Statewide habitat assessment for white-tailed deer in Arkansas using satellite imagery

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Abstract We conducted a statewide assessment of habitat suitability for white-tailed deer (*Odocoileus virginianus*) in Arkansas. We created a habitat suitability index (HSI) model that could be used with satellite imagery for habitat assessment based on life requisites for food and cover. The food and cover life-requisite equations included a vegetation-diversity modifier and distance modifiers to consider the proximity of potentially available resources. We tested model results against indices of relative population abundance and nutritional condition of deer at the county level. The original statewide model accounted for 45% and 23% of variation in abundance and nutritional condition indices, respectively. We adjusted the models to maximize fit with the population indices. The adjusted statewide HSI models accounted for 66% and 52% of variation in population abundance and nutritional condition indices, respectively. Separate models adjusted for each of the 4 physiographic regions of Arkansas were able to account for up to 76% of variation in relative abundance of deer. Landscape models of habitat suitability were most successful in the Gulf region, where large-scale commercial forests dominate, providing relatively equal habitat suitability across the landscape. Models were least successful in the Delta region, where the conversion to agriculture has fragmented habitat and suitability varied widely. Improvements in quality and resolution of population data and greater accuracy of classification of cover types, such as shrub communities, would allow greater understanding of the landscape-level features that are important indicators of habitat quality.

Key words Arkansas, GIS, habitat evaluation, habitat suitability, Landsat, landscape, life requisite, *Odocoileus virginianus*, satellite imagery, white-tailed deer

The spatial scale at which wildlife habitat assessments can be conducted has been broadening in recent years with the increasing availability of Geographic Information Systems (GIS) (e.g., Rickers et al. 1995, Roseberry and Woolf 1998). This computer technology offers the ability to provide more rapid and less expensive inventories of habitat suitability than traditional ground-based habitat assessment methods (Donovan et al. 1987). Coupled with data available from satellite imagery, GIS offers a means of evaluating habitat at very broad scales. For agencies, such as the Arkansas Game and Fish Commission (AGFC), tasked with managing wildlife species at a statewide scale, this approach could be a valuable tool allowing them to quantitatively compare habitat conditions across an entire state.

White-tailed deer (*Odocoileus virginianus*) serve as a good species with which to model and test habitat relationships at a landscape scale because deer interact with the landscape at a broad scale (i.e., home ranges >250 ha; Cartwright 1975, Pledger 1975) and because there is a wealth of knowledge regarding deer-habitat relationships. Several habitat models have been developed and

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tested to evaluate white-tailed deer-habitat relationships (Short 1986, Crawford and Marchinton 1989, Roseberry and Woolf 1998, McClain and Porter 2000). Wildlife-habitat models are common, but many are not properly validated (Roloff and Kernohan 1999), and very rarely are models improved using validation data.

Our objective was to design habitat evaluation models appropriate to use with satellite imagery data and test the models against measures of relative abundance and nutritional condition of deer. Additionally, we sought to improve model performance using the results of model validation.

Study area

The study area was the entire state of Arkansas. The climate in Arkansas was humid subtropical, with warm, humid summers (Smith 1989); winters were mild with brief periods of extreme cold (Hanson and Moneyhon 1989). The growing season was typically >240 days in the southwestern portion of the state and <180 days in the Ozark highlands. Average annual precipitation was about 125 cm, most of it falling in winter and spring (Hanson and Moneyhon 1989, Smith 1989). Elevations in Arkansas ranged from 17 m above sea level where the Ouachita River flows into Louisiana to 839 m at the summit of Magazine Mountain (Smith 1989).

Arkansas was classified into 4 major physiographic regions based on geology, topography, and vegetation: Mississippi River Alluvial Plain, West Gulf Coastal Plain, Ouachita Mountains, and Ozark Plateau (Hanson and Moneyhon 1989, Figure 1). The Mississippi River Alluvial Plain, often called the Delta region, was the largest and most distinct natural division in the state, covering most of the eastern one-third of the state. This region was nearly flat with deep, fertile alluvial soils. Historically, the Delta was covered by bottomland hardwood forests (gum and tupelo [*Nyssa* spp.], oak [*Quercus* spp.], and cypress [*Taxodium distichum*]), which have been removed to allow cultivation of valuable crops. Row crops presently cover a majority of the Delta, with bottomland hardwoods remaining only along some rivers and bayous. The most important crops in the region were soybeans, rice, grain sorghum, and wheat (Smith 1989).

The West Gulf Coastal Plain covered the southwestern quarter of the state and consisted of flat bottomlands and low, rolling hills. The Gulf region was dominated by pine forests (*Pinus* spp.), which were mostly owned and managed by commercial forestry operations (Hanson and Moneyhon 1989).

