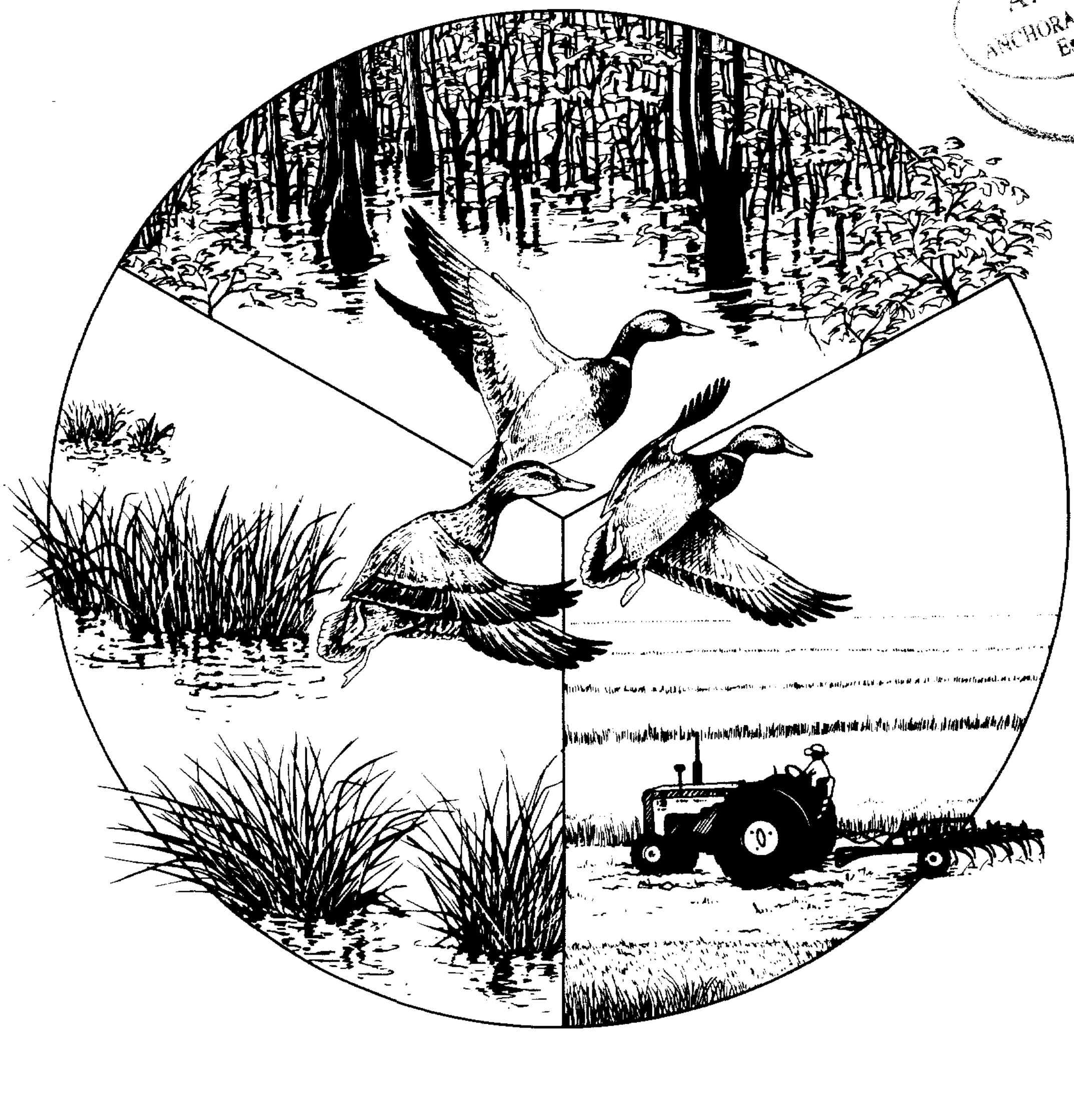
BIOLOGICAL REPORT 82(10.132)
FEBRUARY 1987

HABITAT SUITABILITY INDEX MODELS: MALLARD (WINTER HABITAT, LOWER MISSISSIPPI VALLEY)



and Wildlife Service

Department of the Interior

MODEL EVALUATION FORM

Habitat models are designed for a wide variety of planning applications where habitat information is an important consideration in the decision process. However, it is impossible to develop a model that performs equally well in all situations. Assistance from users and researchers is an important part of the model improvement process. Each model is published individually to facilitate updating and reprinting as new information becomes available. User feedback on model performance will assist in improving habitat models for future applications. Please complete this form following application or review of the model. Feel free to include additional information that may be of use to either a model developer or model user. We also would appreciate information on model testing, modification, and application, as well as copies of modified models or test results. Please return this form to:

Habitat Evaluation Procedures Group
U.S. Fish and Wildlife Service
2627 Redwing Road, Creekside One
Fort Collins, CO 80526-2899

Thank you for your assistance.

Species ______________ Geographic Location ________________________________

Habitat or Cover Type(s) ____

Type of Application: Impact Analysis ____ Management Action Analysis _____
Baseline _____ Other ____

Variables Measured or Evaluated ____
____
____
____

Was the species information useful and accurate? Yes ____ No ____

If not, what corrections or improvements are needed?_____________________
____
____
____

Were the variables and curves clearly defined and useful? Yes ____ No ____

If not, how were or could they be improved? ______________________________

____

____

____

Were the techniques suggested for collection of field data:

Appropriate? Yes ____ No ____

Clearly defined? Yes ____ No ____

Easily applied? Yes ____ No ____

If not, what other data collection techniques are needed? ______________

____

____

____

Were the model equations logical? Yes ____ No ____

Appropriate? Yes ____ No ____

How were or could they be improved? ___________________________________

____

____

____

Other suggestions for modification or improvement (attach curves, equations, graphs, or other appropriate information) ______________

____

____

____

Additional references or information that should be included in the model:

____

____

____

____

____

Model Evaluator or Reviewer ___________________________ Date ____________

Agency ____

Address ____

____

____

Telephone Number Comm: _________________________ FTS _____________________

Biological Report 82(10.132)
February 1987

HABITAT SUITABILITY INDEX MODELS: MALLARD (WINTER HABITAT, LOWER MISSISSIPPI VALLEY)

by

Arthur W. Allen
National Ecology Center
U.S. Fish and Wildlife Service
2627 Redwing Road
Drake Creekside Building One
Fort Collins, CO 80526-2899

National Ecology Center
Division of Wildlife and Contaminant Research
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

This report should be cited as:

Allen, A.W. 1986. Habitat suitability index models: mallard (winter habitat, Lower Mississippi Valley). U.S. Fish Wildl. Serv. Biol. Rep. 82(10.132). 37 pp.

PREFACE

This document is part of the Habitat Suitability Index (HSI) Model Series [Biological Report 82(10)], which provides habitat information useful for impact assessment and habitat management. Several types of habitat information are provided. The Habitat Use Information section is largely constrained to those data that can be used to derive quantitative relationships between key environmental variables and habitat suitability. This information provides the foundation for the HSI model and may be useful in the development of other models more appropriate to specific assessment or evaluation needs.

The HSI Model section documents the habitat model and includes information pertinent to its application. The model synthesizes the habitat use information into a framework appropriate for field application and is scaled to produce an index value between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). The HSI Model section includes information about the geographic range and seasonal application of the model, its current verification status, and a list of the model variables with recommended measurement techniques for each variable.

The model is a formalized synthesis of biological and habitat information published in the scientific literature and may include unpublished information reflecting the opinions of identified experts. Habitat information about wildlife species frequently is represented by scattered data sets collected during different seasons and years and from different sites throughout the range of a species. The model presents this broad data base in a formal, logical, and simplified manner. The assumptions necessary for organizing and synthesizing the species-habitat information into the model are discussed. The model should be regarded as a hypothesis of species-habitat relationships and not as a statement of proven cause and effect relationships. The model may have merit in planning wildlife habitat research studies about a species, as well as in providing an estimate of the relative suitability of habitat for that species. User feedback concerning model improvements and other suggestions that may increase the utility and effectiveness of this habitat-based approach to fish and wildlife planning are encouraged. Please send suggestions to:

National Ecology Center
U.S. Fish and Wildlife Service
2627 Redwing Road
Fort Collins, CO 80526-2899

CONTENTS

FIGURES

ACKNOWLEDGMENTS

This HSI model was initiated in a workshop that included the following participants: Dr. Leigh Fredrickson, University of Missouri; Dr. Ken Reinecke, U.S. Fish and Wildlife Service; Mr. S. Ray Aycock, U.S. Fish and Wildlife Service; Mr. Robert Barkley, U.S. Fish and Wildlife Service; Mr. Charles Baxter, U.S. Fish and Wildlife Service; Mr. Bruce Bell, U.S. Fish and Wildlife Service; Dr. Chris Onuf, U.S. Fish and Wildlife Service; Mr. Don Orr, U.S. Fish and Wildlife Service; and Mr. Robert Strader, U.S. Fish and Wildlife Service. These individuals contributed freely of their extensive experience and knowledge of mallard winter habitat use and requirements in the Lower Mississippi Valley. The time and willingness of these individuals to contribute to the completion of this HSI model is gratefully acknowledged.

In addition to the workshop participants, the following individuals provided valuable critiques on earlier drafts of this HSI model: Dr. Michael J. Armbruster, U.S. Fish and Wildlife Service; Dr. Mickey E. Heitmeyer, University of California; Dr. Richard M. Kaminiski, Mississippi State University; Mr. Mitch M. King, U.S. Fish and Wildlife Service; Dr. Charles Klimas, U.S. Army Corps of Engineers; Mr. David R. Parsons, U.S. Fish and Wildlife Service; Dr. Fredrick A. Reid, University of Missouri; and Mr. Robert L. Willis, U.S. Fish and Wildlife Service. The comments and suggestions of these individuals have significantly added to the quality of this HSI model and their time and contributions are sincerely appreciated.

Richard Schroeder, U.S. Fish and Wildlife Service, served as facilitator for the modeling workshop. The cover of this document was illustrated by Susan Strawn. Word processing was provided by Dora Ibarra and Patricia Gillis. Kay Lindgren assisted with literature searches and information acquisition.

MALLARD (*Anas platyrhynchos*)

HABITAT USE INFORMATION

General

The Mississippi valley south from Cape Girardeau, Missouri, to the Gulf of Mexico is the primary wintering ground for mallards (*Anas platyrhynchos*) in the Mississippi flyway (Bellrose 1976). Half or more of the Mississippi flyway's 3.2 million mallards winter in the Lower Mississippi Valley (Bartonek et al. 1984). Mallards spend nearly as much time on their wintering grounds as on northern breeding areas, yet the question of how the quality of wintering areas influences mallard populations has received minimal attention (Fredrickson and Drobney 1979; Anderson and Batt 1983; Heitmeyer 1985). Recent investigations have begun to clarify the relationships between winter habitat conditions and mallard population dynamics (Fredrickson 1980; Heitmeyer and Fredrickson 1981; Nichols et al. 1983; Heitmeyer 1985; Reinecke et al. 1986). Although these relationships are not entirely clear, changes in the availability and quality of wetlands in the Lower Mississippi Valley can influence mallard distribution, reproduction, and survival (Heitmeyer and Fredrickson 1981; Nichols et al. 1983; Reinecke et al. 1986). Losses of southern bottomland forests have resulted in mallards being forced to concentrate on fewer winter areas and in sites that are of lower overall quality (Heitmeyer and Fredrickson 1981). It is apparent that long-term maintenance of mallard winter habitat quality within the Lower Mississippi Valley can be insured only if areas are provided that satisfy the physiological and behavioral needs of the species. The continued loss and degradation of suitable winter habitat through deforestation, wetland drainage, flood-control projects, conversion of land to agricultural use, disturbance, and inappropriate water management can be expected to further influence the ability of southern wetlands to provide critical habitat requirements for wintering mallards.

Mallards respond to changes in habitat conditions both within and among years by moving to more favorable areas; as a result, there is annual variation in the number of mallards that use the Lower Mississippi Valley (Nichols et al. 1983). Although long-term winter wetland conditions influence habitat use and mallard distribution, the species also responds to yearly variations in temperature, ice cover, and flooding regimes. Mallards are adapted to dynamic wetland conditions that provide a variety of wetland types and sizes in relatively close proximity. Wetland complexes are desirable on both a local and regional basis to meet the diverse habitat requirements of various sex, age, and behavioral segments of the mallard population. Winter habitat conditions influence the abundance and availability of food resources, and the physical condition, social behavior, distribution, reproduction and survival of midcontinent mallards (Reinecke et al. 1986).

