers changed the scale and intensity of management could provide useful information to biologists when landowners are interested in how management recommendations might influence deer nutrient availability.

We collected selected deer forages at 43 properties across 25 states in the eastern United States to assess current conditions across major vegetation types on properties managed for deer. We previously published property-wide NCC estimates from this sampling effort (Turner et al. 2025), but we have not previously considered NCC estimates by vegetation type. We hypothesized that nutrient availability for deer would differ greatly among properties because availability of vegetation types would vary. We predicted nutrient availability would be limited on most properties because they would be represented by vegetation types that provided relatively poor forage availability. We hypothesized forage availability would differ by vegetation type, and we predicted early successional vegetation and food plots would provide greater forage availability than forested areas.

STUDY AREA

Our study area included a variety of properties managed for deer across the eastern United States. We primarily selected properties through a survey of National Deer Association Deer Steward II graduates. The Deer Steward program is a deer management training program provided to landowners and managers that teaches population and

habitat management for deer. The program is open to anyone, but most participants enroll in the program because they want to learn more about improving management on properties they own. Thus, we used the graduate list to find landowners who had deer management as an objective and were willing to participate in our study. We also obtained assistance from state wildlife agency staff to locate suitable properties if we were unable to locate one in a state through the Deer Steward graduate list. We evaluated deer forage availability on 43 properties across 25 states in the eastern United States from 2021–2023 (Figure 1). Property size ranged from 53 ha to 4,553 ha and averaged 567 ha (SE = 111.7). Forty-one of the properties were privately owned, and 2 were public Wildlife

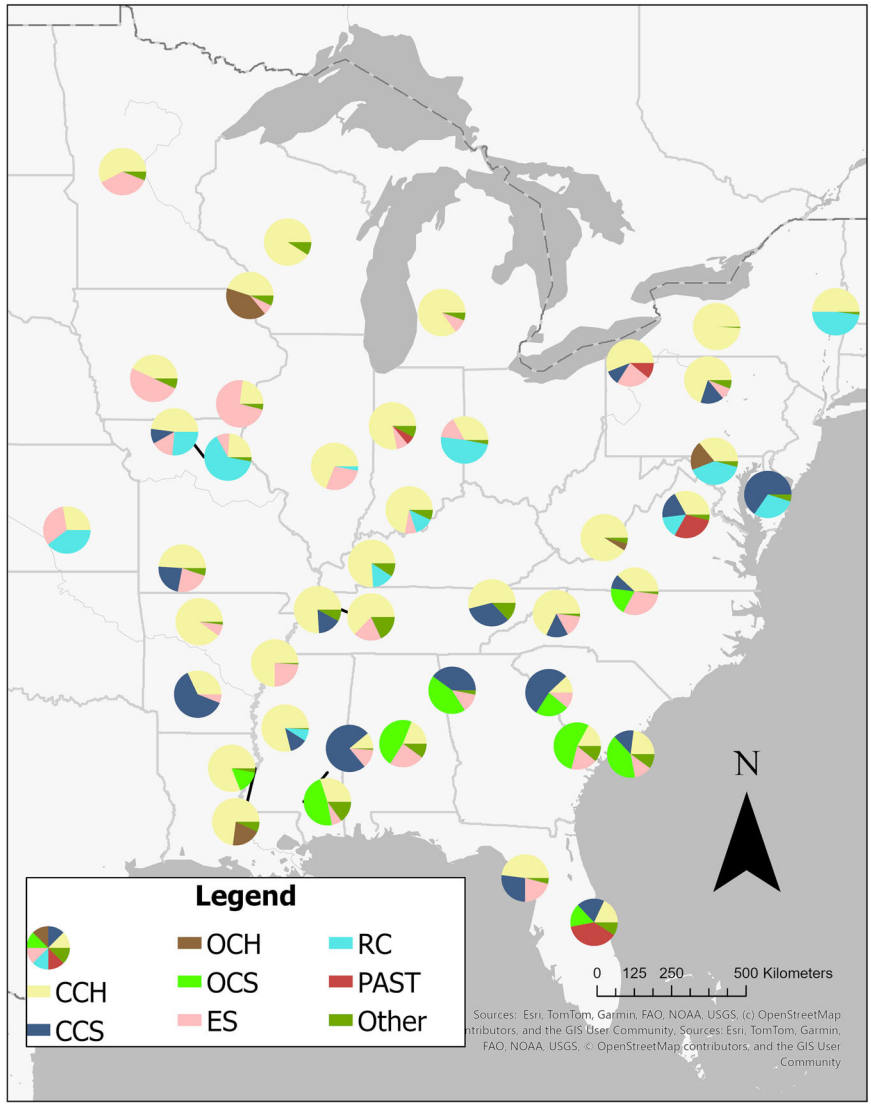

FIGURE 1 Study sites ($n = 43$) where we evaluated white-tailed deer (*Odocoileus virginianus*) forage availability in late May–early August 2021–2023. Pie graphs represent the coverage of dominant vegetation types at each site, including closed-canopy hardwood forest (CCH), closed-canopy softwood forest (CCS), open-canopy hardwood forest (OCH), open-canopy softwood forest (OCS), early successional vegetation (ES), row crop (RC), pasture/hay (PAST), and other (including food plots and vegetation types representing a small proportion of each site).

