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HABITAT SUITABILITY INDEX MODELS: NORTHERN BOBWHITE

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HABITAT SUITABILITY INDEX MODELS: NORTHERN BOBWHITE

by

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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is a formalized synthesis of biological and habitat information published in the scientific literature and may include unpublished information reflecting the opinions of identified experts.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:

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NORTHERN BOBWHITE (*Colinus virginianus*)

HABITAT USE INFORMATION

General

The northern bobwhite (*Colinus virginianus*) is a resident from southeastern Wyoming, east to southern Minnesota and across to southern Maine, south through the central and eastern United States to eastern New Mexico in the West and Florida in the East (American Ornithologists' Union 1983). Characteristics of bobwhite habitat nationwide are grassy areas for nesting, interspersed with brush for escape cover, and crops or native plants for food (Johnsgard 1975). Within any particular region, the long term abundance of bobwhites is mainly a function of habitat conditions, specifically the quantity, quality, and distribution of resources, such as food, cover, and nesting habitat (Roseberry and Klimstra 1984). In general, cover is a limiting factor in the northern portion of this quail's range, and is ample or overabundant in most southern areas (Rosene 1969). Early spring is most often the period of greatest food scarcity.

Food

The bobwhite is primarily a seed-eating bird (Edminster 1954). Plants provide from 97 to 99% of their diet, except during summer, when insects and spiders make up about one-fourth of the total. Edminster (1954) categorized bobwhite foods into the following groups: wild seeds (primarily from annual forbs); legume seeds; cultivated grains; mast; fruits; grass seeds; greens; and insects. Bobwhites eat a large variety of seeds from both wild and cultivated plants (Kabat and Thompson 1963), and the importance of specific foods may change between geographic locations, depending on food availability (Reid and Goodrum 1979). Although bobwhite food habits may be classified into broad categories, a knowledge of local food resources requires the identification of plants utilized in each particular location (Davis 1964).

The bulk of information on food habits for bobwhites is from fall and winter. A summary of 27 food habits studies (mostly fall and winter) from the Southeast included data from approximately 20,000 bobwhites (Landers and Johnson 1976). This summary noted that over 650 different types of seeds were eaten, of which 78 comprised 1% or more of the food volume in one or more of the studies. Plants with both a high percent volume and high percent frequency in bobwhite crops included beggarweeds (*Desmodium* spp.), ragweeds (*Ambrosia* spp.), lespedezas (*Lespedeza* spp.), corn (*Zea mays*), partridge peas (*Cassia* spp.), oaks (*Quercus* spp.), sumacs (*Rhus* spp.), pines (*Pinus* spp.), soybeans (*Glycine max*), and cowpeas (*Vigna* spp.).

Bobwhites in Alabama consumed legume seeds more than seeds from other plant families (Rosene 1969). In Georgia, legume seeds accounted for 52% (by weight) of winter food items, while corn comprised 30%, and acorns 7% (Dickson 1971). Important fall and winter quail foods in southeastern forests were mast from trees and shrubs, and seeds from herbaceous plants (Goodrum and Reid 1952; Reid and Goodrum 1979). Bobwhites required a variety of seed and fruit producing plants in southeastern forest habitats to provide a stable food base and adequate nutrition (Reid and Goodrum 1979).

Wild legumes were the most important fall and winter foods in the Piedmont region of Alabama (Speake 1960). The following plants were considered to be quail foods in the Alabama Piedmont: all legumes, except coffeeweed (Cassia tora) and crotalaria (Crotalaria spp.); panic grasses (Panicum spp.); paspalum grasses (Paspalum spp.); crotons (Croton spp.); and common ragweed (Ambrosia artemisiifolia) (Speake 1966). The abundance of native wild legumes provides a good index to the quality of forested bobwhite range in the South (Speake et al. 1975).

Common ragweed comprised 21% of the food volume and was the single most important winter food in Virginia (Baldwin and Handley 1946). Percent volume of other major foods eaten were as follows: native and naturalized legumes (29%); cultivated legumes (14%); cultivated grains (11%); mast (10%); miscellaneous seeds (7%); fruits (4%); forage and grasses (2%); and animal matter (2%). Important winter foods in Illinois included corn, soybeans, acorns, and ragweed (Bookhout 1958; Larimer 1960). Soybeans, corn, wheat (Triticum aestivum), black locust (Robinia pseudoacacia) seeds, common ragweed, animal matter, and foxtail (Setaria spp.) were the most important winter foods in Indiana (Priddy 1976). Black locust seeds were heavily used during periods of snow cover. In Missouri, Korean lespedeza (L. stipulacea), common ragweed, and corn were predominant winter foods (Korschgen 1948, 1952). Annual plants were favored fall and winter foods in Oklahoma (Baumgartner et al. 1952). The by-products of cultivation, such as ragweeds, sunflowers (Helianthus spp.), and crotons were important food items. Cowpeas and peanuts (Arachis hypogaea) are valuable foods, where available (A. S. Johnson, Institute of Natural Resources, University of Georgia, Athens; letter dated January 4, 1983). .

Major fall and winter foods in Georgia and northern Florida included acorns, corn, and pine seeds (McRae et al. 1979). Spring and summer food items included panic grass seeds, leafy greens, and berries. Oak mast was the preferred food when it was available.

Murray and Frye (1957) recommended that, in order to provide bobwhite food, mast producing trees 25.4 cm dbh or larger be left standing when forests are being cut or thinned. The average expected yield of acorns for several large growth form oaks in Louisiana and east Texas was 0.6 kg/tree for trees that were 17.8 to 22.6 cm dbh and 1.47 kg/tree for trees that were 22.9 to 27.7 cm dbh (Goodrum et al. 1971). Most oaks < 17.8 cm dbh produced no mast at all.

Habitat improvement programs should stress both food quality and palatability (Robel et al. 1979). Sorghum (Sorghum vulgare) and corn were rated excellent for metabolizable energy and acceptability to quail, shrub lespedeza (L. japonica) and hemp (Cannabis sativa) were mediocre, red oak (Q. rubra) acorns were poor, and panicum (Panicum virgatum) was extremely poor. Low quality foods reported from Maryland included wax myrtle (Myrica spp.), poison-oak (Rhus toxicodendron), and dwarf sumac (R. copallina) (Wilson and Vaughn 1944). Loss of quail in Illinois was correlated with the quality of the range, especially the availability of grain foods (Roseberry 1964). The value of croplands in providing winter food for bobwhites is related to the type of crop, time and method of harvest, weather conditions, and the location of suitable access cover (Roseberry and Klimstra 1984). Unharvested grain left standing over winter has a favorable impact on bobwhites. Corn and soybeans are about equally important as bobwhite foods based on the range occupancy rates of quail. The use of certain pesticides can be detrimental to bobwhites in cropland habitats (J. L. Landers, International Paper Company, Southlands Experiment Forest, Bainbridge, GA; letter dated January 11, 1983).