The Ouachita Mountains region was located in west-central Arkansas between the Ozark Plateau and the West Gulf Coastal Plain. Upland pine-hardwood forests dominated the east-west ridges and valleys. The Arkansas River Valley was included in the northern portion of the Ouachita region. The

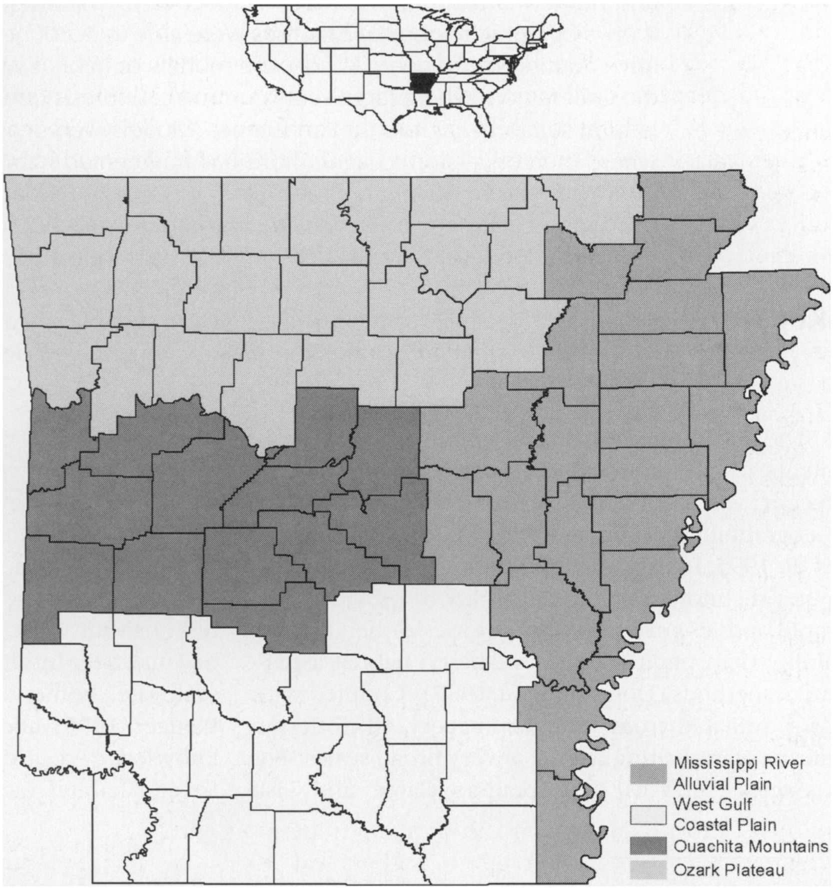

Figure 1. Arkansas counties separated into the 4 major physiographic regions.

50–60-km-wide valley contained rich alluvial soils that supported extensive agriculture along with some remnant bottomland hardwoods.

The Ozark Plateau extended across the north-central and northwestern part of Arkansas and into southern Missouri. The Ozark region was dominated by upland oak-hickory (*Carya* spp.) forests with scattered pines and included most of the 485,000-ha Ozark National Forest.

The statewide deer population was estimated to be approximately 1 million, with annual harvests exceeding 100,000 deer (Arkansas Game and Fish Commission 1999). Estimates of density ranged from 0–39 deer/km^2. The highest deer densities occurred in the West Gulf Coastal Plain region. The Delta region supported the lowest densities of deer (Arkansas Game and Fish Commission 1999).

Methods

Satellite imagery

We acquired satellite imagery from the National Land Cover Database (NLCD) created by the United States Geological Survey (Vogelmann et al. 1998). Based on early-1990s Landsat Thematic Mapper data, the imagery was composed of 21 classified cover types. The classification procedure assigned a single vegetation class to each 30-m pixel based on a modified Anderson level II classification (Anderson et al. 1976) with no minimum mapping unit. Eighteen of the 21 cover types were present in the NLCD imagery for Arkansas (Table 1). The accuracy assessment of the cover-type classification for Arkansas was incomplete at the time of the study.

Habitat Suitability Index (HSI) model

We adapted the HSI model for use with satellite imagery from existing models, including Short (1986), Crawford and Marchinton (1989), and Bender and Haufler (1995). We selected and modified variables for landscape-scale evaluations in consultation with wildlife biologists of the Arkansas Game and Fish Commission (M. E. Cartwright and D. F. Urbston, Arkansas Game and Fish Commission, personal communication). We constructed HSI equations for food and cover life requisites and a vegetation-diversity index.

We estimated food-suitability values (FD) for quality and quantity of food provided by each vegetation type. Similarly, we estimated cover-suitability values (CV) for each vegetation type (Table 1). We based estimates on a synthesis of literature and personal communication with biologists in Arkansas (Blair 1969, Lay 1969, Stransky 1969, Newsom 1984).