Food

Habitat use by mallards is partially dictated by the availability of foods that can be broadly classified as invertebrates associated with leaf litter, moist-soil foods (e.g., invertebrates, seeds, rootlets and tubers of wetland plants), mast, and agricultural grains (Heitmeyer 1985). Few individual foods can provide all of the necessary nutrients throughout the entire winter period. Mallards have learned to use cultivated grains as a source of energy (Heitmeyer 1985), however, grains are less balanced nutritionally than are natural foods (e.g., plants and invertebrates associated with wetlands) (Fredrickson and Taylor 1982; Baldassarre et al. 1983; Jorde et al. 1984; Heitmeyer 1985). Agricultural grains should be considered as an important supplement to natural foods, not a complete substitute (Baldassarre et al. 1983). Heitmeyer (1985) concluded that grains alone provide an unsatisfactory diet since they are low in polyunsaturated fats and consist of energy sources that are not efficiently stored by mallards. Corn is high in carbohydrates but is nutritionally incomplete, particularly in calcium and certain amino acids (Baldassarre et al. 1983). Natural foods are generally higher in protein and minerals that are required to meet the needs of wintering mallards. A diversified diet consisting of invertebrates and moist-soil foods may enhance the value of cultivated grain by providing a better balance of amino acids and minerals (Heitmeyer 1985).

A diet that enhances fat deposition in mallards while on wintering areas probably results in earlier arrival and nest initiation on the breeding grounds (Krapu 1981). Abundant, high-quality foods facilitate the acquisition of nutritional resources in a relatively short period of time, and increase time available for essential courtship and pairing activities (Heitmeyer 1985). Paired female mallards prepare for initiation of prebasic molt by increasing consumption of crustaceans, molluscs, and mast within shallowly flooded bottomland forests. Although low in metabolizable energy in comparison to plant foods, invertebrates are rich in amino acids that serve to replenish protein and fat reserves lost during courtship and pairing activities, and establish new reserves required for the molt and migration. Seeds provide many of the required nutrients, but are a relatively poor source of protein and are often unavailable due to excessive flooding or are nutritionally degraded by late winter (Shearer et al. 1969; Fredrickson and Taylor 1982).

Waterfowl select areas for foraging in response to the overall availability of energy and nutrients in the food items located (Wylie 1985). The flooding regime of bottomland sites provides an indication of their relative importance in terms of availability of macroinvertebrates. Inundation of terrestrial detritus by seasonal flooding rapidly adds nutrients to the water, which in turn supports invertebrate production (Batema et al. 1985). The zooplankton and macroinvertebrates supported by these nutrients provide the link for the transfer of energy and nutrients from litter present in the bottomland forest to foraging waterfowl. Zooplankton typically respond to temporary flooding with a rapid increase in production, reaching a peak soon after flooding, followed by a gradual decline in biomass. Maximum invertebrate production in seasonally flooded pin oaks (Quercus palustris) in Missouri occurred within 4 weeks of initial flooding (Batema et al. 1985). The rapid peak and subsequent decline of invertebrate production may explain a similar pattern of high initial use of flooded sites by mallards, followed by a gradual decline.

Periodic flooding is partially responsible for higher primary production and nutrient return in seasonally flooded bottomland forests than within nonwetland forests or permanently flooded wetlands (Brinson et al. 1980). Maximum invertebrate densities in naturally flooded areas were greater than corresponding densities in managed wetlands subjected to longer flood duration in Missouri (Batema et al. 1985). Invertebrate production in response to flooding appears to vary inversely with flood duration (Heitmeyer 1985; Wylie 1985). Long-term flooding of forests may eventually result in overall nutrient loss, decreased invertebrate productivity and biomass, lower invertebrate species diversity (Batema et al. 1985), and lower fitness and diversity of vegetation (Black 1984).

Any practice or event that sets back wetland succession may benefit waterfowl (Baldwin 1968). Openings in the canopy of bottomland forests, caused by fire, the falling of dominant or codominant trees from windthrow, disease, lightning, and root scour sets back succession (Wharton et al. 1982). Increased insolation resulting from openings in the forest canopy stimulates the growth and production of understory vegetation (Fredrickson 1980; Heitmeyer 1985). Single tree openings in the canopy of bottomland forests provide important foraging sites for mallards due to enhanced production of herbaceous vegetation and possibly an increased availability of invertebrates. The seeds, tubers, and rootlets of vegetation indigenous to flooded bottomland forests and other wetlands provide an important mallard winter food source. The gross energy in seeds from moist soils is as high, or higher, than that available in corn, milo, or soybeans (Fredrickson and Taylor 1982). Some advantages of native vegetation over domestic crops include: (1) greater duration of nutritional qualities under flooded conditions (most cultivated grains deteriorate rapidly when flooded); (2) native vegetation is adapted to a greater diversity of site and climatic conditions and is less likely to suffer crop failures than are domestic grains; and (3) moist soils and their associated native vegetation typically support diverse populations of invertebrates, whereas, invertebrate populations suitable for mallard foraging are essentially absent in cropland.

Successful management of sites for the production of a waterfowl food source differs by geographic region and latitude (Knauer 1977; Fredrickson and Taylor 1982). Variables that influence moist-soil plant production include: the plants desired; the duration, depth, timing, and frequency of flooding and dewatering; soil characteristics; and time since disturbance (Knauer 1977). Sites that have been used for agricultural purposes often have the best potential for wetland restoration using moist-soil management (F.A. Reid, Missouri Cooperative Wildlife Research Unit, University of Missouri, Columbia; letter dated January 16, 1986). Fredrickson and Taylor (1982) provide detailed descriptions of moist-soil management techniques.

Major foods consumed by female mallards wintering in Missouri's Mingo Basin included the acorns of pin oak willow oak (_Q. phellos_) and southern red oak (_Q. falcata_); seeds of barnyardgrass (_Echinochloa_ spp.), rice cutgrass

(*Leersia oryzoides*), beggarticks (*Bidens* spp.), and smartweeds (*Polygonum* spp.); and invertebrates including snails (Gastropoda), crustaceans, spiders (Arachnida), and beetles (Coleoptera). Acorns, predominantly from pin oak, accounted for 40% of the diet (Heitmeyer 1985). Plant foods occurred in 80% of the mallard food samples in another study in the Mingo Basin (White 1982). The most important plant foods were: pin oak acorns, seeds of rice cutgrass, panicum (*Panicum rigidulum*), and beggarticks. These species accounted for 86.9% of all plant foods recorded. Invertebrates occurred in all food samples. Isopods (*Asellus intermedius*), fingernail clams (*Pisidium fallax*), and amphipods (*Crangonyx* spp.) accounted for 89.6% of all recorded animal foods.

Rice and the seeds of grasses associated with rice culture accounted for 47.4% and 18.5%, respectively, of the foods eaten by wintering mallards in Arkansas (Wright 1959). Acorns composed approximately 24% of the foods consumed. Rice, soybeans, and seeds of plants associated with moist-soil areas provided 41.3%, 42.6%, and 10%-11% of the foods consumed by wintering mallards in Mississippi (Delnicki and Reinecke 1986). Year to year variation in consumption of rice and soybeans was observed when water conditions varied. Soybean consumption increased during dry years, whereas rice consumption increased during years of greater surface water availability. Invertebrates occurred more frequently in the diet of mallards that fed on rice than on other foods. Snails (*Physa* spp.) represented 58.7% of the animal foods consumed. The balance of animal foods consisted of 40 taxa of invertebrates and two species of fish [mosquitofish (*Gambusia affinis*) and black crappie (*Pomoxis nigromaculatus*)]. Nonagricultural vegetation accounted for approximately 16% (dry weight) of foods consumed. Plants associated with moist-soil and agricultural areas included: junglerice (*E. colonum*), broad-leafed signalgrass (*Brachiaria platyphylla*), fall panicum (*Panicum dichotomiflorum*), rice cutgrass, and dotted smartweed (*P. punctatum*).

Water

No specific information relating to the dietary water requirements of wintering mallards was located in the literature. The following information pertains to the influence of water and winter flooding on food availability and habitat use by mallards wintering in the Lower Mississippi Valley.

Annual variations in precipitation determine the extent of flooding in bottomland habitat and are essential to stimulate vegetative production, habitat diversity, the availability of high protein foods, and suitable feeding conditions for wintering mallards (Heitmeyer 1985). Variability in terrain and wetland types contribute to food diversity and have a major influence on mallard winter habitat quality. The timing, depth, duration, and extent of flooding determine plant composition within bottomland forests (Fredrickson 1979). Both short- and long-term water fluctuations control the composition of plant communities and directly influence the availability of suitable mallard foods.

Inundation of bottomland sites is the consequence of four types of flooding: (1) on-site rainfall, (2) puddling of rainfall, (3) headwater (flash) flooding, and (4) backwater flooding (Fredrickson 1980; Heitmeyer 1985). On-site rainfall is precipitation that occurs in sufficient quantity to result in standing surface water. Puddling of rainwater occurs from rainfalls of sufficient amounts to inundate depressions and create isolated perched wetlands. Puddling of surface water also may occur as a result of receding flood waters. Puddling of rainwater contributes few nutrients, but is important for the survival of invertebrate populations and enhances habitat diversity by increasing wetland area and edge (White 1982; Batema et al. 1985; White 1985). Headwater (flash) flooding is caused by heavy rainfall over a short period of time in the upstream watershed (Heitmeyer 1985). The rapid inflow and high volume of a flash flood modify drainage patterns, contribute large allochthonous input, cause extensive scouring, and probably contribute to the depletion of nutrients due to the short duration of the event and rapid drainage. Headwater floods normally occur every 4 to 6 years. Backwater floods occur when drainage systems become filled to capacity and flood waters inundate higher elevations in the basin. Backwater flooding typically occurs every year, or every other year, and over a longer period of time than headwater flooding and is a major source of sediments and nutrients in bottomland communities.

Flooding conditions in the Lower Mississippi Valley directly affect mallards by influencing food availability and foraging opportunities, physical condition, survival, distribution, and reproductive effort (Heitmeyer and Fredrickson 1981; Nichols et al. 1983; Heitmeyer 1985; Reinecke et al. 1986). Mallards adjust their seasonal and daily activities to the availability of suitable flooded sites (Heitmeyer 1985). Larger numbers of mallards are attracted to the Lower Mississippi Valley during wet years (Nichols et al. 1983). Minimal flooding of bottomland forests occurs in years of low precipitation, resulting in reduced availability of plant foods and reduced time for invertebrate production, which ultimately results in lower nutrient availability for mallards. These factors may contribute to poorer physiological condition, later pair formation, and, possibly, delayed spring migration.

Insufficient availability and distribution of winter-wetlands may contribute to reduced recruitment during the subsequent breeding season (Heitmeyer and Fredrickson 1981). Delnicki and Reinecke (1986) reported that mallard body weights were positively correlated with winter precipitation and wetland availability, presumably as a result of increased food resources and foraging opportunities. Mallards exhibited average body weights during years of normal precipitation; however, body weight decreased by 5% during abnormally dry years and increased by 5% during years of above average rainfall and seasonal flooding. Heavier birds imply improved physiological condition and potential for greater reproductive success.

Inter- and intra-specific aggressive behaviors can influence waterfowl distribution during the nonbreeding season (Hepp and Hair 1984; Jorde et al. 1984). Less-dominant birds have less access to preferred feeding sites, which may necessitate moving to inferior sites. Adult mallards are dominant over juveniles and outcompete younger birds for preferred, but limited, winter habitat during dry years (Nichols et al. 1983). Juvenile mallards winter with greater frequency in the Lower Mississippi Valley during years of low populations, perhaps in response to less competition between adults and juveniles. Mallards become concentrated when flooded areas are limited in distribution. Increased density results in rapid food depletion, longer flights to foraging areas, increased potential of disease outbreaks (Jorde et al. 1983; Reid unpubl.), and less segregation of pairs from larger groups (Fredrickson and Drobney 1979). The combination of reduced food resources and increased intra-specific contact may contribute to decreased physiological condition, which may ultimately result in lower reproductive success (Fredrickson and Drobney 1979; Hepp and Hair 1984).

Mallard use of bottomland forests in Missouri was positively correlated with the percentage of the forest area flooded during winter (Heitmeyer 1985). The interface between standing water and dry land provides the most beneficial foraging sites for mallards, because the water enhances the availability of terrestrial invertebrates, aquatic or semiaquatic macroinvertebrates, mast, and seeds of native vegetation. Mallards focus their foraging activity along this edge due to the concentration and availability of food items. Although mallards will feed in dry sites (Wright 1959), flooded areas are preferred. Water depth of 20 to 40 cm provides optimum foraging depths for mallards in bottomland forests (Heitmeyer 1985). Water >50 cm deep was believed to be too deep for effective bottom foraging. The microtopography of bottomland forests, however, usually provides adequate foraging sites under all but the most extreme flooding conditions. Diversity in microtopography, and cover provided by fallen timber, debris, and emergent vegetation, also contribute to high-quality winter habitat in flooded bottomland forests by providing loafing and foraging sites, as well as protective cover (R.M. Kaminski, Department of Wildlife and Fisheries, Mississippi State University, Mississippi State; letter dated January 3, 1986).