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Management Areas. All the properties we sampled were managed for deer, and they represent a broad diversity in soil, land use, landscape composition, climate, and deer density.

METHODS

Property sampling

We sampled forage availability across each property once from late May–early August 2021–2023. We used landowner records and aerial imagery to delineate each property into the following vegetation types in ArcGIS Pro (Esri, Redlands, CA, USA): closed-canopy hardwood forest, closed-canopy softwood forest, open-canopy hardwood forest, open-canopy softwood forest, food plot, row crop, early successional vegetation, and pasture/hay. We classified forests based on whether hardwoods or softwoods comprised the majority of the overstory and whether they had >70% canopy closure (closed canopy) or 30–70% canopy closure (open canopy). We classified food plots as agronomic plantings implemented to attract and provide supplemental forages for deer that did not include harvested row crops. We delineated row crops as agronomic plantings, such as soybeans, corn, and cereal grains, that were planted for agricultural production. Early successional vegetation included old fields, grasslands, savannas with <30% canopy cover, and other openings dominated by native, shade-intolerant herbaceous plants (Harper 2017). Pasture/hay included openings managed for livestock or hay production that were dominated by native or nonnative grasses. We excluded developed areas and water from sampling.

We placed random sampling points within each vegetation type using a stratified sampling design. For every 1% of the total site within a vegetation type, we included 1 random sampling point at that site. For vegetation types that comprised <20% of the property, we sampled 20 random points to ensure adequate sampling effort. For example, if a property had 60% coverage of closed-canopy hardwood forest, 25% coverage of row crops, 11% coverage of pasture/hay, and 4% coverage of food plots, we assigned 60 points to closed-canopy hardwood forest, 25 points to row crop, 20 points to pasture/hay, and 20 points to food plots. All sampling points were ≥10 m apart.

We collected selected deer forages that occurred within a 0.5-m^2 frame placed at each random point. Deer forages were identified based on the literature (Miller and Miller 2005, Harper 2019; see Turner et al. 2025 for a complete list) and included leaves of forbs, brambles (*Rubus* spp. and *Smilax* spp.), vines, shrubs, and trees. Within each frame, we collected all leaves from each species that were previously identified as selected by deer and growing within reach of deer (i.e., ≤1.5 m). We collected each species of selected deer forage separately, and we also collected the young and old tissue of each species separately within a frame, as nutrient levels vary by tissue age (Turner et al. 2021, Harper et al. 2025). We defined young tissue as the smaller leaves closer to the tip of each stem, whereas older leaves were larger and located below the younger leaves (Lashley et al. 2014). The young and older tissues were processed and analyzed in the same manner to include in biomass and NCC estimates, but we collected them separately to obtain nutritional values for each. We did not collect woody stems or discolored leaves that deer were unlikely to select during the growing season. We refrigerated forages in a cooler during transportation from the field to the lab, then dried forages in a forced-air dryer at 50°C to constant mass.

We measured forage biomass and nutrition to calculate NCC. First, we weighed the dried forage samples to the nearest hundredth gram. We then combined samples that were the same species and age class within a site and pulled a 5-g subsample for nutritional analysis. When we had <5 g of a given species and age class, we combined age classes from the same species and pulled a 5-g composite (i.e., including young and old tissue) subsample for the species. This approach provided us with a single subsample of each forage we collected on a site for nutritional analysis. In 2021 and 2022, we sent forage samples to Custom Laboratory (Monett, MO, USA) for nutritional analysis. In 2023, we ground samples to a homogenous powder and sent them to Clemson University Agricultural Service Laboratory (Clemson, SC, USA) for nutritional analysis. Samples were analyzed using wet chemistry for

nitrogen and phosphorus (P). We estimated crude protein (CP) by multiplying nitrogen content by 6.25 (Robbins et al. 1987).

We estimated selected forage biomass and NCC estimates based on CP and P constraints for each vegetation type on a site. We first calculated selected forage biomass per vegetation type by summing all forages collected within each frame, converting to kg/ha, and averaging across all frames within that vegetation type on a site. We used our biomass and nutrient results to estimate mixed-diet NCC for CP and P (Hobbs and Swift 1985). Our constraints were based on the intake and requirements of a 45-kg female lactating with twin fawns, and we used a 14% CP constraint, 0.3% P constraint, and 2.3 kg/day intake (National Research Council 2007, Hewitt 2011). We calculated the average NCC and biomass by vegetation type within a site, then calculated the average forage availability across sites where each vegetation type was present. Estimates of NCC are presented in deer days/ha, which represent the number of deer that could be supported for a day at the selected intake and nutrient levels (Hobbs and Swift 1985).

Analysis

We focused on calculating forage availability across each property to compare to estimates from the literature. Additionally, we compared the relative contribution of various vegetation types to forage availability on each property, as this would allow us to identify vegetation types that promote forage while accounting for differences in landscape composition between properties.