We calculated life-requisite values (FDLR, CVLR) to quantify the overall suitability of food and cover. To incorporate food and cover sources in adjacent and nearby areas, suitability values for each pixel were modified according to a distance function (Figure 2):

$$\text{FDLR} = \text{Max}[(\text{FD} \times \text{FDD})^{0.5}]$$

$$\text{CVLR} = \text{Max}[(\text{CV} \times \text{CVD})^{0.5}]$$

These distance modifiers (FDD, CVD) allowed the consideration of all potential food and cover sources estimated to be available within normal daily movements of a deer (Marchinton and Hirth 1984, Crawford and Marchinton 1989, Bender and Haufler 1995). To incorporate the distance modifiers, we used circular assessment windows, which used all pixels within a defined area when making calculations. The radii of assessment windows were defined by the distance at which the value of the distance modifiers became 0 (210 m for cover, 450 m for food). The window sizes defined the spatial extent of the evaluations. The life-requisite values (FDLR, CVLR) were equal to the maximum pixel value within the assessment window. Thus, FDLR and CVLR represent the maximum quality of food and cover resources that could be exploited by a deer during normal daily movements.

Table 1. Original food (FD) and cover (CV) suitability values for 1992 National Land Cover Data cover types in Arkansas.

Cover Type	FD	CV
Water	0.00	0.00
Low intensity residential	0.80	0.50
High intensity residential	0.10	0.10
Commercial/industrial/transportation	0.00	0.00
Bare rock/sand/clay	0.00	0.00
Quarries/strip mines/gravel pits	0.00	0.00
Transitional	0.80	0.00
Deciduous forest	0.40	1.00
Evergreen forest	0.10	1.00
Mixed forest	0.30	1.00
Shrubland	1.00	1.00
Grasslands/herbaceous	1.00	0.00
Pasture/hay	1.00	0.00
Row crops	1.00	0.00
Small grains	1.00	0.00
Urban/recreational grasses	0.80	0.00
Woody wetlands	1.00	0.75
Emergent herbaceous wetlands	1.00	0.00

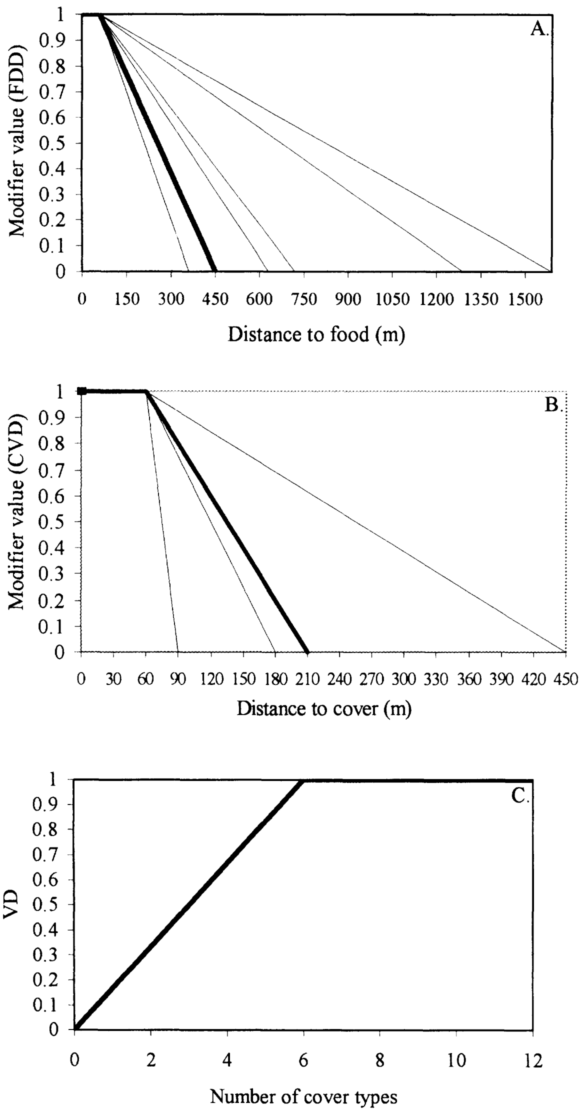

Figure 2. Habitat suitability models for (A) distance to food (FDD), (B) distance to cover (CVD), and (C) vegetation diversity (VD) for white-tailed deer in Arkansas. Optimum values for FDD and CVD range from 0–60 m, and the optimum value for VD occurs when the number of vegetation types within the assessment window is ≥6. Bold lines indicate values used in the original model; fine lines indicate values used in adjusted models.

Final HSI values were calculated as the minimum of the food and cover life-requisite values, modified by a vegetation-diversity index (VD, Figure 2):

$$HSI = [(Min(FDLR, CVLR)) \times VD]^{0.5}$$

We used the minimum function to consider the life requisite that was most limiting for any point in the landscape. The vegetation-diversity modifier was used to address the effects of vegetation quality and quantity changing throughout the year. A given cover type might be a valuable food or cover resource for part of the year but be of minimal value the rest of the year due to seasonal differences in vegetation. At the same time one cover type declines in value at certain times of the year, other types might improve or remain constant. We assumed that more diverse landscapes, with different vegetation types that shift in value at different times of the year, were more likely to consistently provide adequate food and cover throughout the year and therefore were of higher quality than low-diversity areas. We used a circular assessment window to assign a vegetation-diversity value to each pixel based on the richness of cover types (Figure 2). The initial radius of the assessment window was 1,290 m, which corresponded to an average home-range size for deer in Arkansas (520 ha, Cartwright 1975).

