Evaluation of a Mallard HSI Model for the Lower Mississippi Valley

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Abstract: We evaluated a habitat suitability (HSI) model developed for mallards (*Anas platyrhynchos*) wintering in the Lower Mississippi Valley by comparing mallard densities obtained from aerial surveys with habitat suitability indices derived from satellite imagery for 25, 256-km^2 sampling units. Regression models that related mallard densities to habitat suitability indices accounted for only 29% of the variability in the data and the 95% confidence interval of predicted mallard densities included zero for most habitat suitability indices evaluated. Thus, we conclude that the published HSI model is a poor predictor of wintering mallard density in the Lower Mississippi Valley. We suggest model revision to allow users to remotely obtain model inputs for habitat characteristics at landscape scales. Further, we suggest the model be revised to consider yearly variation in habitat and flood conditions that better reflect the ability of an area to support wintering mallards.

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The forested and agricultural wetlands of the Lower Mississippi Valley (LMV) historically have attracted wintering waterfowl, particularly mallards (Bellrose 1976, Reinecke et al. 1989). To evaluate the suitability of these wintering habitats

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for mallards, a Habitat Suitability Index (HSI) model was developed for the LMV (Allen 1987). This model assessed the suitability of habitats based on food availability and foraging opportunity and assumed that food availability is directly influenced by winter flooding. As with all HSI Models, the mallard HSI model provides a range of values between 0 (representing unsuitable habitats) and 1 (optimal habitats); these values are intended to index habitat potential for mallards wintering in the LMV.

Although the mallard HSI model was constructed based on available scientific data, no validation has been attempted. HSI models developed without spatial validation of predictive effects can be used to define and quantify what is known about a species but should not be used for predictions or planning (Van Horne and Wiens 1991). Nevertheless, the mallard HSI model has been used to assess the value of lands in the LMV to waterfowl (A Mueller, U.S. Fish and Wildl. Serv., pers. commun.).

HSI models developed for other species have been evaluated using expert opinion (O'Neil et al. 1988), habitat use (Thomasma et al. 1991), and species density (Cook and Irwin 1985, Schroeder 1990). We evaluated the mallard HSI model using mallard densities estimated from aerial surveys of 256-km^2 sampling units. This model assumes that mallard densities (mallards/ha/day) are directly proportional to HSI values (Allen 1987). Although Van Horne (1983) stressed that population density may not reflect habitat quality, we assumed that mallard density within the LMV during winter reflected short-term habitat quality because flooding and flood-dependent food availability influence the distribution of mallards within the LMV (Reinecke et al. 1988, Reinecke et al. 1992). Density reflects habitat use quantitatively and is thus superior to expert opinion, and density is a relatively economical measure of species response to habitat. Other, perhaps more suitable, indices of species response to habitat suitability (e.g., body mass and condition) are difficult to obtain and may actually reflect habitat conditions at other locations. Consequently, we evaluated the mallard HSI model by relating HSI values to variation in densities of mallards wintering in the LMV.

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Methods

Three food-availability indices (cropland, forested wetland, and nonforested wetland) and 1 habitat-composition index are combined in the mallard HSI model (Allen 1987). Flood duration impacts all 3 food-availability indices. Generally, seasonally flooded areas have greater habitat value than nonflooded areas or permanently flooded areas of the same habitat class. However, because of decreased availability of food at deeper water depths (Heitmeyer 1985, Wylie 1985) or deterioration of seed over time (Nelms and Twedt 1996), the model assumes maximum suitability is achieved in some habitats (e.g., soybean and forest) when shallowly flooded (<40 cm) for less than the 120-day duration of the HSI model. Additionally, the cropland food index incorporates relative values for crop type (corn = 1.0, rice = 0.6, milo = 0.4, soybean = 0.2, and cotton = 0) and post-harvest treatment (stubble/litter = 1.0, tilled = 0.15) based on the suitability and availability of potential food items. The food index for forested wetlands also comprises percent canopy cover by all trees (maximum suitability between 50% and 80%), percent of canopy trees that are oaks (*Quercus* spp.) (maximum suitability at >75%), and total number of oak species (excluding overcup oak [*Q. lyrata*]; 1 species = 0.5, 2 = 0.7, 3 = 0.9, and ≥4 = 1.0). Additional factors in the food index for nonforested wetlands include percent canopy cover (maximum suitability between 50% and 90%) and growth form of herbaceous vegetation with its resultant vegetation-water contact (minimum contact = 0.1, intermediate contact = 0.5, maximum contact = 1.0).