Cover

Specific descriptions of cover (e.g., roosting, loafing, security) requirements for mallards wintering in the Lower Mississippi Valley were not located in the literature. Based on available information, it appears that cover requirements are less important in defining the quality of mallard wintering habitat than are the attributes of flooding and vegetation as they relate to the availability and quality of food resources.

Interspersion and Composition

High quality mallard winter habitat is characterized by a diversity of wetlands within a relatively small geographic area (Heitmeyer 1985). Close proximity of wetlands influenced by differing flooding regimes results in a greater variety or complex of wetlands, and greater food diversity and availability. Conversely, if mallards are forced to make more extensive movements to obtain food resources, greater energy expenditures and potentially poorer physiological condition may result. Mallards typically moved from 1.6 to 8 km from roost sites to foraging areas in Missouri. Movements >8 km were typically in response to changes in flooding conditions, changes in temperature, depleted food resources, or disturbance, and represented the search for and establishment of a new center of activity from which shorter foraging forays were made. Longer foraging flights by mallards are possible. Maximum foraging flight distance from roost sites to grain fields by mallards wintering in Nebraska was 20 km (Jorde et al. 1983). Mallards are capable of locating and concentrating foraging activities in newly flooded areas within 24 hours (Reinecke unpubl.).

Special Considerations

The continued existence of productive mallard populations is, in part, dependent on the protection and effective management of wetlands within the Lower Mississippi Valley (Fredrickson 1980). Bottomland forests are highly dynamic environments dependent upon natural, or near natural, seasonal and annual flooding to perpetuate their productivity (Brinson et al. 1980; Heitmeyer 1985; Reid 1985). Mallard wintering habitat in the Lower Mississippi Valley can be maintained on a long-term basis only if the behavioral and nutritional requirements of the species are provided. The following is a summary of management actions recommended by several authors (Taylor 1977; Fredrickson and Taylor 1982; White 1982; Reid 1983; Batema et al. 1985; Heitmeyer 1985), which may be useful in the formulation of management plans to maintain the quality of mallard winter habitat and mitigate habitat losses.

Water management. Late winter and early spring are important times for mallards to obtain nutrients and build fat reserves. Foraging opportunities for wintering mallards will be enhanced by maintaining shallow water, particularly in bottomland forests, until the majority of mallards have migrated.

Optimum foraging opportunities for mallards will be facilitated by providing water depths of <40 cm.

Gradual flooding or removal, either slowly or in stages, of surface water in flooded sites will provide a continuous and dynamic land/water interface that will maximize the availability of foraging sites and opportunities for wintering mallards and other migrant birds.

Nonforested wetlands should be flooded early in the fall to provide moist-soil foods (native plant seeds, tubers, and invertebrates) for migrants arriving early in the winter. Flooding of bottomland forests later in the winter period will have minimal impact on tree growth and vitality and will provide maximum access to acorns at the time when high-energy foods are needed.

The management of wetland complexes in winter (e.g., greentree reservoirs) has often been directed more towards human use than towards meeting the specific ecological requirements of wintering waterfowl (Wylie 1985). Duration and depth of water in greentree reservoirs should not be consistent from year to year. Variation in the timing, duration, and depth of flooding between years will contribute to higher nutrient levels, greater invertebrate production (Batema et al. 1985), and less detrimental influence on tree vitality (Black 1984) and species composition.

Timber management. Timber management for mallard habitat should be restricted to small localized areas within bottomland forest types (Heitmeyer 1985). Single tree selection, when practical, is the ideal method of timber removal and would emulate naturally occurring single tree openings. Cutting programs for enhancement of waterfowl habitat are probably unnecessary in areas where natural water regimes are maintained. Agricultural grains are lower in protein and minerals than are vegetative and animal foods associated with naturally occurring wetlands, therefore, wetland cover types should not be removed in order to establish croplands, even if the cropland is intended only for waterfowl use.

Management of cover type composition. A variety of cover types is necessary to meet the nutritional requirements of wintering mallards. Optimum conditions for mallards are provided when many food sources are present in close proximity; however, the optimum mix and interspersion of cover types are unknown (Heitmeyer 1985).

Croplands interspersed with moist-soil areas, both managed on 1- to 3-year rotations, can provide high-quality food resources in a relatively small area.

Land leveling of croplands reduces diversity in microtopography by elimination of elevated land, which provides mallard loafing sites during flooding, and depressions that capture rainwater and form small but important ponded or perched wetlands.

To enhance food availability, plant diversity, and foraging opportunities moist-soil management areas should be subdivided into several units that can be inundated at different times with a variety of flooding depths, durations, and techniques.

Disturbance. Late winter and early spring are critical for mallard food acquisition (Fredrickson and Drobney 1979; Heitmeyer 1985). Disturbance during this period may force birds from foraging sites, reduce foraging time, or increase energy expenditures. If energy reserves are depleted, migration and pairing activities may be influenced as well. Refuge from disturbance and hunting should be encouraged, particularly within bottomland forests (Heitmeyer 1985).

Preservation. Acquisition of bottomland forests and restoration of degraded bottomland forests should be continued and encouraged because of the critical role these cover types play in the ecological well-being of wintering mallards (Heitmeyer 1985).

HABITAT SUITABILITY (HSI) MODEL

Model Applicability

Geographic area. This model has been developed for the evaluation of mallard winter habitat in the Lower Mississippi Valley (Figure 1). The model is not intended for the evaluation of winter habitat in the coastal marshes of the Gulf of Mexico. The model also may be applicable for evaluation of bottomland habitats in other areas in the Lower Mississippi drainage.

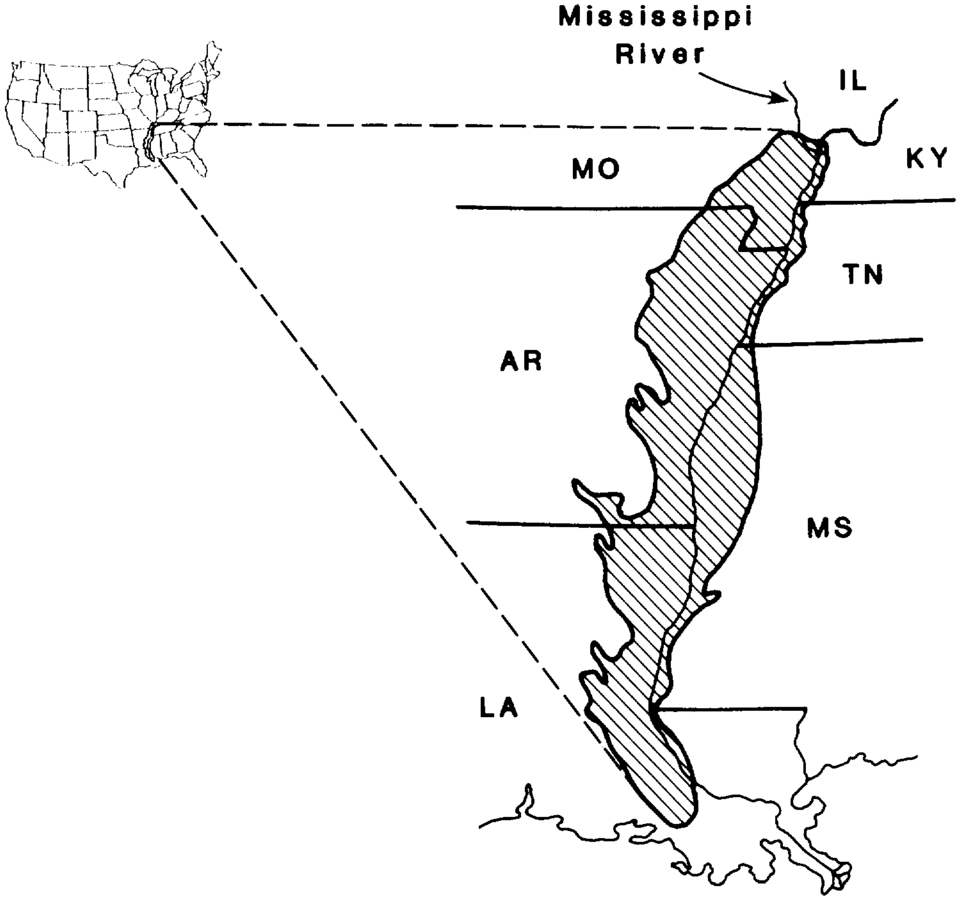


Figure 1. Approximate boundaries of the Lower Mississippi Valley.

The model will produce index values that are assumed to be proportional to an area's ability to provide required food resources for mallards wintering in the Lower Mississippi Valley. The number of mallards/hectare/day that an area can support is assumed to be directly proportional to increasing HSI values. Correlations between HSI values and numbers of mallards/hectare/day, however, are unknown. Areas that receive a 0.0 value are assumed to reflect unsuitable winter habitat.

Season. This HSI model is intended for the evaluation of habitat conditions during the period of mallard winter use. For the purposes of this model winter is defined as the 120-day period between November 1 and February 28.

Cover types. This model has been developed to evaluate the quality of mallard winter habitat in the following cover types: Palustrine (P), Riverine (R), Lacustrine (L) (wetland terminology follows that of Cowardin et al. 1979) and Cropland (C). Wetland cover types are delineated based on the life form of the plants that constitute the uppermost layer of vegetation with ≥30% canopy cover. For example, a wetland with 30% canopy cover of deciduous trees and a deciduous shrub canopy of 40% would be classified as a Palustrine, Forested, broad-leaved deciduous wetland. Conversely, if the same area supported only 25% tree canopy cover the correct classification would be Palustrine, Scrub/Shrub, broad-leaved deciduous wetland. Therefore, scrub-shrub wetlands, as well as other nonforested wetland cover types, may contain sufficient numbers of trees to provide a food source for wintering mallards and merit evaluation using the forested wetland component of this model.

In cover types where mast production is not a consideration (e.g., emergent wetlands, scrub-shrub wetlands, open water), vegetative composition appears to be less important in defining the potential to provide winter food for mallards than is water regime. Therefore, nonforested cover types, other than cropland, are identified in this model following the water regime modifiers described by Cowardin et al. (1979:22).

Permanently flooded. Water covers the land surface throughout the year in all years. Vegetation is composed of obligate hydrophytes.

Intermittently exposed. Surface water is present throughout the year except in years of extreme drought.

Semipermanently flooded. Surface water persists throughout the growing season in most years. When surface water is absent, the water table is usually at or very near the land surface.

Seasonally flooded. Surface water is present for extended periods especially early in the growing season, but is absent by the end of the season in most years. When surface water is absent, the water table is often near the land surface.

Temporarily flooded. Surface water is present for brief periods during the growing season, but the water table usually lies well below the soil surface for most of the season.

Intermittently flooded. The substrate is usually exposed, but surface water is present for variable periods without detectable seasonal periodicity.

Artificially flooded. The amount and duration of flooding is controlled by means of pumps or siphons in combination with dikes and dams.

Flooding of bottomland cover types during the winter has frequently been referred to as seasonal flooding. Cowardin et al. (1979:22), however, define seasonally flooded as follows: "Surface water is present for extended periods especially early in the growing season, but is absent by the end of the season in most years." To reduce confusion in terminology, the flooding of cover types during the period between November 1 and February 28 is described here as "winter flooding."

Minimum habitat area. Minimum habitat area is defined as the minimum amount of contiguous habitat that is required before an area will be occupied by a species. The minimum size of disjunct habitat required by wintering mallards is unknown. It is assumed that if high-quality foods and foraging opportunities exist, mallards will use an area (if perhaps only on a short-term basis) regardless of its size.