We applied the HSI model using software tools available with the Spatial Analyst extension of ArcView (Environmental Systems Research Institute, Inc. 1999). A final suitability value was assigned to each pixel in the area being evaluated. We summarized HSI values as the average pixel value for each county.

Population indices

To validate the HSI models, we used harvest and physical measurement data to create population indices that served as independent data sets. To minimize effects of annual variations in abundance of deer, we averaged all population data for a 10-year period (1987-1996) surrounding the time the satellite images were generated (Roloff 1995). Deer management strategies were consistent throughout this time period (M. Cartwright, Arkansas Game and Fish Commission, personal communication). We assumed that differences in population index values reflected true differences in population abundance and nutritional condition.

AGFC utilized mandatory check stations to collect information from the deer harvest. The county in which each deer was harvested was recorded, and physical measurements (e.g., body weight, antler measurements) were taken at some check stations (M. Cartwright, Arkansas Game and Fish Commission, personal communication). All population data were available at the county level, and we calculated 2 population indices for each county: an abundance index and a nutritional condition index. The abundance index (HARVEST) was the total number of deer harvested divided by total county area (km^2). The harvest data required a natural logarithmic transformation (LOGH=LN [HARVEST]) to reduce skewness before regression analysis. The nutritional condition index (ANTLER) was the average antler-beam circumference for yearling bucks in each county (Severinghaus and Moen 1983). We were able to calculate an abundance index for all 75 counties and a nutritional condition index for 59 counties; 16 counties had insufficient antler data.

Table 2. Coefficient of determination (r^2) for original and adjusted HSI models as applied to each physiographic region of Arkansas, compared to 1987–1996 abundance (LOGH) and condition (ANTLER) indices.

	Original Model		Adjusted Models			
			Abundance		Condition	
Region	Abundance	Condition	Statewide	Regional	Statewide	Regional
Statewide	0.45*	0.23*	0.66*		0.52*	
Delta	0.37*	0.04	0.68*	0.66*	0.13	0.24
Gulf	0.33*	0.46*	0.72*	0.76*	0.41*	0.51*
Ouachita	0.19	0.32	0.09	0.37*	0.06	0.43*
Ozark	0.31*	0.02	<0.01	0.28*	0.20	0.53*

* $P < 0.05$.

Model validation

We tested effectiveness of the model by comparing model results with abundance and nutrition index values for each county. We used simple linear regression (PROC REG; SAS Institute 1989; $\alpha=0.05$) to quantify the fit between model results and population indices statewide and by physiographic region.

Model adjustment

To improve the performance of our models, we adjusted them in a manner similar to O'Neil et al. (1988). We individually changed the original values for FD, CV, as well as analysis window sizes for FDD, CVD, and VD, while holding all other model variables constant. We tested FD and CV values for all values from 0 to 1 by increments of 0.1. We tested maximum distances for FDD and CVD for all values from 0 to 1,890 m by 30-m increments. We tested window size for VD for all values from 90 to 2,190 m by 300-m increments. Adjustments also included the removal of each individual model component (i.e., FD, CV, VD). We compared results of the models after each change to population index values. We identified the value for each input that resulted in the best fit (i.e., highest coefficient of determination) with each index, which we used in the final adjusted HSI models. We developed different models for each physiographic region by maximizing the fit between HSI results and index values for the counties within each region. Testing adjusted models against abundance and nutrition indices separately resulted in 2 distinct models within each region.

Results

Original HSI model

Statewide HSI values were significantly related to both abundance ($r^2=0.37$, $P\leq0.001$, $n=75$) and condition ($r^2=0.25$, $P\leq0.001$, $n=59$) indices. Model performance varied among physiographic regions. Relationships with model results were significant ($P<0.05$) within the Delta and Ozark regions for abundance index and within the Gulf region for both indices (Table 2). The Gulf region had the highest average suitability and the Ouachita region the lowest suitability (Table 3).

Adjusted HSI models

Population abundance. The final suitability values for the statewide HSI model adjusted for the abundance index (Figure 3) were significantly related ($r^2=0.67$, $P\leq0.001$, $n=75$) to the abundance index (LOGH) (Figure 4). HSI values for each region showed the Gulf region to have the highest average suitability and the Delta region the lowest suitability (Table 3).

The statewide abundance model varied in its performance among physiographic regions. The statewide model results were significantly related to

Table 3. Average HSI values calculated from 1992 National Land Cover Data for statewide original, adjusted abundance, and adjusted condition models for physiographic regions of Arkansas.