The habitat-composition index represents the proportions of forest, cropland, and nonforested wetland within each sample unit. The mallard HSI model maximizes the habitat-composition index when a sample unit contains at least 10% cropland, 40% forest, and 10% nonforested wetlands. The HSI value is ultimately calculated by summing the weighted food availability indices and multiplying by the habitat composition index (Allen 1987).

Sampling sites were located within the observation boundaries of a single Landsat thematic mapper (TM) satellite image between 32° 30' and 34° north latitude in west-central Mississippi, southeastern Arkansas, and northeastern Louisiana (Fig. 1). This locale provided greater area within the LMV than any other single Landsat image. Landsat TM data from July 1988 (summer) and January 1989 (winter) were gridded at 16-km intervals, yielding 49 contiguous areas of 256 km^2 (Fig. 1). We randomly selected 23 of these as sample units. Although the minimum habitat area is not specified in the model, we chose the 16-km interval to provide sufficient area to account for typical daily movements of 1.6 to 8 km from roost sites to foraging areas (Allen 1987). Bottomland hardwood forest, a potentially important variable in the mallard HSI model, was not a major habitat class in any of these randomly selected sample units. Therefore, we established 2 additional sample units that contained a high proportion of forest but were located outside the sampling grid (Fig. 1).

Within each of the 25 sample units, land-cover was determined from summer 1988 TM data by the U.S. Army Corps of Engineers Waterways Experiment Station using geographic image analysis technology (Sinclair et al. 1990). Initial classification was improved by incorporating data classified by the U.S. Army Corps of Engineers (USACE), Vicksburg District, which used TM imagery from an additional date during summer 1988 (D. Johnson, USACE, unpubl. data) and by verification of crop distribution data from county offices of U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service archives.

All forested habitat was classified as bottomland hardwood forest, regardless of timber type; upland and pine forests were not present in the study area. Nonforested wetlands included areas covered by water in summer (designated as either aquaculture ponds or as lakes/streams) and areas assigned a cover class of grass/forbs. Six agricultural classes were identified: rice, cotton, soybean, cotton/soybean, corn, and "other agricultural land." The cotton/soybean class was used where we could not distinguish

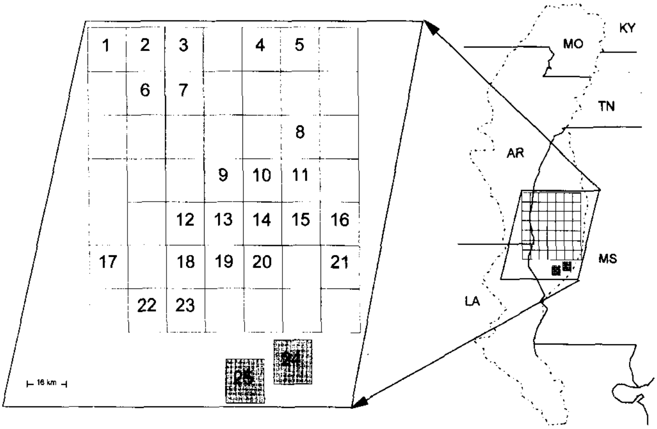

Figure 1. Location of 256-km² sampling units within the Lower Mississippi Valley during 1988–89; open squares were randomly selected from the sampling grid, shaded squares were subjectively chosen because they contained a high proportion of forest.

between the reflectance spectra of cotton and soybean fields. Other agricultural land included all remaining agricultural lands, such as fallow fields and croplands with milo and small grains. We estimated total area in land-cover classes within each sample unit by multiplying number of pixels of a cover class by pixel area (900 m^2).