Spring is the most difficult time for bobwhites due to the low availability of seed and fruit crops (Reid and Goodrum 1979). Bobwhites must rely on the early seed and fruit crop, and the residual crop from the last growing season for survival during the spring.

Preacher (1978) studied deterioration rates and bobwhite preference of seeds from 35 food plants in South Carolina. Six of the top 10 fresh seeds that were preferred were also in the top 10 after 120 days of being on the ground. These six plants were poison ivy (Toxicodendron radicans), sorghum, chiwapa millet (Echinochloa frumentacea), pearl millet (Pennisetum glaucum), browntop millet (Panicum ramosum), and Japanese millet (Echinochloa crusgalli). Soybeans accounted for 71 and 40% of the volume of foods eaten during winter and spring, respectively, in western Tennessee (Eubanks and Dimmick 1974). The abundance of such a nutritious food source during this critical period may have been an important factor in maintaining the dense bobwhite population in this study area. Later studies on the same area, however, showed a negative correlation between increasing soybean acreage and bobwhite populations (Exum et al. 1982). The increase in the soybean food supply apparently failed to compensate for a corresponding dramatic loss of security cover and possibly nest cover as well.

Insects were the most important foods of Mississippi quail chicks 2 to 20 days old (Hurst 1972). Insect abundance is highest in brood habitats containing legumes and mixed forbs. Animal foods, primarily beetles (Coleoptera), bugs (Hemiptera), and grasshoppers (Orthoptera), provided 94.1% of the foods eaten during the first 2 weeks of life of bobwhite chicks in Tennessee (Eubanks and Dimmick 1974). The feeding habits of young quail are similar to those of adults when the young reach 7 to 9 weeks of age.

Bobwhites forage primarily on the ground or in a light litter layer < 5.1 cm deep (Rosene 1969). They cannot feed in thick mats of vegetation, and snow > 7.6 cm deep causes the birds to feed on seeds within reach that have not yet fallen. Ideal foraging habitat in the Southeast consists of open vegetation with some bare ground and a light litter of small-leaved leguminous plants with protective cover nearby (Stoddard 1931). Foraging cover can be of various heights, if plant growth is open enough to permit ease of movement (Davis 1964).

Bobwhites in Kansas depended on early seral stage communities for food and obtained very little food in climax plant communities (Robinson 1957). Bobwhites in Oklahoma showed similar preferences as early seral stages in abandoned fields provided the best foods, while climax prairies provided little quail food (Baumgartner et al. 1952). Ellis et al. (1969:754) noted in Illinois that:

> "As plant succession progresses, the density of vegetation rapidly increases, the percent of bare ground decreases, a "rough" develops, and the incidence of the desirable shade-intolerant quail food plants such as the ragweeds and beggar-ticks is greatly reduced. The necessity for moderately open stands dominated by seed-producing weedy forbs cannot be overemphasized in quail management. Apparently, lesser ragweed is an important indicator species of the early successional stage so critical in quail management."

Controlled burning can be used in southern forests to remove excess herbaceous vegetation and litter, and to increase the leguminous food supply (Stoddard 1931; Goodrum and Reid 1952; Rosene 1969; Cushwa et al. 1971). Plowing (Goodrum and Reid 1952), disking, or chopping (Rosene 1969) can be used for the same purpose. Pine forests of the Atlantic Piedmont can be improved for quail by cutting and burning sites (Cushwa et al. 1971). Burning old fields tends to remove litter and increase insect abundance, providing good habitat for bobwhite chicks (Hurst 1972).

Periodic burning (3 to 5 years apart) of openings in Tennessee produced dense grass stands that were poor bobwhite habitat (Whitehead and McConnell 1979). Annual burning, mowing, plowing or disking was necessary to decrease grass cover and increase forbs and legumes in these openings. However, burning of southern pine-hardwood forests can reduce understory mast production by 70% (Lay 1955). Ideal fire management should allow diverse vegetational types, including mast producing areas, to exist (McRae et al. 1979).

Loblolly pine (Pinus taeda) plantations < 2 years old provided abundant annual vegetation used by bobwhites and were prime feeding areas in Arkansas (Sweeney et al. 1981). Three and four year old plantations provided few annual food plants and were used much less. Seeding domestic grasses is undesirable for bobwhites because the grasses compete with preferred native plants and soon form dense, matted sods that inhibit bobwhite movements and reduce the diversity of foods present (Ellis et al. 1969). Addition of phosphorus to certain areas in Alabama resulted in large increases in legume coverage and legume seed production (Speake et al. 1975). Poorly drained soils are difficult to manage for preferred bobwhite food plants (D. W. Speake, Alabama Cooperative Wildlife Research Unit, Auburn, AL; letter dated January 17, 1983).

Old fields in the Alabama Piedmont that were 1 to 2 years past cultivation contained mostly grasses and composites, and few native legumes (Speake 1966, 1967). Fields 3 to 5 years past cultivation had 22.4% canopy cover of quail food legumes, the highest density noted. As fields reached 11 to 12 years, quail food legumes decreased to 14% coverage, and as fields approached 15 to 25 years, quail food legumes and actual bobwhite use continued to decrease steadily. There may be considerable variation in the specific age at which old fields no longer support wild legumes.

Cropland habitats that are left over winter as rough stubble with annual weeds present provide good feeding areas for bobwhites (Edminster 1954). Croplands where almost all residues are removed or that are fall plowed are of little value (Edminster 1954; Heitmeyer 1980). Food is probably not a limiting factor in habitats that provide crop residues and their attendant weeds, and even moderate amounts of native food plants (Burger and Linduska 1967). Persistent overgrazing caused elimination of quail from an experimental pasture in Oklahoma (Baumgartner 1945). Overgrazing in another Oklahoma study area favored the increase of several important bobwhite foods (Baumgartner et al. 1952).

Water

Bobwhites require water for their survival (Rosene 1969). Water may be obtained as free water, from dew, or from food items. The bobwhite thrives where rain is adequate for its needs and does poorly in the arid western parts of its range. Water is not an important limiting factor in most of this quail's range in most years, but occasional droughts may cause severe losses in quail numbers (Edminster 1954).

Cover

Bobwhites prefer areas where approximately 50% of the ground is exposed, and 50% contains upright growth of herbaceous and woody vegetation (Rosene 1969). Each covey range requires one to three shrubby thickets 0.05 to 0.2 ha in size. Plum (*Prunus* spp.) patches that grow to a height of 1.2 to 1.5 m are ideal. Bobwhites use dense woody vegetation during midday (Robinson 1957; Roseberry and Klimstra 1984). Bobwhites in Kansas typically foraged in open areas in the early morning hours, then occupied the woody "headquarters" until late afternoon, when they resumed foraging in the open until evening (Robinson 1957). Bobwhites may choose habitats and regulate their daily movements in response to the intensity of light at ground level. Their use of areas of high light intensity was restricted, probably as an avoidance of diurnal predators. "Headquarters" areas should be at least 188 m^2 and dense enough to reduce midday light to less than 1,000 footcandles. Davis (1964) described escape cover as usually consisting of dense woody vegetation 1.0 m or more in height. Multiflora rose (*Rosa multiflora*) provides adequate overhead cover, but is too dense near the ground, and inhibits bobwhite visibility and movements (Hanson and Miller 1961). Japanese honeysuckle (*Lonicera japonica*) provides excellent dense understory cover for use as "headquarters" (Roseberry and Klimstra 1984).