Verification level. The habitat requirements and associated variables identified in this model are the result of a modeling workshop held to define characteristics that influence the quality of habitat for mallards wintering in the Lower Mississippi Valley. The model is a hypothesis of species-habitat relationships that is based on pertinent research and the experience of the workshop participants. The model can be used to identify impacts to mallard winter habitat and to identify management actions that may be used to mitigate losses in habitat quality. Workshop participants were as follows:

Dr. Leigh Fredrickson, Gaylord Memorial Laboratory, University of Missouri, Puxico, Missouri

Dr. Ken Reinecke, Wildlife Biologist (Research), U.S. Fish and Wildlife Service, Vicksburg, Mississippi

Mr. S. Ray Aycock, U.S. Fish and Wildlife Service, Jackson, Mississippi

Mr. Robert Barkley, U.S. Fish and Wildlife Service, Vicksburg, Mississippi

Mr. Bruce Bell, U.S. Fish and Wildlife Service, Atlanta, Georgia

Mr. Charles Baxter, U.S. Fish and Wildlife Service, Vicksburg, Mississippi

Dr. Chris Onuf, U.S. Fish and Wildlife Service, Slidell, Louisiana

Mr. Don Orr, U.S. Fish and Wildlife Service, Memphis, Tennessee

Mr. Robert Strader, U.S. Fish and Wildlife Service, Lafayette, Louisiana

The following individuals provided additional review of the model:

Dr. Michael J. Armbruster, U.S. Fish and Wildlife Service, Ft. Collins, Colorado

Dr. Mickey E. Heitmeyer, Department of Fisheries and Biology, University of California, Davis

Dr. Richard M. Kaminski, Department of Wildlife and Fisheries, Mississippi State University, Mississippi State

Mr. Mitch M. King, U.S. Fish and Wildlife Service, Cookeville, Tennessee

Dr. Charles Klimas, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi

Mr. David R. Parsons, U.S. Fish and Wildlife Service, Cookeville, Tennessee

Dr. Fredrick A. Reid, School of Forestry, Fisheries and Wildlife, University of Missouri, Columbia

Mr. Robert L. Willis, U.S. Fish and Wildlife Service, Cookeville, Tennessee

Model Description

Overview. The Lower Mississippi Valley provides critical winter habitat for mallards and other waterfowl. Mallards generally arrive in the northern part of the Lower Mississippi Valley by late October to mid-November. Subsequent movement into the southern portion of the Lower Mississippi Valley normally occurs during December to February. Movements and habitat use, however, are also influenced by temperature and winter flooding. Variations in general migration patterns occur when warmer winter temperatures permit the use of more northern regions. Conversely, drought or extremely cold temperatures in northern regions result in mallards using the more southern portions of the valley.

Flooding and the availability of adequate food resources are requirements for suitable mallard winter habitat. The primary benefit of winter flooding is improved foraging opportunities. In most situations, the absence of surface water within potentially suitable feeding sites renders those sites unsuitable for use by mallards, regardless of the type or amount of food resources available.

Major winter foods of mallards can be grouped into broad categories that include: (1) cultivated grain, (2) mast, (3) invertebrates, and (4) seeds of indigenous vegetation. These food resources are provided within major cover types within the Lower Mississippi Valley that were identified by workshop participants as: (1) cropland, (2) palustrine forested wetlands, and (3) non-forested palustrine, riverine, or lacustrine wetlands. The following model is organized around these cover types in order to evaluate their potential to provide adequate and available food resources for wintering mallards.

The suitability of cropland as a source of winter foods for mallards is dependent on the type of crop grown, the management practices applied to the cropland and the presence of winter flooding. Cultivated grains have become an important source of energy to wintering mallards due to the extensive loss and degradation of natural bottomland communities.

The primary food resource of wintering mallards in forested wetlands consists of the acorns produced by oak trees. The seeds and fruits of other trees and shrubs as well as invertebrates also are components of foods provided to wintering mallards within forested wetlands. The availability of mast to wintering mallards in forested wetlands is influenced by annual mast production and the duration of winter flooding.

Invertebrates and the seeds, rootlets, tubers, and leaves of herbaceous vegetation are the fundamental food resources for wintering mallards within nonforested wetland cover types. Although invertebrate production occurs in all cover types, flooding is essential for the availability of this resource to wintering mallards. Invertebrate production is assumed to generally be negatively related to water permanence. Permanently flooded wetlands are believed to support lower invetebrate diversity and abundance per unit area when compared to less permanent wetlands. Conversely, temporarily and intermittently flooded wetlands are capable of high invertebrate production in relatively short periods of time as a result of nutrient release due to alternating periods of drying and inundation. The availability and abundance of invertebrate and vegetative foods can be enhanced through active management of nonforested wetland cover types. Moist-soil management (e.g., flooding, drainage, burning, tillage) is probably most appropriate in the less permanent wetlands; however, management practices can probably be applied within any of the nonforested wetland types.

This model is based on the major assumption that available food is the key factor that influences winter density of mallards within the Lower Mississippi Valley. The availability of food is directly influenced by the flooding regime in all cover types. Permanently flooded wetlands may be most important to wintering mallards during early winter (prior to seasonal inundation of other cover types), during years of low precipitation and minimal flooding, and during cold periods when ice covers shallow wetlands. Permanently flooded wetlands, however, support lower invertebrate production, lower plant species diversity, and lower production of other food resources than wetlands subjected to fluctuations in the presence of surface water. Deep, open-water areas (e.g., reservoirs, lakes, agricultural ponds) may provide refuge during freeze-over periods in some instances, but are generally of limited value as mallard winter habitat.

<u>Food component (cropland)</u>. Cultivated grains provide a major source of energy to mallards wintering in the Lower Mississippi Valley. The suitability of grains as a winter food source is influenced by the type of crop present, cropland management, and the extent of cropland flooding.

Agricultural grains are low in protein and minerals but are generally high in digestible energy. The principal grains cultivated in the Lower Mississippi Valley vary in digestibility by mallards. For the purposes of this model, corn, rice, and milo are given relative suitability index values of 1.0, 0.6, and 0.4, respectively (Figure 2a). Although raw soybeans contain considerable protein and energy in the form of oil, they also contain chemicals that interfere with digestion; hence, they have been assigned an index value of 0.2. Cotton and other nongrain crops are assumed to have no value as a winter food source for mallards.

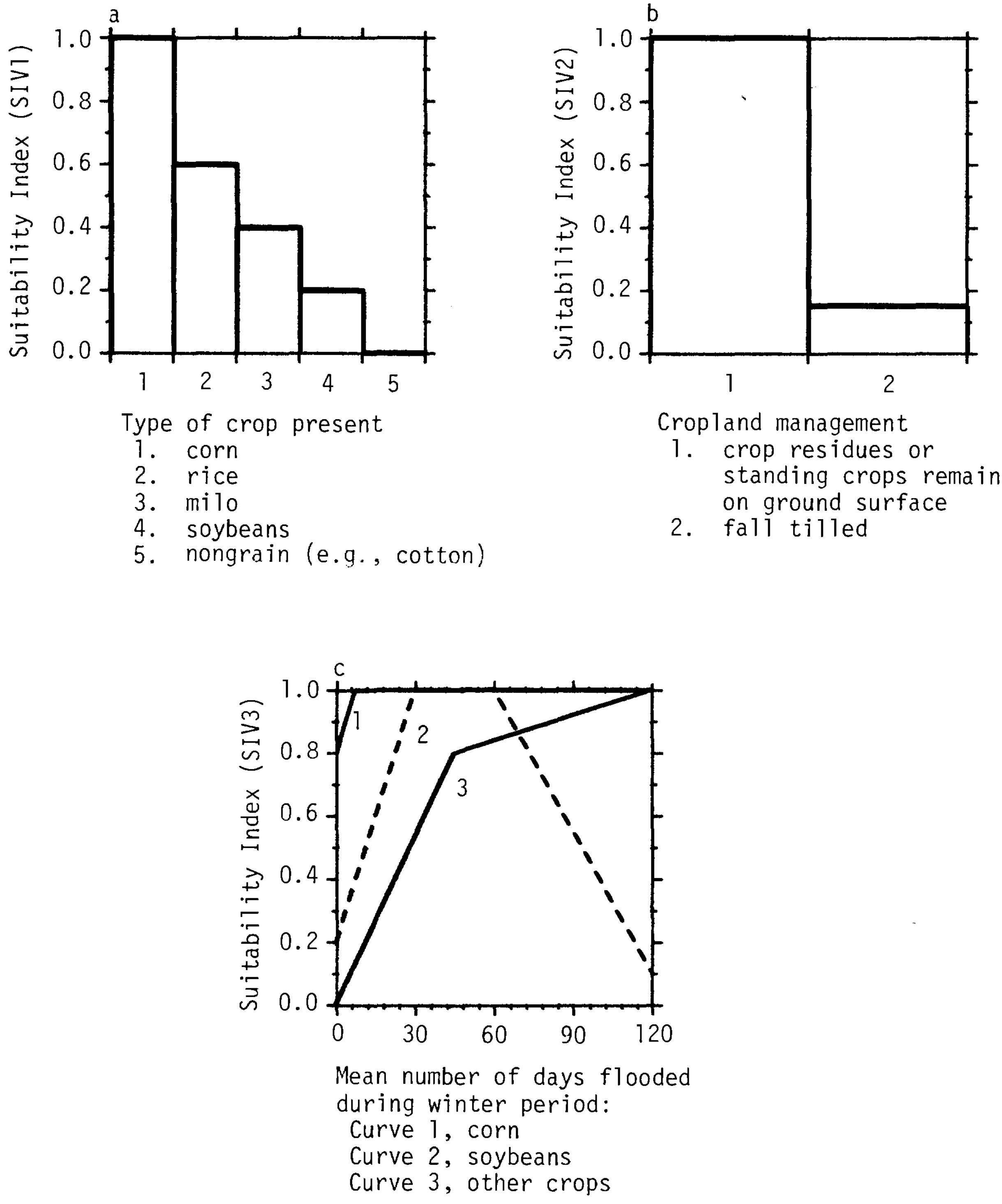


Figure 2. The relationship between habitat variables used to evaluate food availability in cropland cover types and suitability indices for the variables.

Overall availability of cultivated grain as a food source is directly influenced by the management of the cropland following harvest. Fields in which stubble remains throughout winter are assumed to provide maximum availability of waste grain as a food source for wintering mallards (Figure 2b). Conversely, fall tillage of grain fields results in a major reduction of crop residues. Workshop participants estimated that fall tillage eliminates roughly 85% of the waste grain in harvested fields. This estimate is substantiated by a study of waste grain availability and cropland management in Texas (Baldassarse et al. 1983). Discing (<20 cm deep) of corn fields reduced the total amount of waste corn present by 77% and the number of ears/ha by 79%. Waste corn in fields that were disced then deep-plowed (>30 cm deep) was reduced by 97%. This model is based on the assumption that crops will be harvested and will not remain standing throughout the winter as a food source for mallards. Based on the input from workshop participants and an average value of the reduction in waste grain as presented in Baldassarre et al. (1983), fall tillage of fields is assumed to result in an 85% reduction of waste grain availability, corresponding to a suitability index for tilled croplands of 0.15.

Seeds of weeds and residual crops unintentionally grown in croplands represent an additional, but minor, source of mallard winter food. The availability of this food source is influenced by herbicide use and cropland tillage. Due to the comparatively low abundance of this food source the availability of weed seeds is not directly evaluated in this model. However, as with waste grain, weed seeds can be assumed to be more available in non-tilled cropland than in cropland that is fall tilled.

Inundation of croplands is essential for most cultivated grains to be of maximum availability to wintering mallards. The length of time that surface water is present affects the deterioration rate of grains and their suitability for mallard consumption. Figure 2c, curve 2, presents the assumed relationships between flood duration and the suitability of soybeans as a mallard winter food source. Nonflooded soybean fields are occasionally used and are assumed to have low value (0.2) as mallard foraging habitat. Soybeans undergo relatively rapid decomposition when submerged (Wright 1959; Shearer et al. 1969). Ideal foraging conditions for wintering mallards are assumed to occur when soybean fields are flooded for 30 to 60 days during the winter. Soybean fields flooded >60 days have less food potential as a result of decreased soybean availability and quality. Fields flooded for ≥120 days are assigned the value 0.1, based on the assumption that soybean fields inundated for this length of time represent a depleted food source in terms of quality but do maintain minimum value as foraging habitat since weed seeds and invertebrates may be available.

Figure 2c presents the assumed relationships between flood duration and the suitability of corn (curve 1) and other grains (e.g., rice, milo) (curve 3) as mallard winter food. Corn, rice, and other cultivated grains exhibit lower rates of decomposition under flooded conditions than do soybeans (Shearer et al. 1969). As a result, extended periods of flooding do not cause significant decreases in food quality for these grains. Corn is assumed to have relatively high value as potential food for mallards under nonflooded conditions (Figure 2c, curve 1). Optimum conditions exist, however, only when corn fields are flooded for ≥7 days. Apparently, mallards are unable to successfully feed on rice unless they can filter it from shallow water (Delnicki and Reinecke 1986). Therefore, rice and other cultivated grains are assumed to have value as a winter food source for mallards only when inundated (Figure 2c, curve 3). The value of rice and other grains is assumed to increase as the length of inundation increases. Fields flooded for 45 days are assumed to represent a relatively high value (0.8) based on the increased availability of foraging opportunities. Fields flooded for the entire winter period represent ideal (1.0) foraging conditions because of maximum accessibility to grain.