		Adjusted Models	
Region	Original	Abundance	Condition
Statewide	0.61	0.48	0.37
Delta	0.61	0.31	0.19
Gulf	0.71	0.63	0.49
Ouachita	0.43	0.47	0.37
Ozark	0.69	0.50	0.41

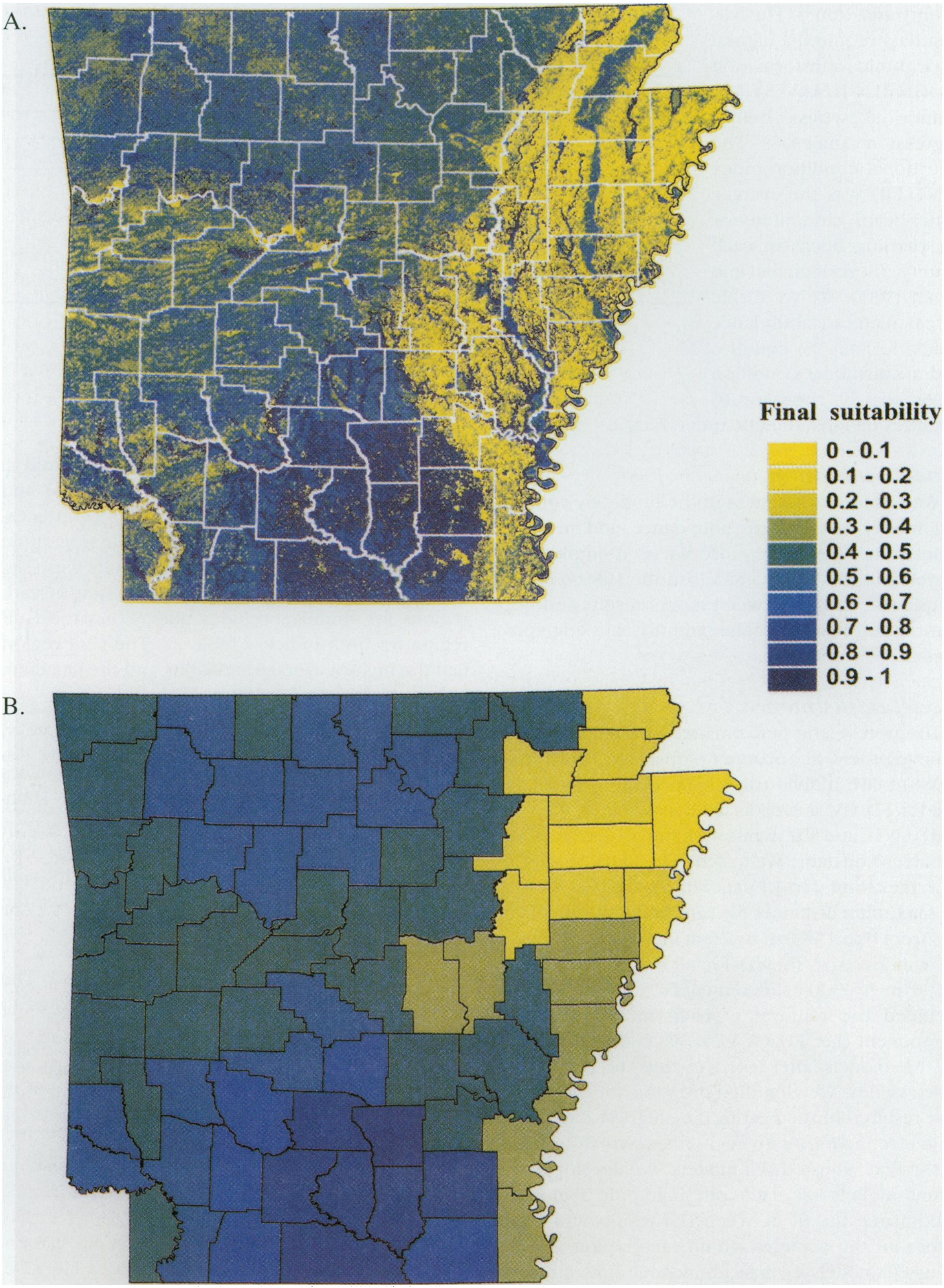

Figure 3. Average habitat suitability index by pixel (A) and by county (B) in Arkansas from the adjusted statewide model using the abundance index (LOGH).

Table 4. Food, cover, and vegetation-diversity (VD) assessment window radius (m) for adjusted regional models using 1987–1996 abundance (LOGH) and condition (ANTLER) indices for white-tailed deer in Arkansas.

	Abundance			Condition		
Region	Food	Cover	VD	Food	Cover	VD
Statewide	720	60	1290	1590	0	990
Delta	360	0	1290	360	450	990
Gulf	1590	0	390	1290	90	390
Ouachita	1590	330	None	1590	180	1290
Ozark	630	0	None	360	450	2190

the abundance index within the Delta and Gulf regions (Table 2), explaining up to 72% of variation. The statewide model results were not significantly correlated with abundance indices within the other 2 regions.

Region-specific abundance models exhibited improved performance within all regions, with the Gulf model performing best overall (Table 2). The adjusted models differed in many model components. The Ouachita and Ozark models performed better when the vegetation diversity index was not included in the model. The statewide, Delta, and Gulf models used assessment windows of various sizes for the vegetation diversity index (Table 4). The appropriate size of food- and cover-assessment windows also varied among models (Table 4). In the models, the radius of the assessment window was the maximum distance from the center pixel that was considered available (i.e., distance at which FDD or CVD= 0). Pixels outside the assessment window had no impact on the calculated value of the center pixel.