We calculated the property-wide average forage availability per hectare by multiplying the forage biomass estimate (in kg/ha) for each vegetation type by its proportional coverage (as a fraction of the total site area) and summing these contributions across all vegetation types. We calculated the property-wide average forage availability per hectare (F_{total}) as:

$$F_{Total} = \sum_{i=1}^{n} (F_i \times C_i),$$

where F_i is the forage biomass of vegetation type i (kg/ha), C_i is the proportional coverage of vegetation type i (proportion of total site area), and n is the number of vegetation types. For each vegetation type, we determined its proportional contribution to the total forage by dividing its forage availability (kg/ha) by the property-wide average forage availability (kg/ha). The proportional contribution of each vegetation type (P_i) to the total forage availability was:

$$P_i = \frac{F_i \times C_i}{F_{total}},$$

where P_i is the proportional forage contribution of vegetation type i, F_i and C_i are defined above, and F_{total} is the total forage availability (kg/ha). We computed the RFC for each vegetation type by dividing its proportional forage contribution by its proportional coverage on the site. This metric reflects the efficiency of each vegetation type in providing forage relative to its spatial extent. The RFC for each vegetation type (RFC_i) was:

$$RFC_i = \frac{P_i}{C_i},$$

where RFC_i is the relative forage contribution of vegetation type i, P_i is the proportional forage contribution, and C_i is the proportional coverage.

We repeated these calculations using CP NCC and P NCC estimates in place of forage biomass. We compared RFC values by vegetation type using analysis of variance (ANOVA) in Program R (R Core Team 2024) to determine which vegetation types contributed the greatest forage availability relative to their coverage. We tested forage biomass and each nutritional constraint separately to determine whether RFC differed between vegetation types.

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When we detected significant differences, we used Tukey's honestly significant difference (HSD) multiple comparisons test to determine which vegetation types differed. We set $\alpha = 0.05$ for statistical comparisons of RFC values.

We also calculated how forage availability changes if management scale, management intensity, or management scale and intensity were increased. Biologists routinely provide recommendations related to management scale and intensity to landowners and managers whose objectives include larger deer with improved body condition (Kammermeyer and Thackston 1995, Hewitt 2011, Harper et al. 2012). Our comparisons represent changes in available nutrition for deer that land managers can expect if they follow those recommendations. We specifically used estimates of biomass for these scenarios, as biomass estimates for comparison are most readily available in the literature and we would expect changes to biomass also would result in changes to NCC. We evaluated 3 potential scenarios that commonly are used to increase the scale of management: converting 10 percentage points of each property from closed-canopy forest to open-canopy forest (either hardwood or softwood, whichever was dominant or was present on a site), converting 10 percentage points of each property from closed-canopy forest (either hardwood or softwood, whichever was dominant) to early successional vegetation, and converting 10 percentage points of each property from pasture/hay to early successional vegetation (Lashley et al. 2011, Nanney et al. 2018, Turner et al. 2020, Harper et al. 2021). For each scenario, we decreased the coverage of one vegetation type and increased the coverage of the other while retaining the forage biomass estimates by vegetation type specific to each property. In the few cases where the original vegetation type (i.e., closed-canopy hardwood, closed-canopy softwood, or pasture/hay) had <10% coverage on a property, we reduced coverage of the original vegetation type to 0% and redistributed that coverage to the converted vegetation type. We made comparisons only on properties where both the original and converted vegetation type were present.

We used 3 scenarios to evaluate whether increased intensity of management would increase deer forage availability: improved management of early successional vegetation, improved management of open-canopy hardwood or softwood (whichever was dominant), and improved management of food plot. We compiled biomass estimates from studies testing experimental treatments to represent the same vegetation types under improved management (Table 1). Specifically, we assigned early successional vegetation 796.1 kg/ha (Nanney et al. 2018,

TABLE 1 Estimates of white-tailed deer (*Odocoileus virginianus*) forage biomass following various management practices in early successional vegetation (ES), food plot (FP), open canopy hardwood (OCH), and open canopy softwood (OCS) from the literature.

Study	Vegetation	Biomass/ha	Note
Nanney et al. (2018)	ES	1,131.3	Average of burn, herbicide, and herbicide + burn
Powell et al. (2022)	ES	687	Average of seedbank + burn
Harper et al. (2021)	ES	570	Average of seedbank response
Lashley et al. (2011)	FP	672.3	Average of July uncaged food plot samples
Turner et al. (2024*b*)	FP	2,546.9	Average of monthly uncaged food plot samples
Lashley et al. (2011)	OCH	542.2	Average of shelterwood and retention cut, with and without fire
Turner et al. (2024*a*)	OCH	527.7	Average of burn treatments
Masters et al. (1996)	OCS	400.3	Average of burn + midstory removal
Edwards et al. (2004)	OCS	435	Leaf biomass of moderate- to high-use forages in treated loblolly stands
Lashley et al. (2015)	OCS	592.5	Average of burned upland longleaf pine
Nichols et al. (2021)	OCS	268.2	Average of burned treatments

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Harper et al. 2021, Powell et al. 2022), food plot 1,610.9 kg/ha (Lashley et al. 2001, Turner et al. 2024*b*), open-canopy hardwood 535.0 kg/ha (Lashley et al. 2011, Turner et al. 2024*a*), and open-canopy softwood 424 kg/ha (Masters et al. 1996, Edwards et al. 2004, Lashley et al. 2015, Nichols et al. 2021). We obtained forage values from studies comparing a variety of treatments (e.g., prescribed fire, herbicide, mowing, timber harvest) that were collected in a similar manner to our methods (i.e., leaves of broadleaf plants selected by deer, uncaged samples collected once during the growing season). We assigned these average forage values to provide a reasonable estimate of expected forage production based on treatment responses from the literature. Although there may have been differences in potential forage production to various treatments at each property based on factors such as latitude, these estimates represent relatively conservative changes in forage production rather than the maximum possible increase a manager might anticipate. In each of the 3 scenarios, we substituted the forage available in a vegetation type on a property with forage estimates from the literature to determine how much property-wide forage availability would change with increased management intensity of a single vegetation type.