Optimum quail habitat in the post-oak region of Texas consisted of heavily grazed pastures with abundant annual weeds, such as croton and partridge pea (Cassia fasciculata), and woody thickets (Parmalee 1953). To produce high bobwhite populations, southern forests should be open enough to allow large patches of sunlight on at least 60% of the area to promote herbaceous and shrub growth (Rosene 1969). The best protective cover in the mid-South is provided by naturally occurring vegetation that develops on undisturbed areas (Eubanks and Dimmick 1974). Good bobwhite management must stress the manipulation of natural succession (Roseberry et al. 1979). Deteriorating habitat conditions in southern Illinois caused an 85% decline in a bobwhite population. Secondary succession eliminated preferred food species, replaced weedy and grassy nesting cover with dense woody growth, and reduced the amount of prime roosting habitat. Large changes in carrying capacity can be caused by slow and subtle land use changes and secondary succession.

Late winter is often a critical period for bobwhites due to low food supplies and poor protective cover (Edminster 1954). Dense thickets of low brush or young pine stands provide the best winter cover. Winter cover in the northern portions of the bobwhite's range is relatively scarce, and the need for such cover is greater than in the South (Rosene 1969). Winter is the critical season for Wisconsin bobwhites due to the lack of high quality food and cover (Errington 1933). Primary winter cover in Wisconsin farmlands is provided by woody hedgerows at least 1.8 m wide (Kabat and Thompson 1963). From 1931 to 1950, this Wisconsin study area had about 23 birds/mile of hedgerow. Bobwhite populations were eliminated as the amount of hedgerows was reduced from 1 km/113 ha to 1 km/164 ha.

Winter cover in Oklahoma was confined to wooded ravines and patches of oaks that were bordered by idle or active croplands (Baumgartner 1945). Rank growths of tall weeds provided some winter cover. Bobwhite coveys in Tennessee spent little time during winter in croplands (Yoho and Dimmick 1972). The presence of Japanese honeysuckle was important, and honeysuckle patches provided 63 of 107 roost sites. Roosting and loafing sites switched from open to woody cover during periods of prolonged snow cover in Illinois (Roseberry 1964). In addition, coveys were more sedentary and range size decreased.

The physical characteristics of vegetation at roost sites are more important than the species of vegetation (Klimstra and Ziccardi 1963). Bobwhites in Oklahoma roosted on the ground, in areas surrounded by herbaceous vegetation ≥ 0.3 m tall, of low to moderate density, and with little overhead canopy or obstruction (Davis 1964). Sixty percent of roosts in Illinois were on bare ground and 31% on duff (Klimstra and Ziccardi 1963). Matted or dense herbaceous cover was avoided. Eighty percent of the roosts were in herbaceous vegetation 30.0 to 90.0 cm tall, and the average stem density was 171.0/m². The average height of the tallest vegetation at roost sites in Oklahoma was 68.0 cm and the average stem density was 168.0/m² (Wiseman and Lewis 1981). Ideal roosts in Illinois were on bare ground or light duff in vegetation 30.0 to 60.0 cm tall (Ellis et al. 1969). Preferred night roosting habitat is provided by wheat stubble fields and other land uses that provide an open canopy, sparse and short vegetation, and a ground surface nearly devoid of dead vegetation (Klimstra and Ziccardi 1963).

Bobwhites in the Southeast generally located their roosts in relatively open areas of herbaceous vegetation, and avoided dense tangles (Stoddard 1931). Rosene (1969) reported that winter roosts in the Southeast generally were in scattered herbaceous vegetation about 0.6 m tall, open at ground level and above. Roost sites shifted to denser cover as cold, snow, or wind became severe.

It is likely that suitable roost cover is a limiting factor in certain habitats (Klimstra and Ziccardi 1963). Although dense, woody thickets provide optimum shelter during severe winter conditions, the open roosting cover that bobwhites prefer during milder weather is more important on a year-to-year basis.

Bobwhite quail prefer open areas, with more than 75% bare soil and vegetation less than 0.3 m tall, for dusting (Rosene 1969).

Reproduction

Bobwhite nests are generally domed, sphere-shaped structures built on the ground with dead grass stems (Klimstra and Roseberry 1975). Bobwhites prefer to nest in open areas, where the ground is only partly covered by vegetation (Rosene 1969). Eighty-two percent of nests observed by Stoddard (1931) were in open growth allowing ease of movement, and 89% were placed in growth of the previous year. Prime nesting cover in Illinois typically contained scattered shrubs and briars interspersed with a moderately dense growth of herbaceous vegetation (Klimstra and Roseberry 1975; Roseberry and Klimstra 1984). Cover that was too dense to provide bare or sparsely vegetated areas was avoided. These conditions were most often found in old fields during the latter part of the perennial weed stage and the early part of the bramble and shrub stage (Roseberry and Klimstra 1984). Fifty-six percent of all nest sites (a 1.0 m^2 area around the nest) contained woody vegetation. Ninety-five percent of the nests in an Iowa study were made of, and placed in, grass (Klimstra 1950). Dead grass stems provide important support for the nest; areas in annual weeds are poor nest sites due to a lack of dead grass stems (Roseberry and Klimstra 1984).

Bobwhite nests are frequently placed along an edge between grass and bare soil areas (Rosene 1969). Stoddard (1931) reported that 74% of the nests were within 15 m of open ground such as roads or paths. Nests in Illinois were frequently located near a change in the cover pattern (Klimstra and Roseberry 1975). Klimstra (1950) reported that 61% of the nests were in, or at the edge of, woody cover. Almost 90% of the nests were in well drained locations while only 2% were in poorly drained locations.

Fifty-six percent of nests in a southeastern study were in broomsedge (Andropogon virginicus) fields, 16% in open woodland, 15% in 1 or 2 year old fallow fields, and 4% in cultivated fields (Stoddard 1931). Preferred nest sites in west Tennessee were old fields dominated by broomsedge or similar grasses 0.3 to 0.6 m tall (Dimmick 1968). Alfalfa (Medicago sativa) fields provide poor nesting cover (Rosene 1969; Roseberry and Klimstra 1984). Eighty-five percent of nests in east-central Texas were located in pasture or grasslands (Parmalee 1955). Nesting cover was apparently not a limiting factor in

Wisconsin (Kabat and Thompson 1963). Although undisturbed nesting cover was usually not overabundant, it was generally adequate compared to brushy cover needed for winter survival.