The indices calculated using the curves presented in Figure 2 are combined in equation 1 to determine the cropland food suitability index (SICF) for mallards wintering in the Lower Mississippi Valley.

$$SICF = SIV1 \times SIV2 \times SIV3 \quad (1)$$

Equation 1 is based on the following assumptions. Winter cropland food suitability is a result of the type of crop present (SIV1), availability of grain (SIV2), and the average number of days flooded during the winter period (SIV3). A zero value for SIV1 or SIV3 indicates that a field has no food value for wintering mallards.

Food component (palustrine forested wetlands). Bottomland forested sites provide a diversity of mallard winter foods, including mast, seeds of other native vegetation, and invertebrates. The availability of all food resources to foraging mallards is influenced by the duration of winter flooding.

Mast used by mallards in bottomland forests includes the acorns produced by oak trees, especially pin oak, Nuttall oak (*Q. nuttallii*), white oak (*Q. alba*), willow oak, water oak (*Q. nigra*), and southern red oak. These species have not been listed in order of mallard preference, and the acorns of other oaks may be consumed when available. The seeds and fruits of other tree and shrub species are also used, but are not as important as acorns as a winter food source. For the purposes of this model, the term mast refers to acorns. The abundance of other fruits and seeds is not directly addressed.

Leaf litter derived from oak trees is important for the sustained production of invertebrates in bottomland communities because it supplies a rich nutrient source with a slow rate of decomposition (White 1982). Sites with large amounts of litter are assumed to produce a greater abundance and diversity of invertebrates than are present in cover types devoid of significant amounts of detritus.

Figure 3 presents the assumed relationships between specific characteristics of winter-flooded bottomland forest and food availability for wintering mallards in the Lower Mississippi Valley. The variables used to evaluate food suitability in winter-flooded bottomland hardwoods are assumed to reflect the availability of mast and provide an indirect measure of the presence of supplemental foods such as invertebrates and seeds from understory vegetation.

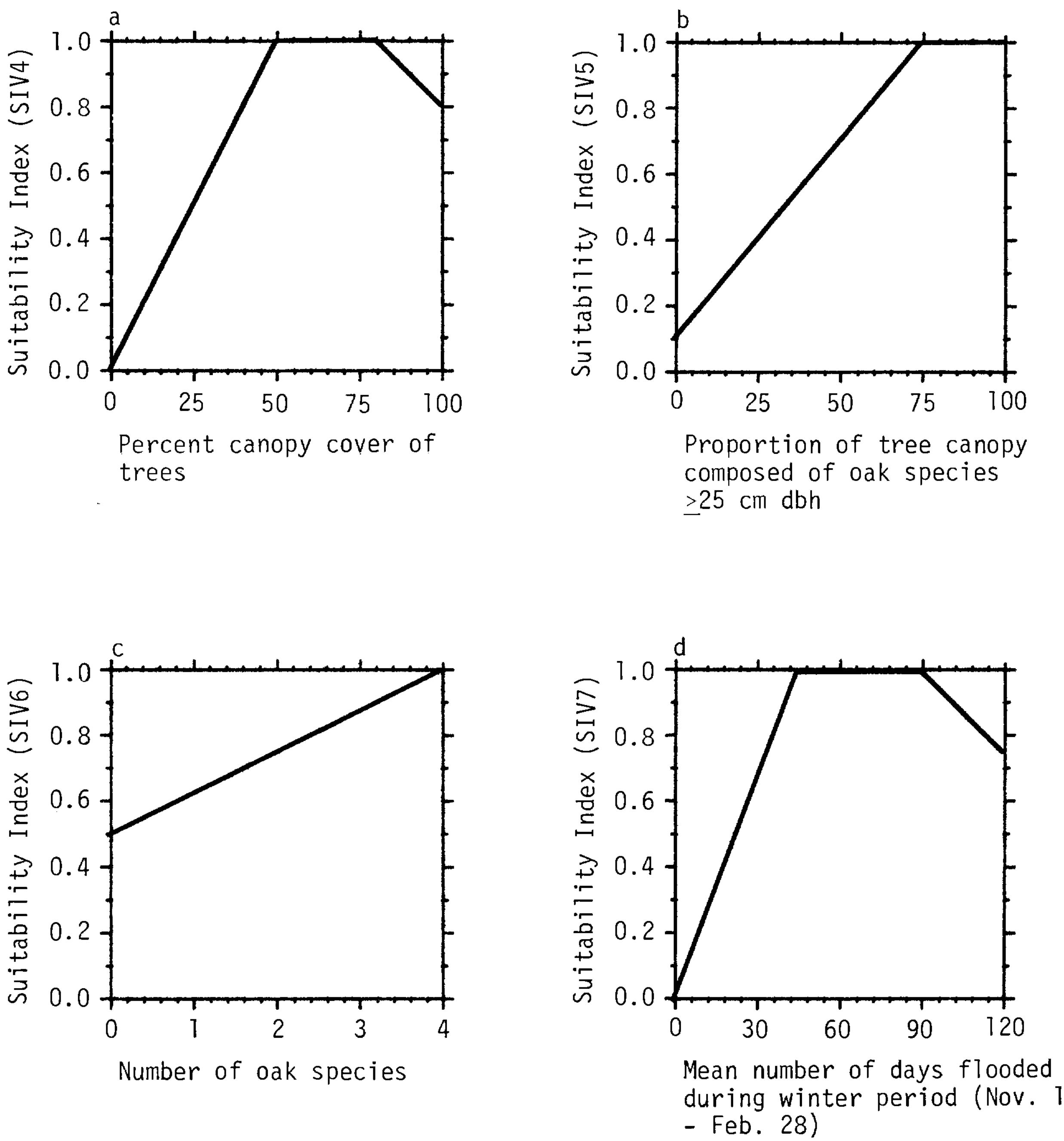


Figure 3. The relationships between habitat variables used to evaluate food availability in palustrine forested wetlands and suitability indices for the variables.

Figure 3a displays the assumed relationship between total tree canopy closure and its suitability. Ideal conditions are believed to exist when tree (woody vegetation >6 m tall) canopy cover is between 50% and 80%. The abundance of understory vegetation (i.e., herbaceous vegetation and shrubs) that provide foods for mallards is assumed to be a function of overstory density. The production of understory vegetation is assumed to vary inversely with overstory tree canopy cover. Dense canopies are believed to intercept sunlight, resulting in minimal production of understory vegetation. Tree canopy cover >80% is assumed to result in lower diversity and abundance of understory vegetation. Stands with totally closed canopies, however, are assumed to be of value to wintering mallards, particularly if the overstory is dominated by oaks, due to their potential to provide mast or other seeds and fruit, as well as invertebrates.

Overall oak mast production in a forest stand is a function of species diversity, tree age, and position in the tree canopy. Large dominant and codominant trees with exposed, sunlit crowns can be expected to produce larger amounts of mast than will small, or overtopped, suppressed trees (Spurr and Barnes 1980). For the purposes of this model it is assumed that oak trees ≥25 cm dbh are of sufficient age and size to produce significant amounts of mast. Figure 3b displays the assumed relationship between the percent of the tree canopy composed of oak species ≥25 cm dbh and mast production. Stands of bottomland forests devoid of oak trees in this size class are assumed to have minimal food potential for wintering mallards and receive a low suitability index (0.1). A minimum value has been assigned for stands lacking large oaks, based on the assumption that other tree genera and small oaks will provide at least small amounts of seeds. Maximum mast production is assumed to occur when ≥75% of the canopy is composed of trees ≥25 cm dbh. However, depending upon site conditions (e.g., climate, soils, moisture, nutrients), oaks in smaller size classes may produce abundant seed crops. Therefore, users of this model may desire to modify the size class constraint in Figure 3b to more accurately reflect local conditions. Due to the large size of acorns produced by overcup oak (Q. lyrata), the seeds of this species are generally unsuitable for mallards and should be excluded from consideration of index values for percent of tree canopy composed of oak species ≥25 cm dbh (Figure 3b).

Ideally, a variety of mast-producing species should be present in order to minimize the effects of mast failure or low mast production by individual species (Nixon et al. 1975). Because the time of flowering varies by species, adverse weather that limits acorn formation would most likely not affect all oak species (Spurr and Barnes 1980). Thus, total failure of mast production in a stand that contains several species of oaks is unlikely. Stands are assumed to have greater food potential for wintering mallards as the number of oak species present increases (Figure 3c). Stands devoid of oaks are assumed to have some food potential, since other genera of trees produce seeds that can be consumed by mallards. The value of such stands is assumed to be half the value of stands containing a high diversity of mast-producing species. On a long-term basis, stands with ≥4 species of oaks present are assumed to provide more stable mast production than do stands with <4 oak species present. As before, overcup oak should be excluded from consideration in the calculation of index values for number of oak species present (Figure 3c).

The major factor contributing to the productivity of bottomland hardwoods is the alternation of dry and flooded conditions (Brinson et al. 1980; Wharton et al. 1982). Decomposition of litter frees nutrients and is enhanced by alternating wet and dry conditions. Sites that are permanently flooded or have more stable water regimes are less productive than bottomland hardwoods subjected to alternating flooded and dry conditions. Winter flooding directly influences the availability of food and foraging conditions for wintering mallards. Mallards prefer to forage on inundated acorns (Wharton et al. 1982) and are more efficient in obtaining mast and invertebrates under flooded conditions (White 1982). Terrestrial invertebrates and seeds of understory vegetation become more accessible to foraging mallards during initial periods of flooding. The availability of aquatic and semiaquatic invertebrates increases with flood duration, and these foods eventually replace terrestrial invertebrates as the primary prey group. Bottomland hardwoods that are not flooded are assumed to be unsuitable foraging sites for wintering mallards (Figure 3d). The suitability of winter-flooded bottomland hardwoods is assumed to increase as the average number of days flooded during the winter period increases because of prolonged accessibility of seed and mast foods, as well as increases in invertebrate production. Optimum foraging conditions are assumed to exist when sites are flooded for a period of 45 to 90 days. Flooding in excess of 90 days is assumed to reflect lower food suitability due to less dynamic habitat conditions, possibly resulting in lower nutrient availability, lower invertebrate production, and fewer ideal foraging opportunities (i.e., fluctuating land/water interface).

The indices calculated using the curves presented in Figure 3 are combined in equation 2 to determine the suitability index for forested wetlands (SIFW).

$$SIFW = [(SIV4 \times SIV5) \times SIV6]^{1/2} \times SIV7 \qquad (2)$$

Equation 2 is based on the following assumptions. Sites with 50% to 80% tree canopy cover represent optimum stand density (SIV4). The value of canopy density is directly modified by the index used to represent the abundance of oak species (SIV5). The diversity of oak species (SIV6) present directly modifies the value representative of total tree canopy closure and the proportion of the canopy composed of oak species. A low diversity of oak species will be compensated for if these trees compose a large proportion of the total tree canopy. Conversely, a relatively low abundance of oaks in the overstory will be compensated for if these trees are of several species. The average number of days flooded during the winter period (SIV7) is used to modify the food value determined for the stand. Bottomland hardwoods that are not flooded will represent unsuitable foraging sites for wintering mallards regardless of the density of trees or abundance and diversity of oak species.

<u>Food component (all lacustrine, riverine, and palustrine classes except forested)</u>. Nonforested wetlands provide invertebrate and vegetative foods for wintering mallards. This model is based on the assumption that on a long term basis nonforested wetlands managed specifically for waterfowl use have a

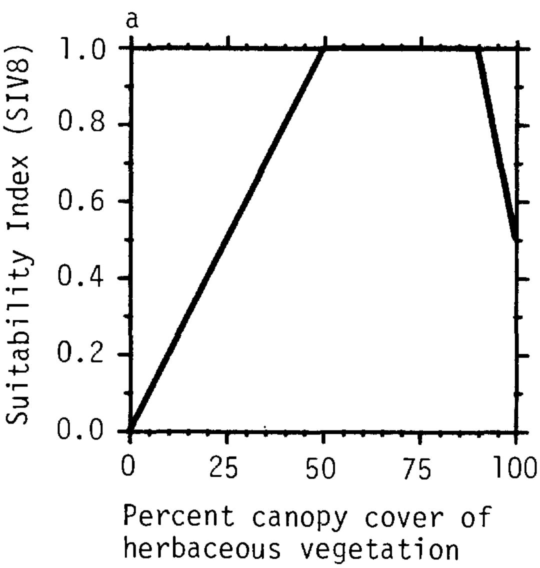
greater probability of meeting the winter food requirements of mallards than do wetlands subject to uncontrolled fluctuations in water level. Wetlands that are not managed for winter waterfowl use may not provide preferred or accessible food resources during the time period corresponding to maximum use by wintering mallards. The following section documents the assumed relationships between nonmanaged and managed nonforested wetlands and habitat quality for wintering mallards.