Finally, we considered simultaneous increases to scale and intensity of management. In these 3 scenarios, we converted 10% of the dominant closed-canopy forest to early successional vegetation, 10% of the dominant closed-canopy forest to open-canopy forest, and 10% pasture/hay to early successional vegetation. We then applied the same values from the literature we used to assess increased intensity to determine how changing scale and intensity of management together would influence forage availability. To assess differences in forage availability in our management simulations, we present the average change in forage availability and error estimates around that change.

RESULTS

Forage availability and relative forage contribution

Property-wide nutritional availability varied but was limited on most properties. Selected biomass averaged 116.5 kg/ha (SE = 30.8) and ranged 9.3–1,334.7 kg/ha. Property-wide NCC estimates were reported in Turner et al. (2025), where CP NCC averaged 33.5 (SE = 13.2) deer days/ha and P NCC averaged 9.7 (SE = 2.2) deer days/ha. There was considerable variability in forage estimates provided across various vegetation types (Table 2; Figure 2).

We identified differences in RFC between vegetation types (Table 3; Figure 3). Early successional vegetation RFC for biomass was >3 times greater than closed-canopy softwood forest ($P < 0.001$), >5 times greater than

TABLE 2 Percent coverage (% cover), the number of properties where a vegetation type was present (*n*), forage biomass (kg/ha), nutritional carrying capacity based on a 14% crude protein constraint (CP NCC), nutritional carrying capacity based on a 0.3% phosphorus constraint (P NCC), and standard errors of each estimate at 43 sites across the eastern United States, 2021–2023.

Vegetation type	% cover	*n*	Biomass	CP NCC	P NCC
Closed-canopy hardwood	62.4 ± 3.9	41	41.3 ± 5.5	10.1 ± 2.2	3.2 ± 0.9
Closed-canopy softwood	26.5 ± 4.9	20	67.6 ± 29.3	15.7 ± 8.3	5.7 ± 4.9
Open-canopy hardwood	12.0 ± 4.9	8	91.9 ± 36.8	24.6 ± 12.0	8.8 ± 3.9
Open-canopy softwood	34.0 ± 5.2	9	97.8 ± 14.6	21.5 ± 6.9	3.5 ± 1.9
Food plot	4.0 ± 0.5	39	136.7 ± 27.5	59.7 ± 12.1	42.7 ± 12.4
Row crop	28.0 ± 5.3	13	294.3 ± 202.1	142.0 ± 87.5	50.2 ± 18.5
Early succession	17.0 ± 2.5	35	218.6 ± 26.6	55.5 ± 7.0	24.2 ± 6.5
Pasture/hay	17.3 ± 7.9	5	14.8 ± 9.8	5.3 ± 4.1	2.0 ± 0.6

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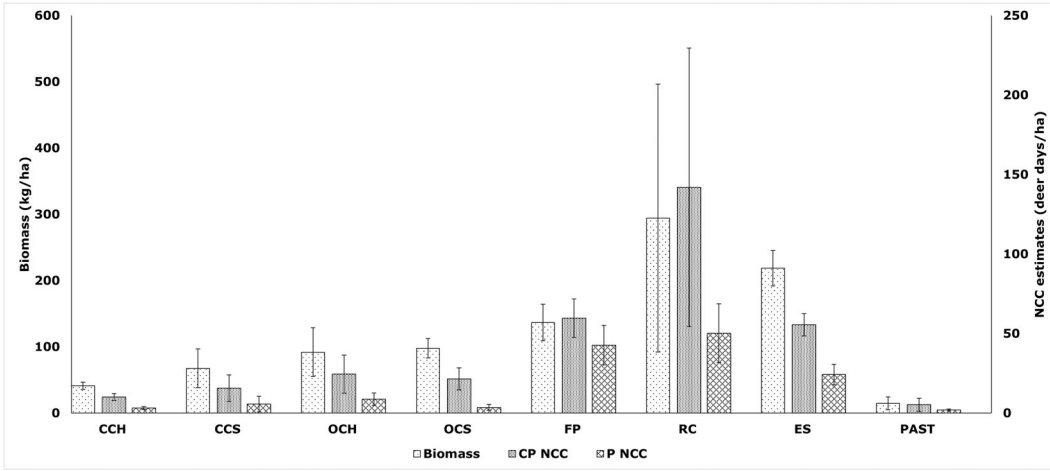

FIGURE 2 Average biomass, nutritional carrying capacity (NCC) based on a 14% crude protein constraint (CP NCC), and NCC based on a 0.3% phosphorus constraint (P NCC) for white-tailed deer (*Odocoileus virginianus*) at 43 sites across the eastern United States, 2021–2023. Error bars represent standard error. Vegetation types included closed-canopy hardwood forest (CCH), closed-canopy softwood forest (CCS), open-canopy hardwood forest (OCH), open-canopy softwood forest (OCS), food plot (FP), row crop (RC), early successional vegetation (ES), and pasture/hay (PAST).