"The amount and quality of nesting cover available in nonagricultural areas is largely dependent upon natural plant succession" (Klimstra and Roseberry 1975:16). Intermediate successional stages provide better nesting habitat than late or early seral stages. Early annual weed stages have a scarcity of dead grass stems needed for nest building. However, establishment of planted fields of tame forage plants does not improve bobwhite nesting. Acreage diversion programs of croplands would be most useful to nesting bobwhites if allowed to undergo natural secondary succession for 5 to 10 years. Nesting use in Illinois was maximum when preferred nest sites were associated with open field habitats. Small, isolated patches of potential nest cover located in or near nonbreeding habitats, such as croplands or forests, were not frequently used.

Nest success in Illinois was highest in idle fields and lowest in hayfields (Klimstra and Roseberry 1975). Overall, 33.7% of 863 nests were successful, with predators accounting for 55% of nest failures, and farming activities causing 18% of failures. Standing vegetation at nest sites should be < 51 cm tall (Rosene 1969). The average height of cover at nest sites in Illinois was 49.5 cm and stem densities within 1.0 m^2 around the nest averaged 1,048 (Klimstra and Roseberry 1975). Areas with an average herbaceous height of < 7.6 cm are unacceptable for nesting bobwhites (Lehmann 1984). Herbaceous cover around late summer nest sites ranged from a low of 10% to a high of 85% (Harshbarger and Simpson 1970). Seventy-three percent of these nests were found in areas where herbaceous canopy cover was between 21 and 60%. Optimal herbaceous cover was apparently about 50%.

Interspersion and Composition

Management for the bobwhite must consider the type of cover needed, the amount of each type needed, and the arrangement of these (Edminster 1954). It is important to have food and cover resources in close proximity (Roseberry and Klimstra 1984). The vulnerability of a winter covey is related to the quality and quantity of escape cover, and the distance between food and cover resources. The interspersion of seasonal resources need not be as tight as those resources needed on a daily basis. Several occupied bobwhite ranges in southern Illinois that generally were devoid of nesting habitat were located ≥ 1.0 km from areas that contained extensively used nest cover.

The highest bobwhite populations occur where a large variety of plants exist (Rosene 1969). Such conditions are best provided in habitats with a mix of woodlands and open fields, with a transition band between them. Bobwhite populations in Illinois were positively correlated with the amount of edge between brushy pastures and cultivated fields (Hanson and Miller 1961). However, there was no correlation between bobwhite numbers and the total amount of all edges, because many edges were not used. Eubanks and Dimmick (1974) believed that the total amount of edge was less important than the abundance of adequate protective cover adjacent to foraging areas. The proximity of woody cover to herbaceous cover was also an important factor influencing bobwhite use of Remington Farms in Maryland (Burger and Linduska 1967). The formation of new quail coveys was most rapid where adequate herbaceous cover was immediately adjacent to either shrub hedgerows or forest boundaries.

Bobwhites can do well in areas where the percentage of land in cropland, forest, or idle land varies tremendously, if the areas are properly managed (Rosene 1969). Good habitat can range from 10 to 90% cropland and 10 to 90% forest, with the best habitats containing 50% in non-woody growth and 50% brush or woodlands. Improved pastures should not be large and should total less than 20% of the area. Edminster (1954) estimated proportions of various cover types necessary to provide good bobwhite habitat. Grassland, used primarily for nesting, should make up 30 to 40% of the area, in 2 to 4 ha units. Croplands provide fall and winter food and should comprise 40 to 60% of the habitat in 0.4 to 2 ha units. Brushy areas, providing escape cover, fall and winter food, and roosting habitat, should total 5 to 20% of the area in 0.1 to 0.4 ha units. Woodlands provide the same needs as brushy cover and should make up 5 to 40% of the total cover in units between 2 and 8 ha in size. An appropriate distribution of cover in relation to food producing areas is critical in managing bobwhites on agricultural lands (Eubanks and Dimmick 1974). Very high bobwhite densities were observed in portions of a Tennessee study area that contained as much as 80% of the area in row crops. Bobwhites may find adequate cover in habitats with either a few areas of high quality woody vegetation or in areas with a large quantity of lower quality woody vegetation (Lehmann 1984).

The average home range of coveys in Oklahoma was 4.4 ha and ranges were centered along stream channels (Wiseman and Lewis 1981). Home range size did not vary from fall through spring. Winter ranges in Alabama and South Carolina varied from 1.6 to 31.2 ha (Rosene 1969). The average size of winter ranges in Tennessee was 6.8 ha (Yoho and Dimmick 1972). Four late winter ranges in southern Illinois varied in size from 12 to 19 ha, with an average size of 15 ha, whereas four ranges in a year of prolonged snow cover averaged 9 ha (Roseberry and Klimstra 1984). The minimum area needed to support a covey of bobwhite quail in the critical season is approximately 4.9 ha (Robinson 1957).

The bobwhite in the Southeast is essentially sedentary and does not undertake large movements (Stoddard 1931). Bobwhites form coveys during late summer and early fall and may move several miles to habitats where food and cover will be available through the winter (Rosene 1969). However, bobwhites in adequate habitats often rear their broods and establish winter covey ranges within a few hundred yards of where they were hatched (Agee 1957). The daily summer range of bobwhite quail in Iowa was 227 m long and 71 m wide, while total summer ranges were 736 m long and 473 m wide (Crim and Seitz 1972). Most fall and winter movements of Missouri coveys were < 0.4 to 0.6 km in their greatest dimension (Murphy and Baskett 1952). Approximately one-half of the bobwhites in this study had a lifetime cruising radius of < 0.8 km. Eighty-six percent of the bobwhites in a Florida study moved < 400 m in a 1 to 5 year period (Smith 1980).

Maximum bobwhite densities are generally believed to be 1 bird/0.4 ha (Edminster 1954; Rosene 1969). However, densities up to 2 or 3 birds/0.4 ha have been noted in southern Georgia and northern Florida (Kellogg et al. 1972), and densities of 1 to 2 birds/0.4 ha are common on good range in southwestern Georgia (F. E. Kellogg, Southeastern Cooperative Wildlife Disease Study, University of Georgia, Athens; letter dated January 15, 1983).

Quail populations in the rolling pinelands of the South can be as high as those of good farm habitat (Goodrum and Reid 1952). Quail numbers in Illinois increased more in response to programs of controlled burning and sharecropping than to the planting of food patches (Ellis et al. 1969).

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area. This model was developed for application within the entire range of the northern bobwhite. Users near the periphery of the range should consult local authorities to confirm the appropriateness of applying this model.

Season. This model was developed to evaluate the year-round habitat needs of the northern bobwhite.