Winter TM data were classified as water and nonwater areas. Winter floodwater was identified by comparing summer and winter data; areas not classified as water in summer but classified as water in winter were considered flooded. We used winter floodwater data to determine flooded areas of forest, nonforested wetland, and each of the six agricultural land classes. A limitation of our model evaluation was that we had quantitative information on flood condition only for the period of our aerial surveys (29 Jan 1989). Typically, however, flood conditions increase from December through February within our study area. We assumed areas flooded on 29 January had been flooded an average of 30 days and remained flooded through 28 February. Thus, any habitat classified as flooded on 29 January was considered to have been flooded for 60 of the 120 days covered by this HSI model.

We assumed crops identified from the summer TM data were harvested but stubble or tilled residue remained during winter. Based on local management practices, we assumed half of the rice area in Mississippi and Louisiana was tilled post-harvest, but only 20% of the rice area in Arkansas was tilled. Land classified as cotton/soybean was equally divided between cotton and soybean for calculation of HSI values.

Proportion of canopy trees that were >25-cm dbh oaks and total number of oak species within bottomland hardwood forests were estimated from randomly selected forest stands within sample units using circular, 0.04-ha sample plots ($N = 114$). We estimated forest canopy cover from 4 densiometer readings taken at the edges of each sample plot. For each sample unit, an average of five (range: 0 to 19) sample plots was obtained; data from the nearest forest stand was used to provide data for 3 sample units in which no forest canopy cover data were obtained.

We did not make physical measurements of the vegetation within nonforested wetlands. We assumed that vegetation on land classified as grass/forb was robust after the growing season and had an average canopy cover of 50% on areas subject to flooding after the growing season. Aquaculture ponds were generally kept free from emergent aquatic vegetation and we assumed they had only 1% canopy cover. Lakes and rivers were assigned 5% canopy cover to account for emergent vegetation along their edges. Vegetation was assumed to have little surface area in contact with water in lakes, rivers, and aquaculture ponds that were permanently flooded. Conversely, because vegetation on grass/forb areas was flooded only after the growing season, we assumed this vegetation had maximum contact with water. For calculation of the habitat composition index, we considered grass/forb areas as nonforested wetlands only if flooded during winter. Although nonforested wetland canopy cover assumptions are tenuous, deviations from these assumed values would have little impact on final HSI values because nonforested wetlands comprised a small proportion (<6%) of the total land base within our study area.

We calculated food availability indices for the flooded and nonflooded components of each cropland, forested wetland, and nonforested wetland class. Indices were subsequently weighted by the area (ha) of each habitat class within sample units.

We estimated mallard densities by conducting aerial surveys covering 25% of the area of each sample unit. Eight east-west oriented transects, 16-km long by 0.5-km wide, were flown in each sample unit between 0800–1700 hours. All transects were flown from 27 to 31 January 1989, 3 to 4 weeks after closure of duck hunting seasons (1 Jan in Arkansas, 8 Jan in Louisiana and Mississippi) Using methods described by Reinecke et al. (1992), experienced observers (JRN, MWB) recorded numbers of mallards, associated habitat, and apparent management status of floodwater. Smith et al. (1995) found that observers of mallards within the LMV observed only 70% of mallards present in cropland, 42% in cypress-tupelo swamps, 31% in scrub/shrub swamps, and 19% in bottomland hardwood forests. Therefore, we adjusted our observed mallard numbers by habitat type to correct for visibility bias using the above percentages.

We assessed overall model performance by regressing observed mallard densities and mallard densities adjusted for habitat visibility bias from each survey against calculated HSI values. Performance of individual HSI model components and the habitat's composition were evaluated through stepwise multiple regression (SAS Inst. 1987; PROC REG; $P_{enter} = 0.15$, $P_{remove} = 0.15$) of mallard densities against these individual components.

Results

The 25 sample units contained more cropland and less forested and nonforested wetlands than idealized by the HSI model (Table 1). Additionally, the quality of forested habitat was not maximally suitable for mallards (Table 1). On average, 11%

Table 1. Habitat composition and characteristics of 25, 256-km^2 sample units used to calculate mallard habitat suitability index (HSI) within the Lower Mississippi Valley during 1988–89.