TABLE 3 Relative forage contribution (RFC) and standard error of vegetation types at 43 sites across the eastern United States, 2021–2023. We calculated RFC based on the proportion of biomass, nutritional carrying capacity based on a 14% crude protein constraint (CP NCC), and nutritional carrying capacity based on a 0.3% phosphorus constraint (P NCC) provided by each vegetation type relative to the coverage of the vegetation type. Vegetation types with different letters within each estimate category (biomass, CP NCC, and P NCC) were significantly different ($P < 0.05$).

Vegetation type	Biomass	CP NCC	P NCC
Closed-canopy hardwood	0.5 ± 0.1 c	0.5 ± 0.1 b	0.3 ± 0.1 b
Closed-canopy softwood	0.8 ± 0.2 bc	0.6 ± 0.2 b	0.4 ± 0.2 b
Open-canopy hardwood	2.5 ± 0.8 ab	2.6 ± 1.3 ab	5.0 ± 2.6 ab
Open-canopy softwood	1.7 ± 0.4 abc	1.4 ± 0.4 ab	1.8 ± 1.2 ab
Food plot	2.1 ± 0.4 ab	3.9 ± 0.8 a	8.0 ± 1.9 a
Row crop	1.0 ± 0.2 bc	1.4 ± 0.3 ab	1.7 ± 0.4 ab
Early succession	2.7 ± 0.3 a	3.1 ± 0.4 a	3.5 ± 1.0 ab
Pasture/hay	0.2 ± 0.1 bc	0.4 ± 0.3 ab	0.7 ± 0.5 ab

closed-canopy hardwood forest ($P < 0.001$), >13 times greater than pasture/hay ($P = 0.032$), and >2 times greater than row crop ($P = 0.027$). Open-canopy hardwood forest provided 5 times greater RFC for biomass than closed-canopy hardwood forest ($P = 0.029$). Food plot provided >4 times greater RFC for biomass than closed-canopy hardwood forest ($P < 0.001$). Food plot RFC for CP NCC was >6 times greater than closed-canopy softwood ($P < 0.001$) and >7 times greater than closed-canopy hardwood ($P < 0.001$). Early successional vegetation had >6 times greater RFC for CP NCC than closed-canopy hardwood forest ($P = 0.002$) and >5 times greater than closed-canopy softwood forest ($P = 0.038$). Food plot RFC for P NCC was 20 times greater than closed-canopy softwood forest ($P = 0.002$) and >26 times greater than closed-canopy hardwood ($P < 0.001$).

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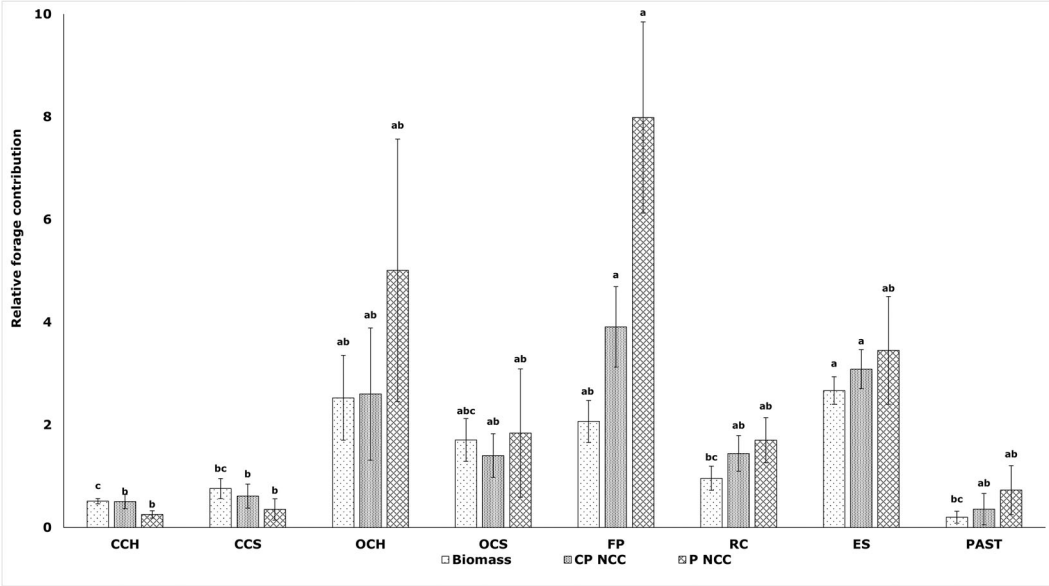

FIGURE 3 Relative forage contribution (RFC) for white-tailed deer (*Odocoileus virginianus*) of closed-canopy hardwood forest (CCH), closed-canopy softwood forest (CCS), open-canopy hardwood forest (OCH), open-canopy softwood forest (OCS), food plot (FP), row crop (RC), early successional vegetation (ES), and pasture/hay (PAST) at 43 sites across the eastern United States, 2021–2023. We calculated RFC based on the proportion of biomass, nutritional carrying capacity based on a 14% crude protein constraint (CP NCC), and nutritional carrying capacity based on a 0.3% phosphorus constraint (P NCC) provided by each vegetation type relative to the coverage of the vegetation type. Vegetation types with an RFC < 1 provided less forage availability per unit area than the average amount provided on a site, whereas those with an RFC > 1 provided greater forage availability per unit area than the average amount provided on a site. Error bars represent standard error. Vegetation types with different letters within each estimate category (biomass, CP NCC, and P NCC) were significantly different ($P < 0.05$).