Cover types. This model was developed to evaluate habitat in the following cover types (terminology follows that of U.S. Fish and Wildlife Service 1981): Evergreen Forest (EF); Deciduous Forest (DF); Evergreen Tree Savanna (ETS); Deciduous Tree Savanna (DTS); Evergreen Shrubland (ES); Deciduous Shrubland (DS); Evergreen Shrub Savanna (ESS); Deciduous Shrub Savanna (DSS); Grassland (G); Forbland (F); Pasture and Hayland (P/H); and Cropland (C). In order to adequately assess bobwhite habitat suitability, it is essential to consider the existence of hedgerows, brushy thickets, windbreaks, and similar areas. Such areas should be mapped as deciduous or evergreen, shrubland or forest, as appropriate, so as not to overlook their importance to the northern bobwhite.

Minimum habitat area. Minimum habitat area is defined as the minimum amount of contiguous habitat that is required before a species will live and reproduce in an area. Robinson (1957) estimated the minimum habitat area for bobwhites to be 4.9 ha. If less than 4.9 ha of habitat are available, the HSI for the bobwhite will equal 0.0.

Verification level. This model represents several hypotheses of species-habitat relationships and does not reflect proven cause and effect relationships. Previous drafts of this model were reviewed by Ralph W. Dimmick, Department of Forestry, Wildlife, and Fisheries, University of Tennessee, Knoxville; A. Sydney Johnson, Institute of Natural Resources, University of Georgia, Athens; Forest E. Kellogg, Southeastern Cooperative Wildlife Disease

Study, University of Georgia, Athens; J. Larry Landers, International Paper Company, Southlands Experiment Forest, Bainbridge, GA; W. Alan McRae, 1173 Canton Street, Rosewell, GA; Carroll J. Perkins, Department of Wildlife and Fisheries, Mississippi State University, Mississippi State; John L. Roseberry, Illinois Cooperative Wildlife Research Unit, Carbondale; and Daniel W. Speake, Alabama Cooperative Wildlife Research Unit, Auburn. Improvements and modifications suggested by these persons have been incorporated into this model.

Information gathered from ongoing studies of the bobwhite in the southeastern United States (L. J. O'Neil, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS; unpubl.) was also used in the development of this model. These studies involve the application of an earlier version of an HSI model for the bobwhite and comparisons of model outputs to both population data and expert rankings of bobwhite habitat.

Model Description

Overview. The bobwhite may use a wide variety of habitats to meet its life requirements. This model considers the ability of the habitat to meet the bobwhite's needs for winter food, cover, and nesting as an indication of overall habitat suitability. It is assumed that an assessment of winter food requirements will include the foods needed during fall and spring, and that summer food requirements will never be more limiting than winter food needs. Water needs of the bobwhite are assumed not to be limiting over most of the range, and to be reflected in the vegetation structure in arid habitats. Therefore, the availability of water is not assessed in this model. Bobwhite cover requirements are primarily related to a need for low, dense, woody vegetation for escape and protection from the weather. Nesting needs are provided by grassy habitats, and it is assumed that mild weather roosting needs and brood needs will be adequate if nest sites are available.

Adequate interspersion of life requisites is essential for optimal bobwhite habitat. This model assesses the type of cover needed to provide the necessary life requisites, the amount of each needed, and their arrangement, as suggested by Edminster (1954).

The following sections provide a written documentation of the logic and assumptions used to interpret the habitat information for the bobwhite in order to explain the variables and equations that are used in the HSI model. Specifically, these sections identify important habitat variables, describe suitability levels of the variables, and describe the relationships between variables.

Winter food component. The primary winter food items for bobwhites are annual and perennial leguminous plant seeds, other annual plant seeds, cultivated crops, and pine and oak mast. All cover types listed in this model have the potential to provide herbaceous plant seeds. In addition, croplands may provide cultivated crop foods, and forests may provide mast.

The majority of bobwhite food habits studies indicate that herbaceous plant seeds and domestic crop foods are the primary winter food resources. It is assumed that cropland food resources alone are adequate to support maximum numbers of bobwhite, due to the high caloric content of cropland foods. Food resources obtained from either herbaceous plant seeds or from oak and pine mast alone are assumed to be inadequate to support maximum bobwhite numbers. It is assumed that herbaceous plant seeds are twice as important as mast from oaks and pines in their contribution to supporting bobwhites, and that both of these food sources are required to provide optimum food suitability.

Bobwhites consume a wide variety of herbaceous plant seeds, primarily from annual and perennial legumes, and from other annual plants. A knowledge of local food resources requires the identification of herbaceous plants used in each particular location (Davis 1964). Therefore, this model requires the user to identify preferred bobwhite food plants in each area of model application. It is suggested that local bobwhite authorities be consulted to develop a list of preferred foods. Based on discussions with model reviewers (O'Neil, pers. comm.), it is assumed that habitats with 25 to 75% canopy cover of preferred herbaceous food plants (as measured in the summer) will be optimum. Habitats with no preferred foods may provide low suitability levels, due to the flexibility of the bobwhite's diet. Habitats with 100% canopy cover of preferred plants will have less than optimal suitability due to their high density which inhibits bobwhite movements. The assumed relationship between the percent canopy cover of preferred herbaceous food plants and a suitability index (SIV1) for the bobwhite is presented in Figure 1a. Access to seeds is very important for bobwhites, and it is estimated that the best habitats have bare ground or light litter over 30 to 60% of the area. Habitats with no bare ground or with deep litter are assumed to provide very low suitabilities due to the difficulty of movement for bobwhites and the inaccessibility of seeds in such areas. Habitats with > 60% bare ground or light litter will have progressively lower suitabilities. The relationship between the percent ground that is bare or covered with a light litter and a suitability index (SIV2) for the bobwhite is presented in Figure 1b.

Bobwhite winter foods in herbaceous and shrub-dominated cover types are provided by preferred herbaceous food plants whose seeds are easily accessible. The relationship between herbaceous food suitability (HFSI) and habitat variables in shrub and herbaceous cover types is based on these assumptions: (1) herbaceous food resources alone cannot support maximum numbers of bobwhites; (2) herbaceous food resources are twice as important as mast from oaks and pines; and (3) maximum suitabilities of both herbaceous foods and mast from oaks and pines are required to provide optimum food resources for bobwhites. Therefore, herbaceous food plants alone provide two-thirds of the food resources needed to support maximum bobwhite numbers. The relationship describing winter food suitability in herbaceous and shrub-dominated cover types (WFSI1) can be expressed mathematically, as shown in Equation 1.