Nutritional condition. The final suitability values for the statewide HSI model adjusted for the

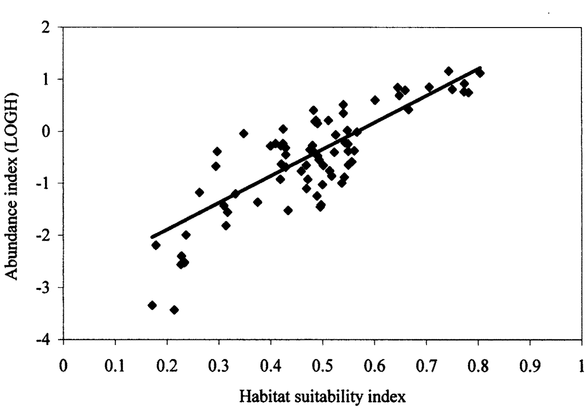

Figure 4. Plot of adjusted statewide abundance HSI results against the abundance index (LOGH) for counties in Arkansas: LOGH = 0.05236 × HSI – 2.97296 ($r^2 = 0.6637$, $P \leq 0.001$, $n = 75$).

nutritional condition index (Figure 5) were significantly related ($r^2 = 0.52$, $P \leq 0.001$, $n = 59$) to the nutrition index (ANTLER) (Figure 6). It is important to note the negative relationship between HSI values and the condition index. The Gulf region had the highest average HSI value, and the Delta region had the lowest average value (Table 3).

The statewide nutritional condition model varied in its performance among physiographic regions. The model results were significantly related to the condition index within the Gulf region (Table 2), explaining about 41% of variation. Statewide model results were not significantly correlated with condition indices within the other 3 regions.

Adjusting HSI models for each region resulted in slightly different models for each physiographic region. Tailoring the nutritional condition models to regions improved performance within all regions, with the Gulf model performing best overall (Table 2). All nutritional condition models performed better when the vegetation-diversity index was included in the model. The appropriate size of the vegetation-diversity, food, and cover-assessment windows all varied among regions (Table 4).

Discussion

Model performance

Performance of our HSI models was measured by how well the results related to population index values. Initially, our model was able to account for 23–45% of statewide variation in the nutritional condition and abundance indices at the county level. After adjustment, our models accounted for 52–66% of variation in condition and abundance indices, which exceeded the estimate of Morrison et al. (1992) that HSI models can explain up to 50% of the variation in species abundance.

When interpreting the results of nutritional condition models, it is important to note the negative relationship between HSI values and the condition index (Figure 6). In this case, lower HSI values represent higher-quality habitat. This result was a product of the initial strong negative relationship between abundance and condition indices. This relationship may be related to lower nutrition associated with resource competition in counties that support high population densities. The negative relationship also may be an artifact of counties, primarily in the Delta region, where isolated blocks of high-quality habitat exist within a larger landscape of low-quality habitat. In these counties harvest