Management scale and intensity

For analysis of changes to management scale, simulations of converting 10% of the dominant closed-canopy forest type into the corresponding open-canopy forest type on properties where both were present ($n = 15$) resulted in property-wide biomass increasing by 7 kg/ha (±2; Figure 4), which corresponded to a 12% increase in property-wide biomass. When we considered properties that had closed-canopy forest and early successional vegetation ($n = 35$), converting 10 percentage points from the dominant closed-canopy forest type into early successional vegetation resulted in property-wide biomass increasing 18 kg/ha (±2), which corresponded to a 21% increase in property-wide biomass. Converting 10 percentage points of pasture/hay into early successional vegetation on properties where both were present ($n = 5$) resulted in property-wide biomass increasing 32 kg/ha (±7), which corresponded to a 39% increase in property-wide biomass.

For analysis of changes to management intensity, simulations of improving management to the dominant open-canopy forest that was present on each property ($n = 15$) to match averages from the literature increased property-wide forage biomass 71 kg/ha (±15), which corresponded to a 122% increase in property-wide biomass. Improving management to early succession on properties where it was present ($n = 35$) to match averages from the literature increased property-wide forage biomass by 94 kg/ha (±13), which corresponded to a 110% increase in property-wide biomass. Improving management to food plots on properties where they were present ($n = 39$) to match averages from the literature increased property-wide forage biomass by 59 kg/ha (±7), which corresponded to a 52% increase in property-wide biomass.

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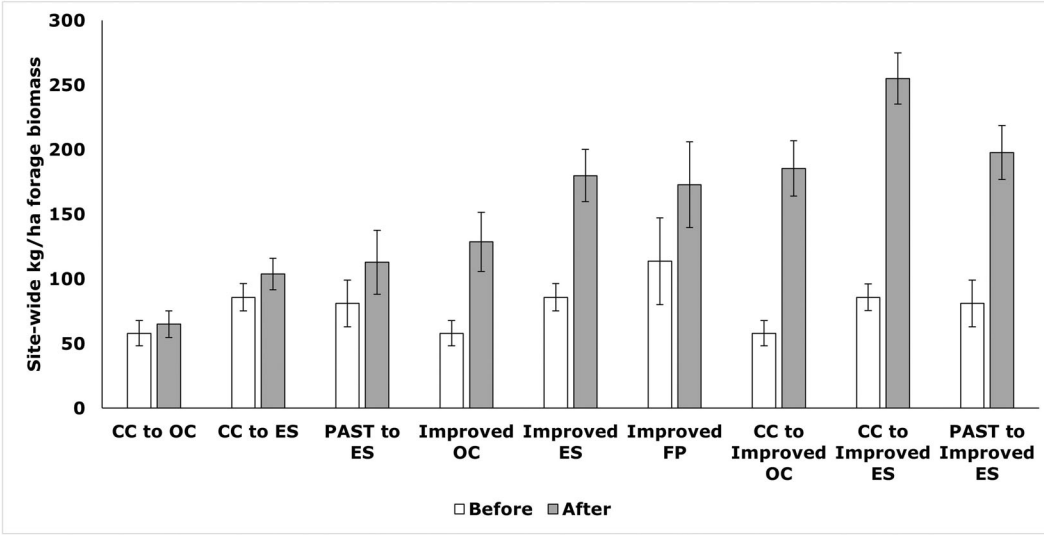

FIGURE 4 Site-wide forage biomass (kg/ha) before and after simulations of changes in management scale and intensity on properties managed for white-tailed deer (*Odocoileus virginianus*) across the eastern United States, 2021–2023. Scenarios to increase management scale included converting closed-canopy forest to open-canopy forest (CC to OC), converting closed-canopy forest to early successional vegetation (CC to ES), and converting pasture/hay to early successional vegetation (PAST to ES). Scenarios to increase mangement intensity included improving management of open-canopy forest (improved OC), early successional vegetation (improved ES), and food plot (improved FP) to match average forage biomass values from the literature. Scenarios to increase management scale and intensity combined the 2 strategies.

When investigating changes to management scale and intensity, simulations of converting 10% of closed-canopy forest to open canopy and improving management to the dominant open-canopy forest that was present on each property ($n = 15$) to match averages from the literature increased property-wide forage biomass 127 kg/ha (±14), which corresponded to a 219% increase in property-wide biomass. Converting 10% of closed-canopy forest to early succession and improving management to early succession on properties where it was present ($n = 35$) to match averages from the literature increased property-wide forage biomass by 169 kg/ha (±13), which corresponded to a 197% increase in property-wide forage biomass. Converting 10% of pasture/hay to early successional vegetation and improving management to early successional vegetation on properties where both occurred ($n = 5$) to match averages from the literature increased property-wide forage biomass by 116.6 kg/ha (±9), which corresponded to a 144% increase in property-wide biomass.