$$WFSI1 = HFSI = \frac{2}{3} \ (SIV1 \times SIV2) \qquad (1)$$

Fig. 1a

Fig. 1b

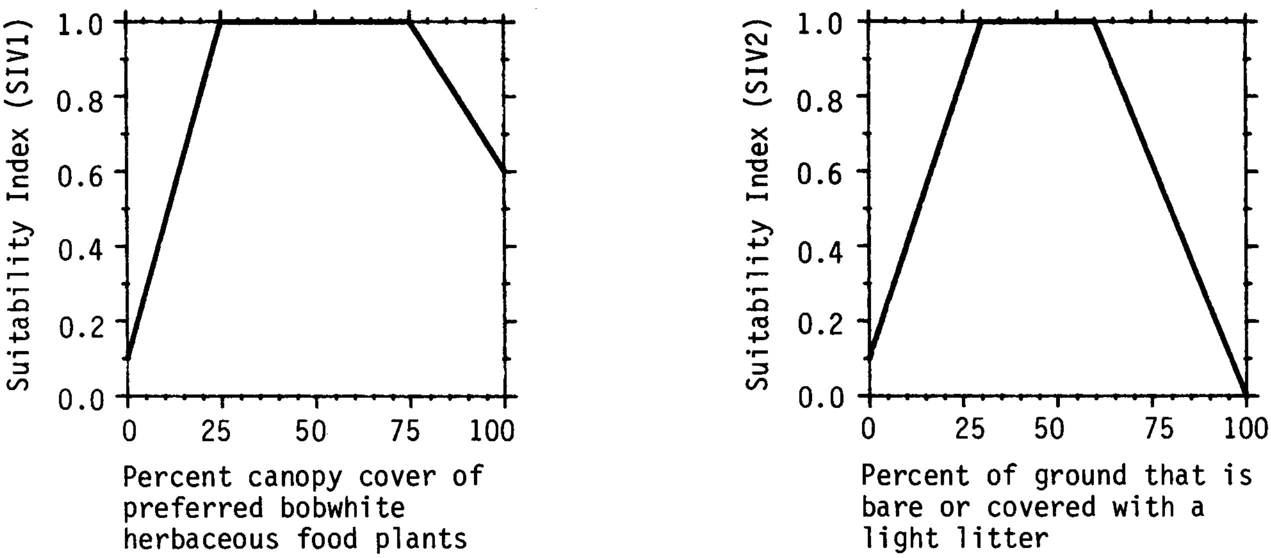
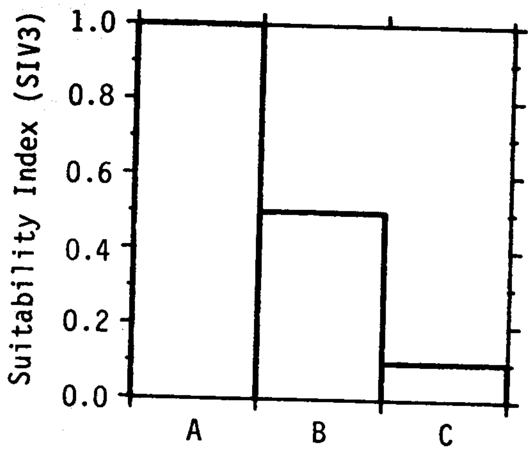


Figure 1. The relationships between habitat variables used to evaluate herbaceous food and the suitability indices for the variables.

The relationship expressed in Equation 1 must be expanded for croplands. Suitability of winter food in croplands also is related to the type of crop present and the overwinter management practices. Corn, sorghum, soybeans, cowpeas, and peanuts provide the highest food value for bobwhites. Other grain crops may provide moderate values, while all other crops provide low suitability. The relationship between the type of crop and a suitability index (SIV3) for the bobwhite is presented in Figure 2a. Management practices that leave crop and forb residues on the surface during winter are best for bobwhites. Unharvested croplands are best, croplands that are spring plowed provide moderate values, and croplands that are fall plowed will have very little winter food value for bobwhites. The relationship between overwinter crop management and a suitability index (SIV4) for bobwhites is presented in Figure 2b. The overwinter crop management practices included in SIV4 are general guidelines, and other practices are likely to be encountered during site specific applications of this model. These should be assigned suitability indices according to the estimated amount of food provided to bobwhites.

As described previously, herbaceous plant foods may provide up to two-thirds of the food resources, whereas crop residues alone may provide all of the food resources, to support maximum numbers of bobwhites. The combined value of both of these food sources is assumed to be directly affected by the overwinter management practices in the cropland. The suitability of winter food in croplands (WFSI2) can be determined with Equation 2.

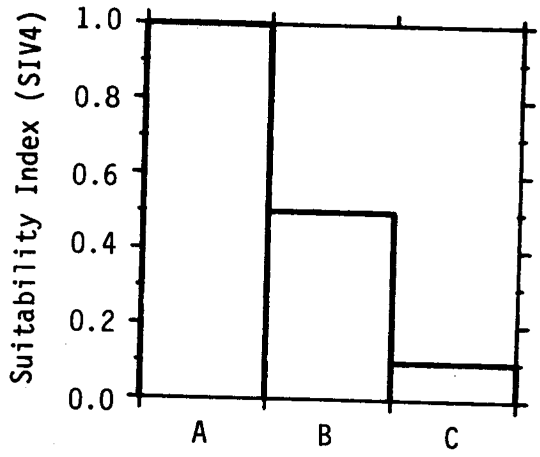
Fig. 2a



Type of crop present

A) corn, soybeans, sorghum, cowpeas, or peanuts
B) other grain crops
C) vegetable, fruit, fiber crops, or tobacco

Fig. 2b.



Overwinter crop management

A) crop left unharvested
B) crop harvested, spring plowed
C) crop harvested, fall plowed

Figure 2. The relationships between habitat variables used to evaluate winter food in croplands and the suitability indices for the variables.

$$WFSI2 = (HFSI + SIV3) \times SIV4 \qquad (2)$$

Note: When the sum of HFSI + SIV3 exceeds 1.0, it should be reduced to 1.0 before computing the winter food value.

Forested habitats may provide food both from preferred herbaceous food plants and from mast produced by oak and pine trees. Habitat variables to determine the value of preferred herbaceous food plants were previously described (Fig. 1). The amount of acorn mast produced in a forest varies from year to year, from species to species, and from tree to tree of the same species (Shaw 1971). The number of acorns produced per tree increases in a linear relationship with increased tree diameter (Goodrum et al. 1971; Shaw 1971).

Although acorn production is positively correlated with individual tree diameters, overall acorn production in forest stands is influenced by the canopy conditions and shading. Shaded trees produce less mast than trees grown in more open habitats. The exact structural forest conditions that must exist to maximize mast production have not been reported in the literature.

McQuilkin and Musbach (1977) conducted a 14-year study of pin oak (Q. palustris) acorn production on both flooded and unflooded sites in Missouri. Their data indicated that mast production on plots with trees mostly ≥ 27.9 cm dbh was 84% higher than on plots with most trees < 25.4 cm dbh. On unflooded plots, which would be most representative of bobwhite habitat, there were no statistically significant differences in acorn production on plots with low, medium, or high stocking rates. Low stocking rate plots had basal areas of 9.2 m^2/ha, medium plots had basal areas of 13.8 m^2/ha, and high plots had basal areas of 17.2 to 20.7 m^2/ha.