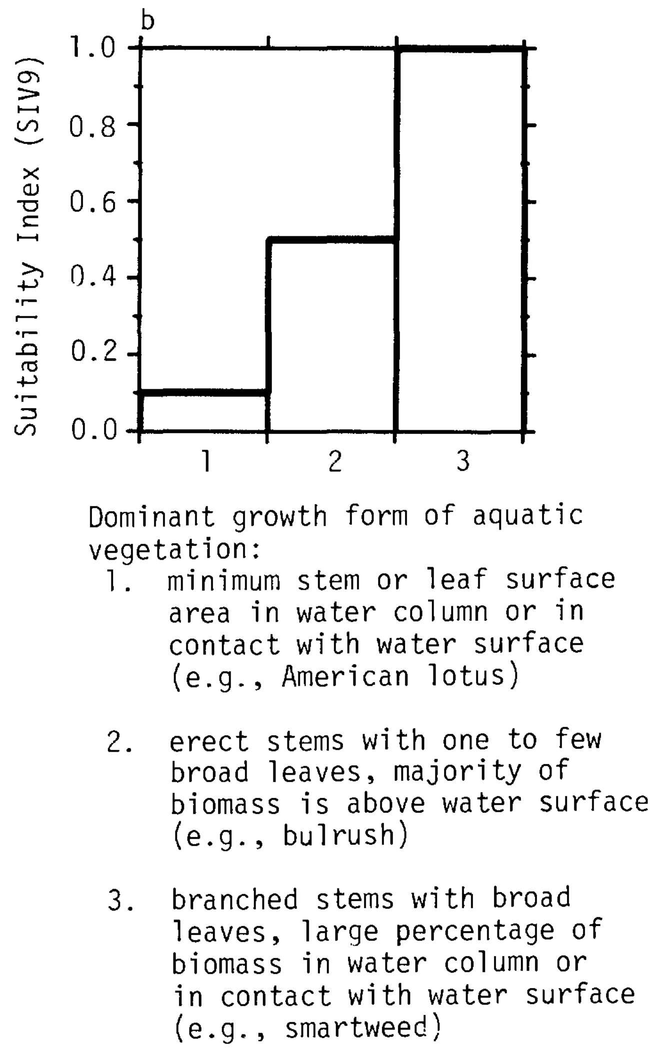
Management of wetlands specifically for wildlife has been characterized by Fredrickson and Taylor (1982) as "moist-soil" management. Moist-soil management offers opportunities to attract and hold waterfowl by providing high quality food and cover as a result of controlled changes in water levels and production of preferred stages of succession within both man-made and natural wetlands. Management actions may be directed toward: (1) enhancement of desirable seed producing vegetation [e.g., millet (e.g., Panicum spp., Echenochloa spp., Setaria spp.), crabgrass (Digitaria spp.), smartweed (Polygonum spp.)]; (2) increased availability of tuber-producing plants (e.g., arrowhead (Sagittaria spp.), bulrush (Scirpus spp.,); and (3) control or elimination of woody and undesirable herbaceous vegetation. Factors that influence vegetation and faunal responses to moist-soil management include: timing and duration of drawdown and inundation, existing vegetative associations, season, weather, and geographic location. Therefore, this model does not address specific techniques for enhancement of nonforested wetlands as mallard winter habitat. Definition of goals and refinement of moist-soil management techniques intended to maximize winter habitat for mallards are the responsibility of local biologists and managers and cannot be addressed in this model due to the wide range of options available.

Determination of the value of nonforested palustrine, lacustrine, and riverine wetlands as a source of food for wintering mallards is, however, based on the assumption that managed wetlands have the greatest potential to provide required resources when compared to nonmanaged wetlands. Moist-soil management within natural or constructed impoundments through manipulation of water level, burning, tillage, or desiccation can increase the production and availability of plant and animal foods that contribute to meeting the winter food requirements of mallards. Conversely, nonmanaged wetlands are less likely, on a long-term basis, to produce preferred or abundant and accessible winter foods because of variability in water regime and undesirable seral stages of wetland vegetation.

Nonforested wetlands that contain a high percentage of herbaceous vegetation are assumed to provide plant and invertebrate foods for wintering mallards. Food potential is assumed to increase as density of herbaceous vegetation increases to 50% canopy cover (Figure 4a). Maximum food production and availability is assumed to occur when the canopy cover of herbaceous vegetation ranges from 50% to 90%. Vegetation density >90% is assumed to reflect reduced foraging conditions due to less accessibility to foods.

Food availability within nonforested wetlands also is assumed to be a function of the structural and species composition of herbaceous vegetation. Aquatic invertebrate occurrence and density are influenced by food conditions, water chemistry, and hydrophyte structure (Reid 1983, 1985). Invertebrate





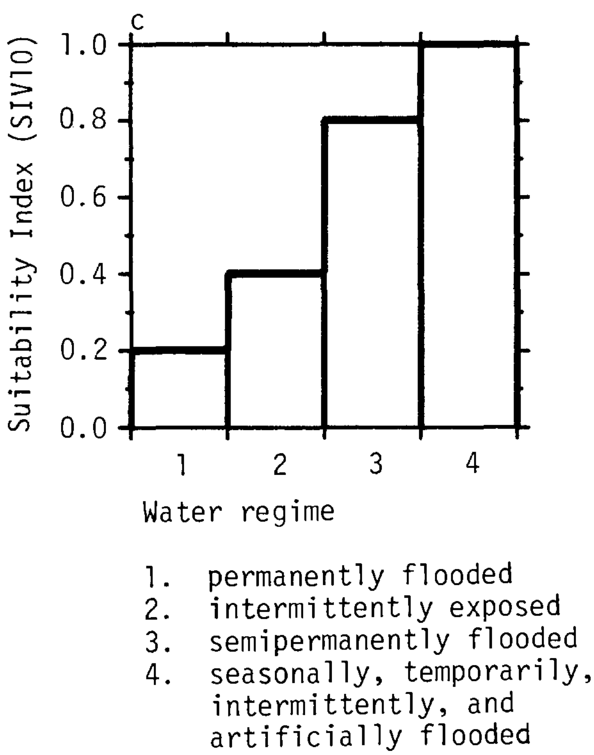


Figure 4. The relationships between habitat variables used to evaluate food availability in nonforested palustrine, lacustrine, and riverine wetlands and the suitability indices for the variables.

abundance has been directly related to hydrophyte structure and surface area. Peak invertebrate densities occurred in association with water smartweed (P. coccineum) and rice cutgrass in Missouri. These plants have relatively large leaf and stem surface areas that provide a large detrital food base for invertebrate production. In contrast, American lotus (Nelumbo lutea), which is associated with deeper portions of basins or basins flooded on a long-term basis, has little stem and leaf area and consistently supports invertebrate fauna of low diversity and density (Reid 1983; Wylie 1985). Vegetation with minimal leaf and stem surface area in the water column or in contact with the water surface is assumed to support low invertebrate production (Figure 4b). A growth form with high leaf and stem surface area is assumed to provide more substrate and nutrients, and, therefore, greater invertebrate production.

Species composition of herbaceous vegetation in nonforested wetlands is not directly addressed in this model due to the wide variety of possibilities throughout the Lower Mississippi Valley. It is assumed, however, that moist-soil management intended for enhancement of food conditions for wintering mallards will reflect beneficial changes in vegetative growth form (Figure 4b) as well as species composition of vegetation.

As a result of variation in water levels, seasonally, temporarily, intermittently, and artificially flooded wetlands support a greater diversity and abundance of herbaceous vegetation, contain higher nutrient levels, and have greater invertebrate productivity than do permanently flooded, intermittently exposed, and semipermanently flooded wetlands. The continous or near continuous presence of surface water in these latter wetlands results in: (1) lower levels of nutrients and invertebrate productivity; (2) a shift toward more water-tolerant vegetation, which generally has lower value as foods for wintering mallards; and (3) lower vegetative density and diversity than in less permanent wetlands (White 1982; Heitmeyer 1985; Wylie 1985). Permanently flooded and intermittently exposed wetlands, however, provide important habitat for mallards early in the winter season, during freeze-over periods, and during years of below normal precipitation. Figure 4c illustrates the assumed relationships between water regime in nonforested palustrine, lacustrine, and riverine wetlands and suitability index values that reflect food availability for wintering mallards.

In terms of winter waterfowl use, nonforested wetlands ideally should have shallow surface water present during the winter period in order to maximize food availability and foraging opportunities. Nonforested wetlands that do not have surface water present during the winter period are assumed to provide unsuitable foraging opportunities and represent unsatisfactory conditions for wintering mallards (Figure 5). Food availability and foraging conditions are assumed to improve as the number of days with surface water present increases. Optimum conditions are assumed to occur when nonforested wetlands contain surface water for ≥75% (90 days) of the winter period.

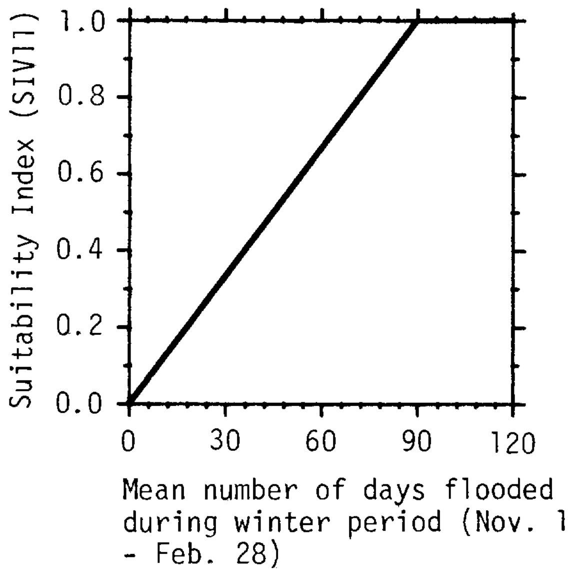


Figure 5. The relationship between mean number of days flooded during the winter period in nonforested wetlands and habitat suitability for wintering mallards.

The relationships described above have been combined in equation 3 to determine a nonforested wetland food index (SINFW).

$$SINFW = [(SIV8 \times SIV9)^{1/2} \times SIV10] \times SIV11 \qquad (3)$$

Equation 3 is based on the following assumptions. The density of herbaceous vegetation (SIV8) is assumed to be compensatory with its growth form (SIV9). A high density of aquatic vegetation will be low value if its growth form has minimum stem and leaf surface area in contact with the water. Maximum food production is assumed to occur when 50% to 90% of the wetland supports herbaceous vegetation with growth forms that provide a large stem/leaf surface area in contact with the water column. The index value resulting from the combination of SIV8 and SIV9 is directly modified by the water regime (SIV10) of nonforested wetlands. Permanently flooded wetlands are assumed to support an invertebrate fauna with relatively low density and diversity when compared to that of the more ephemeral wetland types. As a result of variation in water levels and higher nutrient levels, invertebrate productivity is assumed to increase as water permanence decreases. Maximum invertebrate and vegetative production is assumed to occur in seasonally, temporarily, intermittently, and artifically flooded wetlands. Realistically, there are probably differences in invertebrate production between these latter water regimes. However, the precise differences in productivity are unknown and are not addressed in this model. The mean number of days flooded during the winter period (SIV11) is used to modify the value resulting from evaluation of the vegetative and water regime characteristics of nonforested wetlands. The presence of naturally occurring or induced surface water within nonforested wetlands during the winter period is assumed to ensure food availability and foraging opportunities for wintering mallards.

Composition component. In order to support greater numbers, wintering habitat for mallards requires a diversity of cover types within relatively close proximity, which provides a diverse winter food source and minimizes mallard energy expenditures. The precise mix of cover types required to provide optimum winter habitat is unknown. This model is based on the assumption that at least minimum amounts of palustrine forested wetlands, cropland, and nonforested palustrine, lacustrine, or riverine wetlands must be present within an evaluation area for optimum conditions to exist. It is assumed that ≥10% of an evaluation area must be composed of grain-producing croplands, ≥40% or more of the area must be in winter-flooded bottomland forest, ≥10% of the area must be composed of nonforested wetlands. Each of these major cover types has been assigned a suitability index for habitat composition (SIHC) that is assumed to reflect its relative importance in defining habitat quality for mallards wintering in the Lower Mississippi Valley (Table 1).