HSI component	$\bar{x} \pm$ SE	Model ideal
Habitat composition		
Forest	25% ± 3%	≥40%
Cropland	64% ± 3%	≥10%
Corn	1%	
Rice	7%	
Soybean	28%	
Cotton/soybean	19%	
Cotton	32%	
Other	13%	
Nonforested wetland	6% ± 1%	≥10%
Other or unclassified	5% ± 1%	
Forest characteristics		
Proportion oaks (>25-cm dbh)	0.23 ± 0.04	≥0.75
N oak species	2.6 ± 0.3	≥4
Flood conditions		
Forest	1350 ± 194 ha (range: 303–4066)	≥10,240 ha
Soybean	689 ± 148 ha (range: 0–3457)	}sum ≥2,560 ha
Rice	239 ± 49 ha (range: 0–805)	
Index components		
Forest food index	0.030 ± 0.006 (range: 0.01–0.13)	
Cropland food index	0.016 ± 0.001 (range: 0.01–0.04)	}sum = 1.0
Nonforested wetland food index	0.001 ± 0.001 (range: 0.00–0.01)	
Habitat composition index	0.339 ± 0.053 (range: 0.17–0.84)	1.0

(SE = 1%) of the sample units were seasonally flooded, with more forest flooded than cropland (Table 1). As a result of the limited flooding of the less than ideal habitat matrix, food indices for all sample units were low (≤0.132) and the average habitat composition index was only 0.34 (Table 1). The sum of the weighted food availabilities multiplied by the habitat composition index resulted in HSI values ranging from 0.002 to 0.121 (Fig. 2).

Mean observed mallard density over all sample units was 9.8 (SE = 2.8) birds/km^2, and mean mallard density adjusted for visibility bias was 14.5 (SE = 4.0) birds/km^2. Mallards were observed in cropland (85%), nonforested wetlands (11%), and forests (4%). Most mallards, 67%, were observed in unmanaged floodwater, but 33% were observed in fields where water appeared to be managed for waterfowl. We observed no mallards on dry land.

Although the slope of the regression of adjusted mallard densities against HSI values was significantly different from 0 (b = 364.6, SE = 118.4, P = 0.005), the regression did not have high predictive ability (R^2 = 0.29; Fig. 2). Results for the regression of observed mallard densities and HSI values were similar (R^2 = 0.29, P = 0.005; Fig. 2). In both regression models, the 95% confidence band for predicted mallard density included 0 for all but the highest 2 HSI values encountered, which occurred on the 2 subjectively chosen sample units.

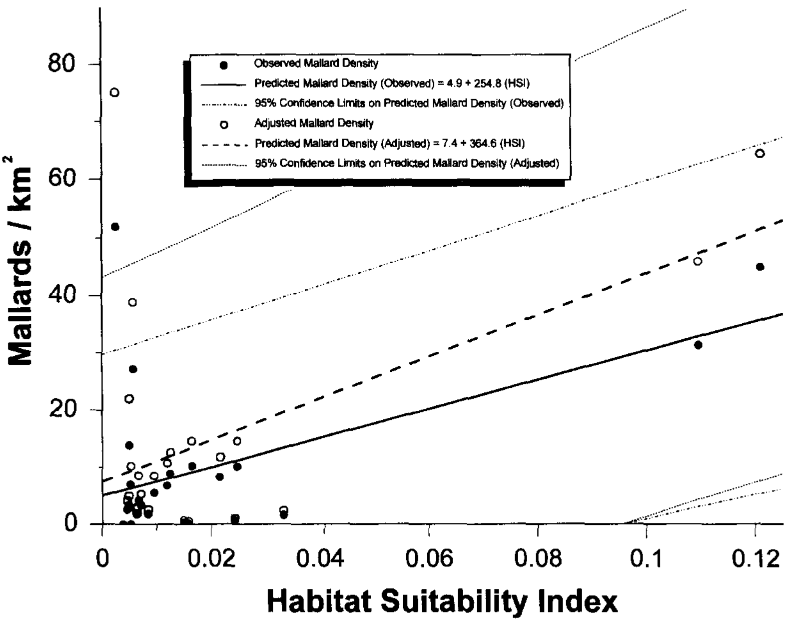

Figure 2. Regression of observed (•) and adjusted (○) mallard densities against habitat suitability indices obtained from 256-km^2 sampling units in the Lower Mississippi Valley during 1988–89 ($R^2 = 0.29$, $P = 0.005$ for both relationships).