The low stocking rate in McQuilkin and Musbach's (1977) study is about equal to the lower limits of upland central hardwood stands that are termed understocked by the U.S. Forest Service (Gingrich 1971). The stocking chart from Gingrich (1971:66) can be used to estimate the minimum numbers of trees of specific size classes that are required to reach the lower limit of understocked stands. It is assumed that forests with tree densities below this level will show reduced mast production. Using the stocking chart, it can be determined that, for 25.4 cm diameter trees, 235 trees/ha are needed to be at the lower limit of understocked stands. For trees 38.1 cm in diameter, 124 are needed per ha to reach the minimum stocking level. The relationships between the numbers of trees of various diameter classes and suitability indices (SIV5) for the bobwhite are shown in Figure 3. It should be noted that SIV5 consists of two measured habitat variables: (1) average diameter of pine and oak trees > 25.4 cm dbh; and, (2) number of pine and oak trees/ha > 25.4 cm dbh.

It is assumed that total forest mast production will not increase at tree densities above those shown as optimal in Figure 3. This is based on the logic that although there will be more trees in such stands, the amount of mast produced per tree will be lower due to shading and, thus, overall mast production will be the same. This assumption is further supported by the study of McQuilken and Musbach (1977), that showed no difference in acorn production at low, medium, and high stocking conditions. Although the preceding mast relationships were developed using data from oaks, it is assumed that the basic relationships will apply to mast produced from pine trees as well.

As previously stated, it is assumed that herbaceous food resources are twice as important as mast in their contribution to supporting bobwhites, and that both of these food sources are needed to provide optimum food suitabilities. Winter food suitability in tree-dominated cover types (WFSI3) can be determined with Equation 3.

$$WFSI3 = HFSI + \frac{1}{3}\,SIV5 \qquad (3)$$

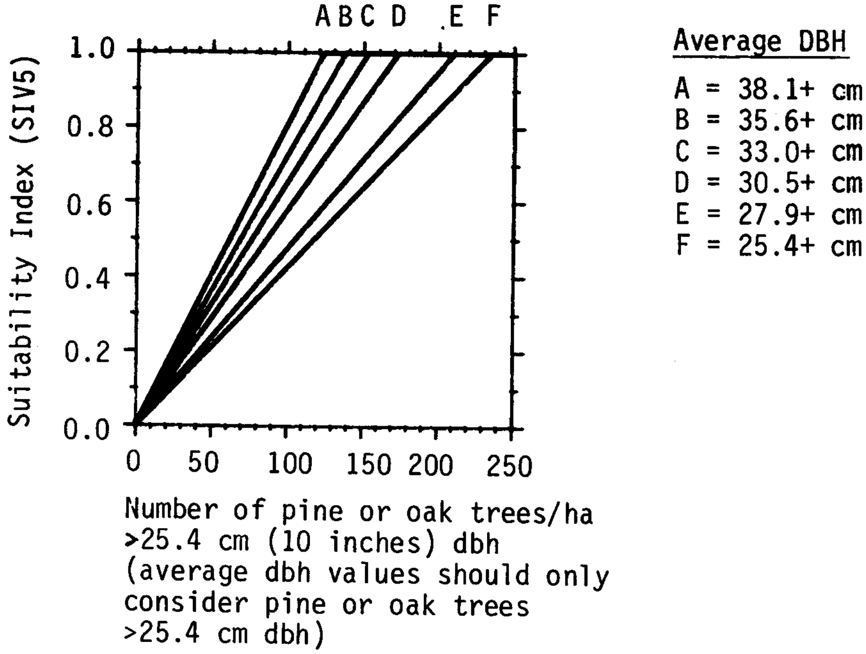


Figure 3. The relationship between habitat variables used to assess mast production and the suitability index for the variables.

Cover component. Cover needs of the bobwhite are primarily provided by low, dense woody vegetation. It is assumed that such vegetation < 2.0 m tall is required by bobwhites to provide an adequate amount of protective cover near the ground. Shrubby or forested habitats with a few areas containing 40 to 80% canopy cover of shrubby and other woody vegetation in this height zone are assumed to be optimal. (Note: The total amount of cover needed is described under the Interspersion component.) As canopy cover decreases to zero, habitats will become unsuitable. Canopy closures of 100% are assumed to be somewhat less than optimum due to their extreme density that restricts bobwhite movements. The relationship between woody vegetation density and a suitability index (SIV6) for the bobwhite is presented in Figure 4. The cover value in tree and shrub-dominated cover types is equal to SIV6.

Nesting component. Bobwhites nest in habitats with moderate herbaceous vegetation density and height that contain a moderate amount of grass. Optimal density of herbaceous cover is assumed to occur between 40 and 60% canopy cover. Areas with < 10% herbaceous cover are assumed to be too sparse to provide nest sites, while habitats with 100% herbaceous canopy cover will have lower nesting values due to excessive vegetation. The relationship between herbaceous canopy cover and a suitability index (SIV7) for the bobwhite is presented in Figure 5a. Herbaceous vegetation that is 40 to 60 cm tall in the summer is assumed to provide ideal nesting conditions, and as average heights approach either 7.6 or 100 cm, areas are assumed to be unsuitable for nesting. The relationship between vegetation height and a suitability index (SIV8) for the bobwhite is presented in Figure 5b.

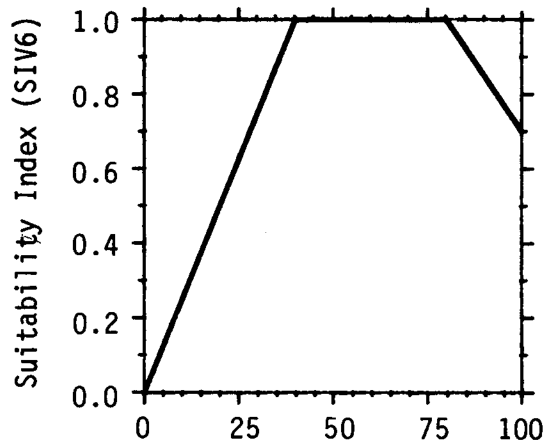


Figure 4. The relationship between the density of low woody vegetation and a suitability index for the bobwhite.

Bobwhites nest in grassy clumps and prefer to nest in areas with moderate amounts of grass cover. It is assumed that 40 to 60% of the herbaceous canopy should be comprised of grass to have optimal conditions. If none of the herbaceous vegetation is grass, it is assumed the habitat will have very low suitability for nesting. Areas with 100% of the vegetation in grass will have less than optimal suitabilities due to the lack of diversity in the herbaceous layer in such habitats. The relationship between the relative abundance of grass and a suitability index (SIV9) for the bobwhite is presented in Figure 5c. Dead grass stems are an important component for optimal bobwhite nest conditions. It is assumed that most habitats will have dead grass stems present in adequate quantity to meet nesting requirements.