DISCUSSION

Nutrient availability varied widely between properties and across vegetation types, as we expected, and forage availability was relatively limited compared to scenarios when management scale or intensity was increased. Not surprisingly, row crop, food plot, and early successional vegetation provided the greatest forage availability, whereas closed-canopy hardwood and pasture/hay provided the least. Row crop had greater variation in forage availability relative to other vegetation types. The RFC values we calculated generally were greatest in early successional vegetation, food plot, and open-canopy hardwood and least in closed-canopy hardwood and closed-canopy softwood. Vegetation types that consistently provided greater forage availability tended to be limiting on most properties, which indicates a transition in coverage of dominant vegetation types (i.e., increased

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scale of management) is necessary to significantly improve forage availability and associated deer morphometrics. Furthermore, forage availability in several vegetation types was limited relative to similar plant communities monitored in experimental studies, suggesting greater management intensity would improve deer forage availability. Scenarios where we increased scale and intensity of management resulted in large increases in property-wide nutrition, with the greatest increases resulting from simultaneous changes to scale and intensity, followed by changes to management intensity.

Most properties had extensive coverage of vegetation types with limited forage availability. For example, closed-canopy hardwood comprised more than half of the property on sites where it was present, but the associated RFC value for biomass averaged 0.5, meaning it contributed approximately half as much forage relative to its coverage than would be expected if forage was equally distributed across a property. Conversely, open-canopy hardwood was present only on 8 properties with an average of 12% coverage, but the associated RFC value was 5 times greater than that of closed-canopy hardwood. Our property-wide forage biomass estimates were most similar to estimates from unmanaged forests in the literature (Edwards et al. 2004, Lashley et al. 2011, Nanney et al. 2018, Turner et al. 2024*a*), which reflects extensive coverage of vegetation types that provide limited forage biomass. Given many landowners would like to support a moderate density of deer with maximum nutrients available to all individuals, nutrients generally are limiting for deer relative to what they could be with increased scale of management. Although areas of a property without extensive growing-season forage availability can provide important resources to deer (e.g., cover, mast), most properties lacked the amount of high-quality forage needed to meet management objectives. Identifying this discrepancy in stated management objectives and nutrient availability across a variety of properties may be useful to find opportunities to increase the scale of management. Many landowners use food plots to provide increased forage and improved nutrient availability, but food plot coverage on properties we sampled was already at the upper end of typical recommendations, averaging 4% coverage (Harper 2019). We did not consider increasing food plot coverage to be a realistic recommendation to increase deer forage availability for most landowners given budget, time, and tillable acreage limitations (Edwards et al. 2004, Lashley et al. 2011). Rather, a more efficient approach would be converting vegetation types providing limited forage into those where forage was more readily available naturally, without the expense associated with planting.

Row crop coverage provided the greatest forage availability, but there was extensive variation between properties, which was related to crop rotation. Agriculture can provide high-quality nutrition for deer during the growing season (Harper 2019), and larger deer morphology is associated with areas with greater coverage of agriculture (Strickland and Demarais 2000, Kissell et al. 2002, Strickland and Demarais 2008, Hefley et al. 2013, Michel et al. 2016). Row crop had the greatest recorded biomass for any vegetation type in our study at 2,692.6 kg/ha, which we recorded on a property with fields planted to soybeans, representing a highly selected and high-quality forage during the growing season. Several other properties were dominated by row crops planted to corn, which can provide nutrition during the dormant season but is not selected forage while green and growing (Harper 2019). Although corn and soybeans commonly are planted in a rotation (Porter et al. 1997, Sindelar et al. 2015), growing-season forage provided by agriculture may be spatially or temporally inconsistent in many systems. Landowners on >80% of the properties we sampled with row crop leased the agricultural rights and did not determine which crops were planted. Thus, managers should consider growing-season forage availability provided outside of agricultural fields to maintain consistent nutrition on a property.

Nutritional carrying capacity estimates across properties were limited more by forage availability and plant species composition than nutrient concentrations in key forage plants. For example, common ragweed (*Ambrosia artemisiifolia*) was present on 20 properties and averaged 18.9% CP and 0.30% P, horseweed (*Conyza canadensis*) was present on 20 properties and averaged 17.4% CP and 0.40% P, and soybeans were present on 22 properties and averaged 27.4% CP and 0.35% P. We collected plant species at most properties that met or exceeded maximum CP and P requirements for lactation and antler growth, but increased scale or intensity of management would be required to increase their availability across a property to increase NCC. Overall, the available biomass of nutrient-dense forbs such as these should be increased to improve NCC. Increased coverage of forbs is required to

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improve nutrition on many properties, as most semiwoody and woody plants fail to meet nutritional requirements for maximum lactation or antler growth (Nanney et al. 2018; Harper et al. 2021, 2025; Turner et al. 2025). Blackberry (*Rubus* spp.) was present on 32 properties and averaged 12.5% CP and 0.16% P. Virginia creeper (*Parthenocissus quinquefolia*) was present on 18 properties and averaged 13.8% CP and 0.25% P. Understory oaks (*Quercus* spp.) were present on 18 properties and averaged 10.5% CP and 0.11% P. Many properties had extensive coverage of semiwoody and woody plants, but nutritional analyses indicate these species often do not meet nutritional requirements. Although each of the properties we sampled included deer as a focal species for management, most had limited availability of nutrient-dense forages.