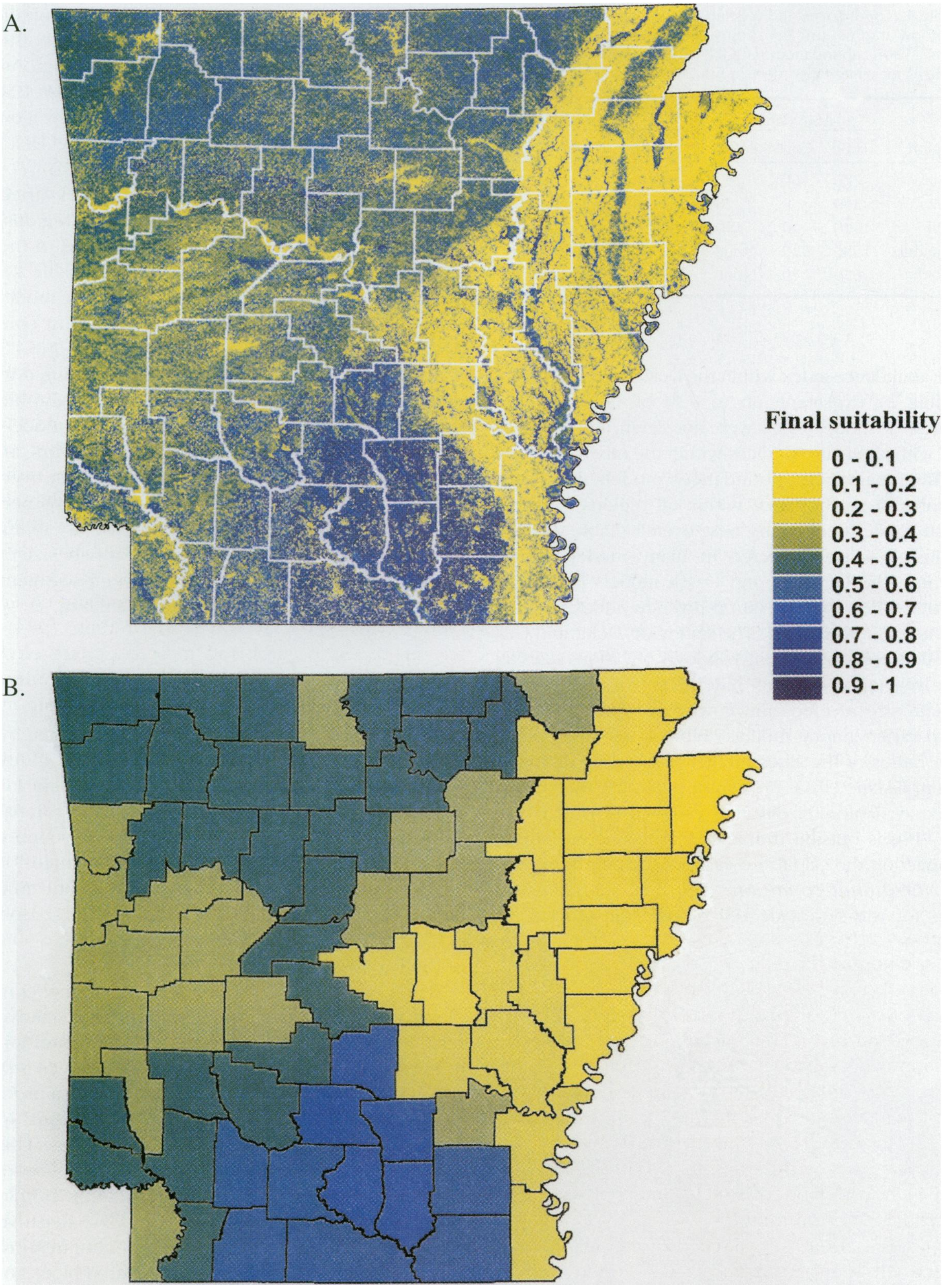

Figure 5. Average habitat suitability index by pixel (A) and by county (B) in Arkansas from the adjusted statewide model using the nutritional condition index (ANTLER).

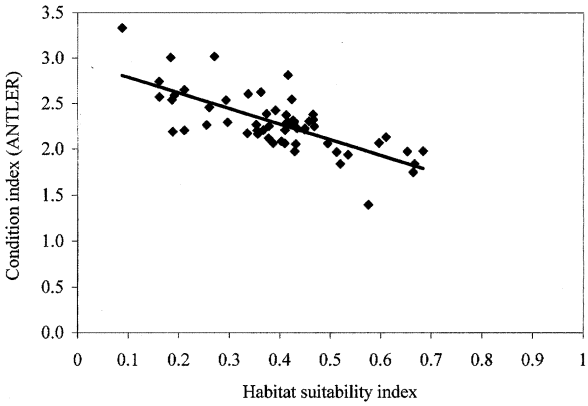

Figure 6. Plot of adjusted statewide condition HSI results against the nutritional condition index (ANTLER) for counties in Arkansas. ANTLER = –0.0175 × HSI + 2.96017 (r^2 = 0.5228, $P \leq 0.001$, n = 59).

density was generally low, but those deer that were harvested were in excellent nutritional condition. Our approach to maximize the r^2 value of the correlation during model adjustment also contributed to the negative relationship of model results. Our original HSI results were positively related to the abundance index and negatively related to the condition index. Consequently, starting with a negative relationship and seeking to increase r^2 values for the results led to models with stronger negative relationships with the condition index.

While habitat often is assumed to be the dominant factor driving wildlife populations, many other factors can play important roles in population dynamics. For deer these factors include weather, predation, poaching, harvest pressure and hunter selection, and disease (Segelquist et al. 1969, Logan 1973, Newsom 1984). Consequently, we should not expect a perfect fit between habitat suitability models and population indices. Considering all the nonhabitat factors potentially influencing deer populations, our models corresponded well with the population indices. The success of these models demonstrated that variations in deer abundance and nutritional condition could be partially explained by models using broad-scale habitat data. The adjusted HSI models should be viewed as improvements on the original hypothesized model, but as they have not been validated, they should be considered with caution.

Other attempts to produce HSI models for deer based on satellite imagery have shown varying success. Using classified Landsat TM imagery and other GIS data, Roseberry and Woolf (1998) were able to account for 81% of variation in population densities at the county level in Illinois. The HSI model of McClain and Porter (2000), using New York State GAP imagery for the Adirondack Mountain region, accounted for about 30% of variation in a township harvest index. The high degree of landscape variability statewide in Arkansas (heavily forested Ozark Mountains to intensive agriculture in the Delta) and the Adirondack region (alpine wilderness to agricultural valleys) potentially contributed to decreased model performance, compared to the relatively homogeneous landscape of Illinois.