Table 1. Determination of a habitat composition index for mallards wintering in the Lower Mississippi Valley.

Cover type		Recommended minimum % composition of cover type	Habitat[a] composition index
Cropland		≥10	0.17
Palustrine forested wetlands		≥40	0.67
Nonforested palustrine, lacustrine, and riverine wetlands		≥10	0.16
	Totals	60	1.00

[a]Individual SIHC values are determined by dividing the minimum composition value for each cover type by the total combined % minimum composition value for all required cover types, e.g., cropland index = (10/60) = 0.17.

The index values presented in Table 1 are based on the following assumptions. It is assumed that all three major cover types must be present within an evaluation area in order to provide optimum food diversity and availability for wintering mallards. Each major cover type may account for a larger percentage of the evaluation area and will not detract from the composition value until one of the other cover types is decreased in area. For example, optimum habitat composition may be present when cropland accounts for 10% to 50% of an evaluation area. If cropland composition exceeds 50%, the area in some other cover type is decreased, resulting in less than optimum habitat composition. The habitat composition index values are independent of food index values calculated for each respective cover type. For example, cropland composition may be ideal (i.e., ≥10% and ≤50% composition); however, if unsuitable crops are present, the cropland food index value is 0.0 regardless of the amount of cropland present.

In evaluation areas where one or more of the required cover types are absent or present at less than optimum composition, a less than optimum SIHC value will be calculated and used to reflect lower habitat quality. The SIHC for areas with less than optimum habitat composition is calculated as follows.

1. Identify which cover type(s) is present at below optimum composition.

2. Divide the actual percent composition for each identified major cover type by the total of minimum percent composition required (60) for all cover type(s) identified in Table 1.

3. Replace the SIHC value (Table 1, column 2) for the appropriate cover type(s) with the modified value(s) determined in step 2. The sum of the index values for all cover types provides the final habitat composition index (SIHC). An example recalculation of the SIHC value is provided in Table 2.

HSI determination. The presence of surface water is a major influence on winter habitat quality for mallards in the Lower Mississippi Valley. All elevations, or flooding zones, within the Mississippi's floodplain probably have at least some potential to provide suitable flooded feeding sites on a long-term basis. Areas of comparatively high elevation within the floodplain that are subject to less frequent flooding, however, provide lower habitat suitability regardless of the food resources present. Conversely, low elevation areas inundated by the average winter flood represent sites with the greatest potential to provide suitable food conditions on a long-term basis. This model is based on the assumption that areas flooded frequently represent the most critical sites for mallards wintering in the Lower Mississippi Valley.

Table 2. Example calculation of a habitat composition index (SIHC) value. Determination of the actual percent composition of cover types reveals that 5% of the area is dominated by forested wetland, 5% is dominated by nonforested wetland, and 90% is dominated by cropland. Calculation of the actual habitat composition index is determined by dividing the actual percent composition of each cover type by the percent minimum composition value (60) for those cover types that are present at below recommended minimum composition only. For example, the habitat composition index for forested wetlands (0.05/0.60) is 0.08. Cover types that are present at above recommended composition are assigned the optimal habitat composition index value. This value does not increase with greater area of the cover type. For example, the maximum value that can be assigned to cropland is 0.17, even though the cover type accounts for 90% of the area. The sum of the actual habitat composition index values yields the SIHC value. In this scenario, the SIHC = 0.33, chiefly due to the scarcity of forested wetlands.

Cover type		Recommended minimum % composition of cover type	Optimal habitat composition index	Actual % composition of cover type	Actual habitat composition index
Cropland		≥10	0.17	90	0.17
Palustrine forested wetland		≥40	0.67	5	0.08
Nonforested palustrine, lacustrine, or riverine wetland		≥10	0.16	5	0.08
	Totals	60	1.00	100	0.33

The following steps are recommended for determination of an HSI value.

1. Determine the study area boundary on the basis of an average winter flood, 2-year winter flood, or other appropriate hydrologic event.

2. Stratify the study area into the following cover types as appropriate: cropland, forested wetlands, and nonforested wetlands. Determine the percentage of the study area composed of each of these major cover types.

3. Calculate a food index value for each cover type by applying the appropriate food index equations: cropland, equation 1; forested wetlands, equation 2; nonforested wetlands, equation 3.

4. Calculate a weighted (by area) food index for the study area by multiplying each cover type food index (step 3) by its respective percentage of area (step 2) within the flood zone. Sum these values.

   In some situations it may be necessary to calculate a weighted food value for an individual cover type. For example, the cropland cover type may be composed of rice, soybean, and nongrain fields that each have different values as winter food for mallards. The following steps are recommended for determination of a weighted (by area) food index for a major cover type.

   A. Stratify the major cover type (e.g., cropland) into its component cover types (e.g., rice, soybeans, nongrain). Determine the total cropland area and the percentage of the cropland area composed of each cropland type.

   B. Calculate a food index for each cropland type by applying equation 1.

   C. Multiply the food index value (step B) for each cropland type by its respective percentage of the total cropland area (step A). Sum these values to obtain a single weighted food value for the cover type.

5. Determine the percentage of the study area composed of cropland, forested wetland, and nonforested wetland (step 2). If cropland accounts for ≥10%, forested wetlands ≥40%, and nonforested wetland ≥10% the HSI equals the value calculated in step 4.

   If one or more required cover types are absent, or present at less than optimum composition (Table 1), the weighted index food value should be modified by the habitat composition index (SIHC). The weighted food life requisite value (step 4) multiplied by the SIHC equals the HSI value for the evaluation area.

Information pertaining to the exact amount and interspersion of each major cover type required to support the maximum number of wintering mallards was not located in the literature. Therefore, the habitat composition component is the least documented element of this model. The habitat composition values presented in the model represent the best estimates of workshop participants and reviewers of the relative amount of each major cover type required to provide optimum winter habitat in the Lower Mississippi Valley.

Conservatively, mallards may forage up to 8 km from a roost site. A circle with a radius of 8 km contains 201 km^2 (77.6 mi^2). The logistical difficulties of mapping and evaluating cover types and land use in such a large and potentially undefinable area (depending on actual movement of mallards to suitable foraging areas) and their influences on mallard winter habitat quality in bottomland habitats is beyond the scope and capability of this model. However, the habitat composition component is probably most accurate when applied to large areas (i.e., area contained within foraging radius) due to the mallards' mobility and ability to locate and utilize distant food resources. As previously indicated, recommended application of this HSI model is restricted to a specific area that is defined by flooding frequency. Because habitat composition and quality in geographic areas outside of the evaluation site may influence its suitability to support wintering mallards model output may yield an artificially low HSI in relation to the sites' actual potential to support wintering mallards.

This model is based on the assumption that optimum winter habitat for mallards in the Lower Mississippi Valley requires the presence of at least minimal amounts of forested wetlands, cropland, and nonforested wetlands. The model does not address the implications of changes in, or trade offs between, cover types in terms of U.S. Fish and Wildlife Service Mitigation Policy (Federal Register 1981). Decision factors and constraints in terms of cover type scarcity, replaceability, and value are the responsibility of the model user.

Application of the Model

Summary of model variables and equations. A number of habitat variables and equations are used in this model to evaluate food availability within specific cover types for mallards wintering in the Lower Mississippi Valley. Figure 6 presents a summary of the equations used to calculate food and composition values. The relationships between habitat variables, life requisite values, and the HSI for mallard winter habitat are summarized in Figure 7. Habitat variable definitions and suggested measurement techniques (Hays et al. 1981) for the variables are provided in Figure 8.

Food component	Equation	Page
Cropland food index	(1) $SICF = SIV1 \times SIV2 \times SIV3$	16
Forested wetland food index	(2) $SIFW = [(SIV4 \times SIV5) \times SIV6]^{1/2} \times SIV7$	19
Nonforested wetland food index	(3) $SINFW = [(SIV8 \times SIV9)^{1/2} \times SIV10] \times SIV11$	23
Habitat composition component		
Habitat composition index (SIHC)	SIHC is derived from Table 1	24

Figure 6. Summary of equations used in the mallard winter habitat HSI model. Equations are explained on the pages indicated.

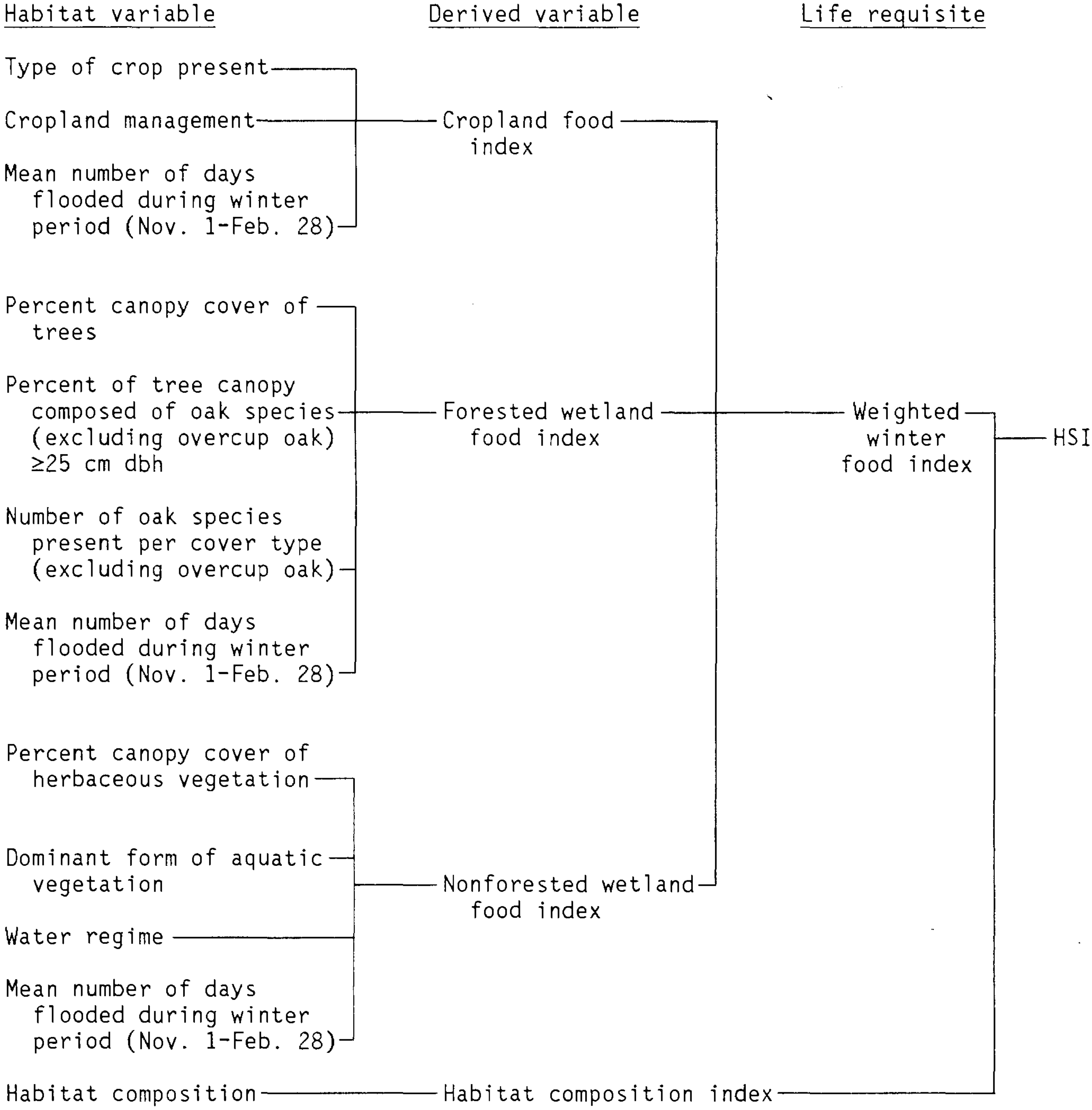


Figure 7. The relationships between habitat variables, derived variables, life requisite, and an HSI for mallard winter habitat in the Lower Mississippi Valley.

Variable (definition)	Cover types	Suggested techniques
Type of crop present (the present or last crop grown): 1. corn 2. rice 3. milo 4. soybeans 5. cotton (or other nongrain crops).	C	Remote sensing, on-site inspection, interview with Soil Conservation Service District personnel
Cropland management (an evaluation of winter availability of agricultural crops based on the application or absence of tillage subsequent to crop harvest).	C	Remote sensing, on-site inspection interview with Soil Conservation Service District personnel
Mean number of days flooded during winter period (an estimation of the number of days that a cover type is covered by surface water between the dates of November 1 to February 28).	P,R,L,C	Data from U.S. Army Corps of Engineers hydrologist, interview with Soil Conservation Service District personnel (cropland)
Percent canopy cover of trees [the percent of the ground surface that is shaded by a vertical projection of the canopies of all woody vegetation ≥6.0 m (20 ft)].	P,R,L	Remote sensing, line intercept, ocular estimate in circular plot

Figure 8. Definitions of variables and suggested measurement techniques.