The forage availability estimates we calculated by vegetation type generally were lower than what previous research has reported, especially for nonforested and open-canopy forest types, suggesting management intensity limited available nutrition. Estimates of NCC are meant to serve as an index for comparison between sites or treatments (Hobbs and Swift 1985) and should not be used as an absolute measure of carrying capacity. The relative differences in forage availability we measured were similar to what others have reported, with pasture/hay and closed-canopy forest providing the least forage availability and food plot, early successional vegetation, and row crop providing the greatest (Lashley et al. 2011, Nanney et al. 2018, Powell et al. 2022). Deer forage availability in pasture/hay was low because perennial grasses dominated those sites with few forbs available. Closed-canopy forest provided limited forage availability, which was similar to control units in manipulative studies investigating forest management for deer (Edwards et al. 2004; Lashley et al. 2011; Turner et al. 2020, 2024*a*). Conversely, several studies have documented greater NCC estimates in early successional vegetation, food plots, and open-canopy forests managed for deer forage than what we measured (Edwards et al. 2004, Lashley et al. 2011, Powell et al. 2022, Turner et al. 2024*a*). We designed our study to estimate relative forage availability across properties managed for deer rather than determine treatment effects, and these differences in NCC suggest most properties are not managed at similar intensity as studies designed to increase forage availability. For example, our average food plot NCC estimate was much less than those reported elsewhere (Lashley et al. 2011, Harper 2019), partially because of inadequate weed control, poor forage planting selection, and a lack of forages that are productive during the growing season. Early successional vegetation at several properties was dominated by grasses, which reduced NCC estimates relative to the literature (Harper et al. 2021, Powell et al. 2022). Similarly, many open-canopy forests we sampled were dominated by low-quality woody plants that either were not selected by deer (e.g., sweetgum [*Liquidambar styraciflua*]) or did not meet minimum nutritional requirements (Turner and Harper 2024), which indicates fire frequency and timing were inadequate to meet management objectives (Sparks et al. 1998, Lashley et al. 2011, Nanney et al. 2018, Bones et al. 2026). The NCC estimates we calculated represent average forage availability across properties in the eastern United States but do not reflect forage availability following management specifically to improve deer nutrition. Therefore, many properties could be managed with greater scale and intensity to increase nutritional availability for deer during the growing season.

Scenarios with increased management scale and intensity within a single vegetation type resulted in improved deer forage availability. Common practices to increase management scale include reducing canopy coverage in forest, converting forest into early successional vegetation, and converting fields dominated by nonnative grass into native early successional vegetation, all of which can increase forage availability within a given stand by 300%–900% (Lashley et al. 2011, Nanney et al. 2018, Turner et al. 2020, Powell et al. 2022). Converting one vegetation type to increase the scale of management resulted in an average of a 24% increase in property-wide forage availability in our scenarios. Increased scale can benefit deer nutrition but likely to a lesser extent than increased intensity because of the limited biomass on properties we sampled. Increasing management intensity within a single vegetation type to match average estimates from the literature resulted in a 94% increase in site-wide forage availability on average. The greatest increase resulted from improved management of open-canopy forest, which would include the use of more frequent or differently timed prescribed fire (Nichols et al. 2021, Lashley et al. 2022, Turner et al. 2024*a*, Zeitler et al. 2025, Bones et al. 2026). Improved management of early successional vegetation would include more frequent fire or disking and reduced coverage of grasses to promote

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greater forb availability (Harper et al. 2021, Powell et al. 2022). Even increased management intensity of food plots, which comprised only 4% of the properties we sampled, through more careful species selection and weed control would result in a >50% increase in property-wide nutrition. Of course, the practices and prescriptions to increase forage availability vary based on climate, soil, and other factors across the distribution of deer, but management practices to increase forb availability are needed to improve deer nutrient availability. On average, increasing both the scale and intensity of management increased property-wide forage availability by 187%, which essentially doubled the response from increasing intensity alone. Thus, changing the current management practices on most properties would result in tremendous changes to property-wide nutrition and help many landowners reach their management objectives.

MANAGEMENT IMPLICATIONS

Management scale and intensity are limiting on properties with deer management for larger deer and antlers as an objective across the eastern United States. Managers should consider increasing their scale of management by converting vegetation types with limited forage (i.e., closed-canopy forest and pasture/hay) into those with greater forage production (i.e., open-canopy forest and early successional vegetation). Management intensity on many properties also could be increased by using more frequent prescribed fire during various times throughout year in open-canopy forests and reducing grass coverage to <30% in openings to promote forbs and thereby enhance nutrient availability for deer. Managers using food plots should consider practices to better promote growing-season forage, such as incorporating warm-season plantings, planting longer-lived annual cool-season species, and better managing perennial cool-season forages by reducing weed pressure. Practices to improve deer nutrition are widely recommended, but our results suggest that most properties are not managed near to their potential to reach their stated deer management objectives.

ACKNOWLEDGMENTS

We thank the University of Tennessee School of Natural Resources and the Tennessee Valley Authority for financial support. This work also was supported by the USDA National Institute of Food and Agriculture under Hatch project OKLO3519. We thank K. Adams, M. Ross, and the National Deer Association for their assistance with site selection, as well as the numerous landowners and managers who allowed us to collect forage samples on their properties. We thank Lee Mitchell and the US Army Corps of Engineers, St. Louis District for providing access to a study site.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

This study did not involve experiments on live vertebrate animals, human participants, or animal handling procedures. The research was conducted solely using forage samples.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Associate Editor: Andrew Barnas.

How to cite this article: Turner, M. A., C. A. Harper, B. K. Strickland, and M. A. Lashley. 2026. Management scale and intensity limit forage availability on properties managed for white-tailed deer. Journal of Wildlife Management e70223. https://doi.org/10.1002/jwmg.70223

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