Our confidence in the Arkansas models was enhanced by the congruence between optimal values for habitat variables identified through model adjustment procedures and well-established habitat preferences of deer. For instance, preference of woody wetlands, or bottomland forests, was indicated by consistently high food and cover suitability values for this cover type (Stransky 1969, Newsom 1984, Mott et al. 1985). Shrubland also was identified as a valuable cover type, which supported the high value of shrubs as food and cover sources (Halls and Crawford 1960, Newsom 1984). The inclusion of shrubland must be interpreted with caution, however, because shrubland is often difficult to discern from satellite imagery (Glennon and Porter 1999).

The vegetation-diversity index was not important in some regional HSI models, although access to a diversity of vegetation types has been shown to be important to deer in the South (Lay 1969, Zeedyk 1969). Our index may not have improved these models because it measured only richness of cover types and did not consider configuration or composition of the landscape.

Regional models

We were able to improve our HSI models by adjusting them for the different physiographic regions of the state and fitting results to population data for each region. In all 4 regions, the relationships between HSI values and population indices improved, with the adjusted Gulf abundance model accounting for about 76% (r^2=0.78, $P \leq 0.001$, n= 18) of abundance index variation. The improvement in performance suggested the habitat attributes that were most important to deer depended on the specific landscape context, and consequently models of this type should be constructed for areas of similar physiography.

Recommendations

Landscape-scale habitat assessment displays excellent evaluative potential, and wildlife agencies should pursue continued development for other locations and wildlife species. Adjusted HSI models accounted for >52% of statewide variation in both harvest and antler indices. Adjusted regional HSI models accounted for up to 76% of variation in the abundance index. Considering all the nonhabitat factors that potentially influence deer populations (i.e., harvest, predation, poaching, weather, disease), this level of correspondence makes these models valuable for assessing habitat suitability at broad scales. Potential uses of these models include evaluating changes in habitat suitability over time, using historical satellite imagery data or more recent satellite imagery as it becomes available.

Population abundance and condition should both be considered when evaluating overall habitat quality for a species (Van Horne 1983). We chose to evaluate the 2 components separately to allow greater flexibility in model applications. Those wishing to evaluate habitat quality could use the models to separately assess population abundance and nutritional condition suitability and combine the 2 indices as they see fit. Keeping the models separate also allows users to focus on either abundance or condition individually.

Improvements in habitat assessments from satellite imagery could be achieved with attention to 2 issues. First, classification of satellite imagery needs to be improved. The accuracy of the image classification we used was not known, but other NLCD classifications had an estimated overall accuracy of 59.7% (Yang et al. 2001). NLCD classification error has been attributed to narrow class definitions and heterogeneous landscapes (Zhu et al. 2000). NLCD accuracy for the eastern United States improved to 80.5% using the major land-cover types (i.e., forest, agriculture, developed, etc.) or the Anderson Level I classification (Yang et al. 2001). Our models differentiated all 18 land-cover classes in the state, but most classes in each major land-cover type were similar in suitability value in the models. Having similar values in the models effectively collapsed the classification into the more general classes. Most important, we could not distinguish key habitat types such as early successional types, and early-stage forest regeneration from other forestland.

Second, development of habitat assessment models would be improved with population data that are of better quality and finer resolution. While harvest data have been used successfully as an index of relative abundance, control for variations in hunter effort would enhance this measure (Roseberry and Woolf 1991). Furthermore, abundance alone may not adequately quantify habitat suitability differences (Van Horne 1983). We were able to pair our population data with an index of nutritional condition because the relationship of antler-beam diameter in yearlings to nutritional condition has been well documented in deer (Severinghaus and Moen 1983; Rasmussen 1985; K. Kammermeyer, Georgia Department of Natural Resources, personal communication).

An important aspect of population data is resolution of data collection and summarization. The finest-resolution population data available were aggregated to the county level, which limited the resolution at which we could assess model performance. Wildlife agencies should consider collecting data on harvest and antler measurements for deer at the township level to improve statistical power and resolution of the habitat models. Township (or finer) resolution data would allow validation of HSI models at a finer scale. Finer-resolution models will better assess habitat suitability because deer interact with the landscape at a scale much smaller than a county. Summarizing suitability to county scales obscures some of the spatial variation within the counties that may be important to deer.

To further improve the performance of habitat assessments, specific models should be used for each physiographic region rather than applying one model to an entire state. The physiographic regions of Arkansas were sufficiently distinct to warrant the use of different models. Our HSI models improved significantly by being tailored to each region.

Although we have put a strong emphasis on validating the models at the county level and recommend population data at finer resolutions to allow validation at smaller scales, our inability to validate the models at the same resolution as raw results (30-m pixels) does not necessarily mean the models cannot be used at that initial fine resolution. For many purposes, results at the pixel level will likely be adequate and useful, even though there was no way to test their validity. After all, the county-level values were simply a summarization of the pixel-level values. Fine-resolution output would be potentially useful for managers, for example, to identify areas of poor habitat suitability as targets for management activities. Although we have confidence in results of the models at finer scales, the results can only be validated at the finer scales with finer-scale population data.

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