The 2 subjectively chosen units yielded high forested-wetland food indices and favorable habitat compositions that resulted in HSI values more than 3 times greater than for any other sample unit in this study but were still relatively low. These sample units exerted disproportionate influence on the regression models. When these 2 heavily forested units were removed, regression models were not significant ($R^2 = 0.06$, $P > 0.25$), and HSI values were not associated with mallard densities in the LMV.

In a multiple regression using individual components of the HSI model as candidate explanatory variables and data from all 25 sample units, only the weighted food index from forested wetlands was significantly related to mallard densities ($R^2 = 0.25$, $F = 7.5$, $P = 0.01$). Similarly, in a multiple regression using the areas of flooded and non-flooded habitats, only the area of flooded forest entered the model for mallard densities ($R^2 = 0.11$, $F = 2.7$, $P = 0.11$). When we used data from only the 23 randomly chosen sample units, neither the food indices nor the habitat composition index were related to mallard density ($P > 0.15$).

Discussion

Habitat suitability indices for our sample units were relatively low but wide variation in mallard densities (CV = 139%) was associated with these HSI values. This result and the weak regression indicated that these low HSI values were not related to observed mallard densities. A relatively low proportion of forested habitat and little flooded habitat were responsible for low HSI values within our sample units. At the scale used in our assessment (256 km^2) within the LMV, current land use (i.e., limited forested habitat) and hydrology (i.e., limited winter flooding) constrained HSI values. Reducing the scale for habitat assessment to levels at which high HSI values may be attained, however, would result in small sample units that are not likely to encompass the daily movements of mallards.

A significant limitation of our evaluation of this HSI model was the use of a single survey of mallard density. Reinecke et al. (1992) noted that mallard densities in the LMV, and probably habitat availability and quality, were dynamic among and within winters. Therefore, mallard densities from a single survey may not reflect long-term or potential habitat suitability. Future evaluations should use multiple surveys to estimate mallard densities. Ideally, these surveys would be conducted under different flood conditions.

In exploratory regressions, potential food availability in forested wetlands and area of flooded forest were positively related to mallard density and accounted for 24% and 11% of the variability in density. Thus, HSI model revision should continue to emphasize flooded forested habitats, but not exclude other important habitats of mallards in the LMV.

HSI model revisions should evaluate habitat at spatial scales that account for mallard mobility. At these spatial scales, however, both forest and flooded areas are limited in area relative to the size of the sampling units and will likely result in low HSI values. Thus, model inputs should be adjusted to allow a wider range of HSI values to be attained. Additionally, field sampling of forests over large areas is often impractical. An alternative is to distinguish among bottomland hardwood forest types (oak-dominant forests, mixed-species forests, and cypress-tupelo forests) and categorize canopy closures via remote sensing (e.g., Bauer et al. 1994, Thomasson et al. 1994, Zhu and Evans 1994). We recommend reassignment of forest values within the mallard HSI model based on data that can be obtained via remote sensors.

Similarly, direct assessment of flood conditions over large areas for extended periods is difficult. We propose that an alternative is to use satellite imagery collected over a series of years to assess frequency and duration of flooding within the LMV. Flood probability values should be assigned to small areas (e.g., pixels) based on their historic record of flooding and the seasonal duration of flooding.

Similar to our recommended approach for assessing flood probabilities, we propose using digital classifications of crop distribution (e.g., Bellow and Graham 1992) over several years within the LMV to determine probability of small areas (e.g., pixels or fields) being planted to a specific crop. These probabilities would more accurately describe long-term habitat suitability for mallards than do single-season assessments.

Revision of the mallard HSI model should allow a wider range in HSI values to be assigned to large areas, at least as large as the daily wintering range of mallards. To achieve this objective, model inputs for flood potential and crop distribution should be based on broader scales (both regional and temporal) than are currently used. Habitat characteristics that can be obtained remotely and at landscape scales should be encouraged as model inputs, whereas model components that can only be obtained from on-site field sampling of habitats should be reduced or eliminated. Finally, evaluation of future model revisions should incorporate multiple surveys of mallard density under different flood conditions and preferably over ≥2 years. Incorporation of these suggestions for model revision and following our recommendations for model evaluation may provide a model with greater ability to predict mallard densities based on habitat suitability within the LMV.

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