Variable (definition)	Cover types	Suggested techniques
Percent of tree canopy composed of oak species ≥25 cm dbh [the canopy closure of oak trees ≥25 cm (10 inches) diameter at breast height (1.4 m/4.5 ft above ground). For the purposes of the mallard model, overcup oak should be excluded from this calculation due to the large size of acorns produced by this species].	P,R,L,	Remote sensing, line intercept, ocular estimate in circular plot
Number of oak species present per cover type (the number of individual oak species that are present with ≥1% canopy cover encountered within each cover type. For the purposes of the mallard model, overcup oak should be exluded from this calculation due to the large size of the acorns produced by this species).	P,R,L	Remote sensing, line intercept, ocular estimate in circular plot
Percent canopy cover of herbaceous vegetation (the percent of the ground, or substrate surface that is shaded by a vertical projection of all nonwoody vegetation).	Nonforested P,R,L	Line intercept, quadat

Figure 8. (Continued)

Variable (definition)	Cover types	Suggested techniques
Dominant form of aquatic vegetation [an estimate of the dominant growth (≥50% of total cover) form evaluated individually for submerged, floating, and emergent vegetation].	Nonforested P,R,L	On-site inspection, line intercept, quadrat
1. Vegetation characterized by minimum stem or leaf surface area in water column or in contact with water surface.		
2. Vegetation characterized by erect stems with one to few broad leaves, majority of biomass is typically above water surface.		
3. Vegetation characterized by branched stems with broad leaves, large percentage of plant biomass in water column or in contact with water surface.		
Water regime [the permanence of water in a wetland defined by Cowardin et al. 1979. See page 10 for definitions].	Nonforested P,R,L	National Wetland Inventory Program maps, remote sensing on-site inspection

Figure 8. (Concluded)

Model assumptions. In addition to those discussed in the previous text, the mallard winter habitat model is based upon the following major assumptions.

1. The quality and availability of food is the most influential characteristic that defines winter habitat suitability for mallards in the Lower Mississippi Valley.

2. Optimum food conditions can exist only if cultivated grains, acorn mast, and invertebrates are present within the evaluation area. If one or more of these food components are absent or unavailable, winter food conditions are assumed to be less than optimum.

3. Sites that are subjected to frequent flooding represent potentially optimum habitat. Areas that flood with less frequency may actually produce more food, but because of the infrequency of flooding are unavailable as suitable foraging habitat on a long-term basis.

4. Specific techniques of moist-soil management are not described in this model. It is assumed, however, that management, in terms of manipulation of surface water and vegetative composition, can increase the abundance and quality of food for wintering mallards where winter flooding and the abundance or quality of foods are less than ideal.

5. Optimum habitat composition is assumed to provide suitable distribution of foraging habitats, food diversity, and cover availability.

Limitations of the model. The current winter habitat model has the following major limitations.

1. The model addresses habitat quality and composition only within a specified evaluation area. The availability of food resources outside of the evaluation area are not addressed.

2. Best estimates of workshop participants were used to formulate values that define habitat composition (Table 1). Actual data to define optimum cover type composition are not presently available.

3. The model does not address a minimum area required for a specific cover type, or complex of cover types, necessary before they are suitable for winter use by mallards.

4. The current model addresses winter flooding resulting from headwater and backwater flooding. The availability of isolated wetlands in small basins and depressions is not addressed. These small wetlands, however, are a highly important component of winter habitat.

5. The model does not address water quality (e.g., turbidity, contaminants) or its influence on wetland productivity and habitat suitability for wintering mallards.

6. The model does not address the influence of disturbance on habitat quality for wintering mallards.

7. The model does not consider the presence and abundance of loafing sites, specific cover composition required for pair formation, or security cover within assumed important cover types.

8. Model output has not been tested against measures or estimates of actual habitat use by wintering mallards.

SOURCES OF OTHER MODELS

No other habitat models for the evaluation of mallard winter habitat were located in the literature.

REFERENCES

Anderson, M.G., and B.D. Batt. 1983. Workshop on the ecology of wintering waterfowl. Wildl. Soc. Bull. 11(1):22-24.

Baldassarre, G.A., R.J. Whyte, E.E. Quinlan, and E.G. Bolen. 1983. Dynamics and quality of waste corn available to postbreeding waterfowl in Texas. Wildl. Soc. Bull. 11(1):25-31.

Baldwin, W.P. 1968. Impoundments for waterfowl on South Atlantic and Gulf coastal marshes. Pages 127-133 in J.D. Newsom, ed. Proc. of the Marsh and Estuary Management Symp. Louisiana State University, Baton Rouge.

Bartonek, J.C., R.J. Blohm, R.K. Brace, F.D. Caswell, K.E. Gamble, H.W. Miller, R.S. Pospahala, and M.P. Smith. 1984. Status and needs of the mallard. Trans. N. Am. Wildl. Nat. Resour. Conf. 49:501-518.

Batema, D.L., G.S. Henderson, and L.H. Fredrickson. 1985. Wetland invertebrate distribution in bottomland hardwoods as influenced by forest type and flooding regime. Pages 196-202 in Proc. Fifth Annu. Hardwood Conf. University of Illinois, Urbana.

Bellrose, F.C. 1976. Ducks, geese, and swans of North America. Stackpole Books, Harrisburg, PA. 543 pp.

Black, A. 1984. Water relations of Quercus palustris: field measurements on an experimentally flooded stand. Oecologia 64:14-20.

Brinson, M.M., H.D. Bradshaw, R.N. Holmes, and J.B. Elkins, Jr. 1980. Litterfall, stemflow, and throughfall nutrient fluxes in an alluvial swamp forest. Ecology 61(4):827-835.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish Wildl. Serv., FWS/OBS-79/31. 131 pp.

Delnicki, D., and K.J. Reinecke. 1986. Mid-winter food use and body weights of mallards and wood ducks in Mississippi. J. Wildl. Manage. 50(1):43-51.

Federal Register. 1981. U.S. Fish and Wildlife Service Mitigation Policy; Notice of Final Policy. 46(15):7644-7663.

Fredrickson, L.H. 1979. Floral and faunal changes in lowland hardwood forests in Missouri resulting from channelization, drainage, and impoundment. U.S. Fish Wildl. Serv. FWS/OBS-78/91. 130 pp.

_____________. 1980. Management of lowland hardwood wetlands for wildlife: problems and potential. Trans. N. Am. Wildl. Nat. Resour. Conf. 45:376-386.

Fredrickson, L.H., and R.D. Drobney. 1979. Habitat utilization by post-breeding waterfowl. Pages 119-131 in T.A. Bookhout, ed. Waterfowl and wetlands - an integrated review. LaCrosse Printing Co., Inc., LaCrosse, WI.

Fredrickson, L.H., and T.S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish Wildl. Serv. Resour. Publ. 148. 29 pp.

Hays, R.L., C.S. Summers, and W. Seitz. 1981. Estimating wildlife habitat variables. U.S. Fish Wildl. Serv. FWS/OBS-81/47. 111 pp.

Heitmeyer, M.E. 1985. Wintering strategies of female mallards related to dynamics of lowland hardwood wetlands in the upper Mississippi Delta. Ph.D. Dissertation. University of Missouri, Columbia. 378 pp.

Heitmeyer, M.E., and L.H. Fredrickson. 1981. Do wetland conditions in the Mississippi Delta hardwoods influence mallard recruitment? Trans. N. Am. Wildl. Nat. Resour. Conf. 46:44-57.

Heitmeyer, M.E., and P.A. Vohs, Jr. 1984. Distribution and habitat use of waterfowl wintering in Oklahoma. J. Wildl. Manage. 48(1):51-62.

Hepp, G.R., and J.D. Hair. 1984. Dominance in wintering waterfowl (ANATINI): effects on distribution of sexes. Condor 86(3):251-257.

Hepp, G.R., R.L. Blohm, R.E. Reynolds, J.E. Hines, and J.D. Nichols. 1986. Physiological condition of autumn-banded mallards and its relationship to hunting vulnerability. J. Wildl. Manage. 50(2):177-183.

Jorde, D.G., G.L. Krapu, and R.D. Crawford. 1983. Feeding ecology of mallards wintering in Nebraska. J. Wildl. Manage. 47(4):1044-1053.

Jorde, D.G., G.L. Krapu, R.D. Crawford, and M.A. Hay. 1984. Effects of weather on habitat selection and behavior of mallards wintering in Nebraska. Condor 86:258-265.

Knauer, D.F. 1977. Moist soil plant production on Mingo National Wildlife Refuge. M.S. Thesis. University of Missouri, Columbia. 189 pp.

Krapu, G.L. 1981. The role of nutrient reserves in mallard reproduction. Auk 98(1):29-38.

Nichols, J.D., K.J. Reinecke, and J.E. Hines. 1983. Factors affecting the distribution of mallards wintering in the Mississippi Alluvial Valley. Auk 100:932-946.

Nixon, C.M., M.W. McClain, and R.W. Donohoe. 1975. Effects of hunting and mast crops on a squirrel population. J. Wildl. Manage. 39(1):1-25.

Reid, F.A. 1983. Aquatic macroinvertebrate response to management of seasonally-flooded wetlands. M.S. Thesis. University of Missouri, Columbia. 100 pp.

__________. 1985. Wetland invertebrates in relation to hydrology and water chemistry. Pages 72-79 in M.D. Knighton, ed. Water impoundments for wildlife: A habitat management workshop. U.S. For. Serv. St. Paul, MN.

Reinecke, K.J., R.C. Barkley, and C.K. Baxter. 1986. Potential effects of changing water conditions on mallards wintering in the Mississippi Alluvial Valley. In M.W. Weller, ed. Waterfowl in winter - a symposium and workshop. [In press.]

Shearer, L.A., B.J. Jahn, and L. Lenz. 1969. Deterioration of duck foods when flooded. J. Wildl. Manage 33(4):1012-1015.

Spurr, S.H., and B.V. Barnes. 1980. Forest ecology. John Wiley and Sons, New York. 687 pp.

Taylor, T.S. 1977. Avian use of moist soil impoundments in southeastern Missouri. M.S. Thesis. University of Missouri, Columbia. 98 pp.

Wharton, C.H., W.M. Kitchens, and T.W. Sipe. 1982. The ecology of bottomland hardwood swamps of the southeast: a community profile. U.S. Fish Wildl. Serv. Biol. FWS/OBS-81/37. 133 pp.

White, D.C. 1982. Leaf decomposition, macroinvertebrate production and wintering ecology of mallards in Missouri lowland hardwood wetlands. M.S. Thesis. University of Missouri, Columbia. 293 pp.

__________. 1985. Lowland hardwood invertebrate community and production in Missouri. Arch. Hydrobiol. 103(4):509-533.

Wright, T.W. 1959. Winter food of mallards in Arkansas. Southeast. Assoc. Game Fish Comm. 13:291-296.

Wylie, G.D. 1985. Limnology of lowland hardwood wetlands in southeast Missouri. Ph.D. Dissertation, University of Missouri, Columbia. 146 pp.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. Biological Report 82(10.132)	2.	3. Recipient's Accession No.

4. Title and Subtitle Habitat Suitability Index Models: Mallard (Winter Habitat, Lower Mississippi Valley)	5. Report Date February 1987
	6.
7. Author(s) Arthur W. Allen	8. Performing Organization Rept. No.
9. Performing Organization Name and Address National Ecology Center U.S. Fish and Wildlife Service Drake Creekside One Bldg. 2627 Redwing Rd. Fort Collins, CO 80526-2899	10. Project/Task/Work Unit No.
	11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address National Ecology Center Division of Wildlife Contaminant Research Fish and Wildlife Service Department of the Interior, Washington, DC 20240	13. Type of Report & Period Covered
	14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop a Habitat Suitability Index (HSI) model for the mallard (Anas platyrhynchos). The model consolidates habitat use information into a framework appropriate for field application, and is scaled to produce an index between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). HSI models are designed to be used with Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service.

17. Document Analysis a. Descriptors

Birds
Wildlife
Habitability
Mathematical models

b. Identifiers/Open-Ended Terms

Mallard
Anas platyrhynchos
Habitat suitability

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited	Unclassified	37
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce

☆ U.S. GOVERNMENT PRINTING OFFICE:1987-774-482/65086

TAKE PRIDE IN AMERICA

Preserve Our Natural Resources

DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.