Bobwhites avoid nesting in areas with poor soil drainage, and such habitats will have very low suitability. Optimal conditions are provided in habitats that are typically dry during the nesting season. The relationship between soil moisture conditions and a suitability index (SIV10) is presented in Figure 5d.

The vegetative portion of nesting suitability is a function of grass height, grass density, and the amount of bare or lightly littered ground. Each of these variables exerts a major influence on nesting suitability. Optimum vegetation conditions for nesting exist only when all three variables are optimum. Low values of any one variable may be partially offset by higher values of the remaining variables. Habitats with low values of two or more

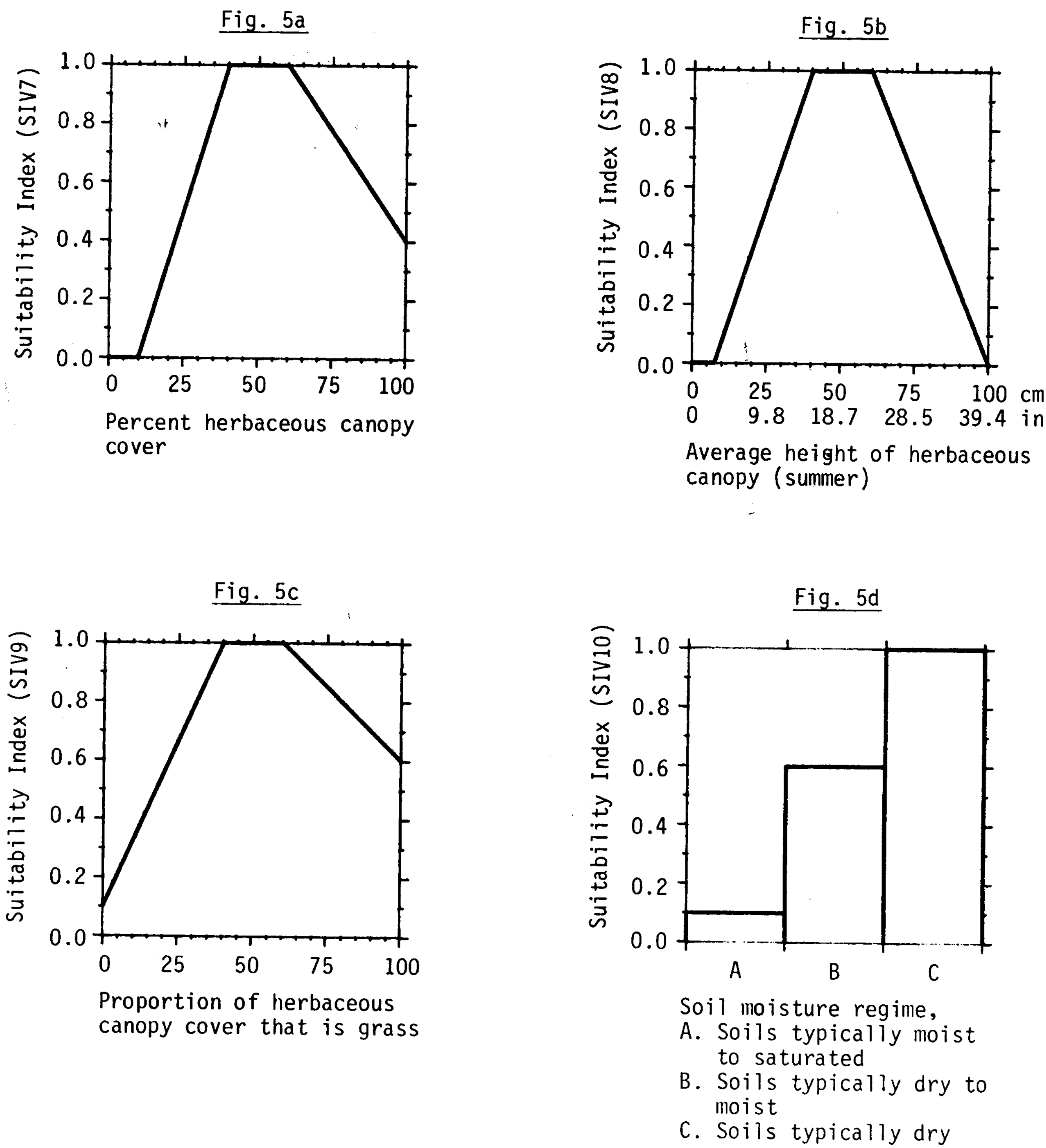


Figure 5. The relationships between habitat variables used to assess herbaceous vegetation conditions and soil moisture and the suitability indices for the variables.

variables will have low nesting suitability. Nesting suitability is assumed to be optimal only when both vegetation and soil drainage conditions are optimal. Poor soil drainage conditions will directly lower the value of the vegetative portion of the nesting component. An estimate of the suitability of nesting habitat (NSI) for all cover types except cropland can be determined with Equation 4.

$$NSI = (SIV7 \times SIV8 \times SIV9)^{1/2} \times SIV10 \qquad (4)$$

Interspersion and composition component. Maximum bobwhite densities exist when food, cover, and nesting needs occur in the proper amounts and at the proper spacing. Maximum habitat suitability is assumed to exist when 80% or more of an area provides optimum winter food conditions, 20% or more provides optimum cover, and 10% or more provides optimum nesting. These estimates account for more than one use for a given piece of land and are derived primarily from Stoddard and Komarek (1941), Edminster (1954), and Rosene (1969). The relationships between the amounts of area needed in food, cover, and nesting and suitability indices (SIV11, SIV12, and SIV13, respectively) for the bobwhite are presented in Figures 6a-c. The distance separating food, cover, and nesting resources will also affect the suitability of habitats in supporting bobwhites. It is assumed that habitat units providing individual life requisites should be ≤ 2 ha in size for optimum conditions. A circle 2 ha in size has a radius of approximately 80 m. Therefore, it is assumed that optimum conditions exist when the distance separating food, cover, and nesting resources is ≤ 80 m. It is further assumed that bobwhites may move up to 400 m to obtain missing resources (C. J. Perkins, Department of Wildlife and Fisheries, Mississippi State University, Mississippi State; letter dated January 24, 1983; J. L. Roseberry, Illinois Cooperative Wildlife Research Unit, Carbondale; letter dated January 20, 1983). Therefore, suitability will decrease to zero as the distance separating resources approaches 400 m. The relationship between this distance and a suitability index (SIV14) for bobwhites is presented in Figure 6d.

HSI determination. Determination of an HSI for a species over several cover types requires an estimate of the amount of the total area providing each life requisite, modified by the quality of each life requisite in each cover type and by the availability of other life requisites. The overall proportion of an area providing a given life requisite at equivalent optimal quality can be determined by Equation 5.

$$EOALR_j = \sum_{i=1}^{n} (q_i a_i d_i) \qquad (5)$$

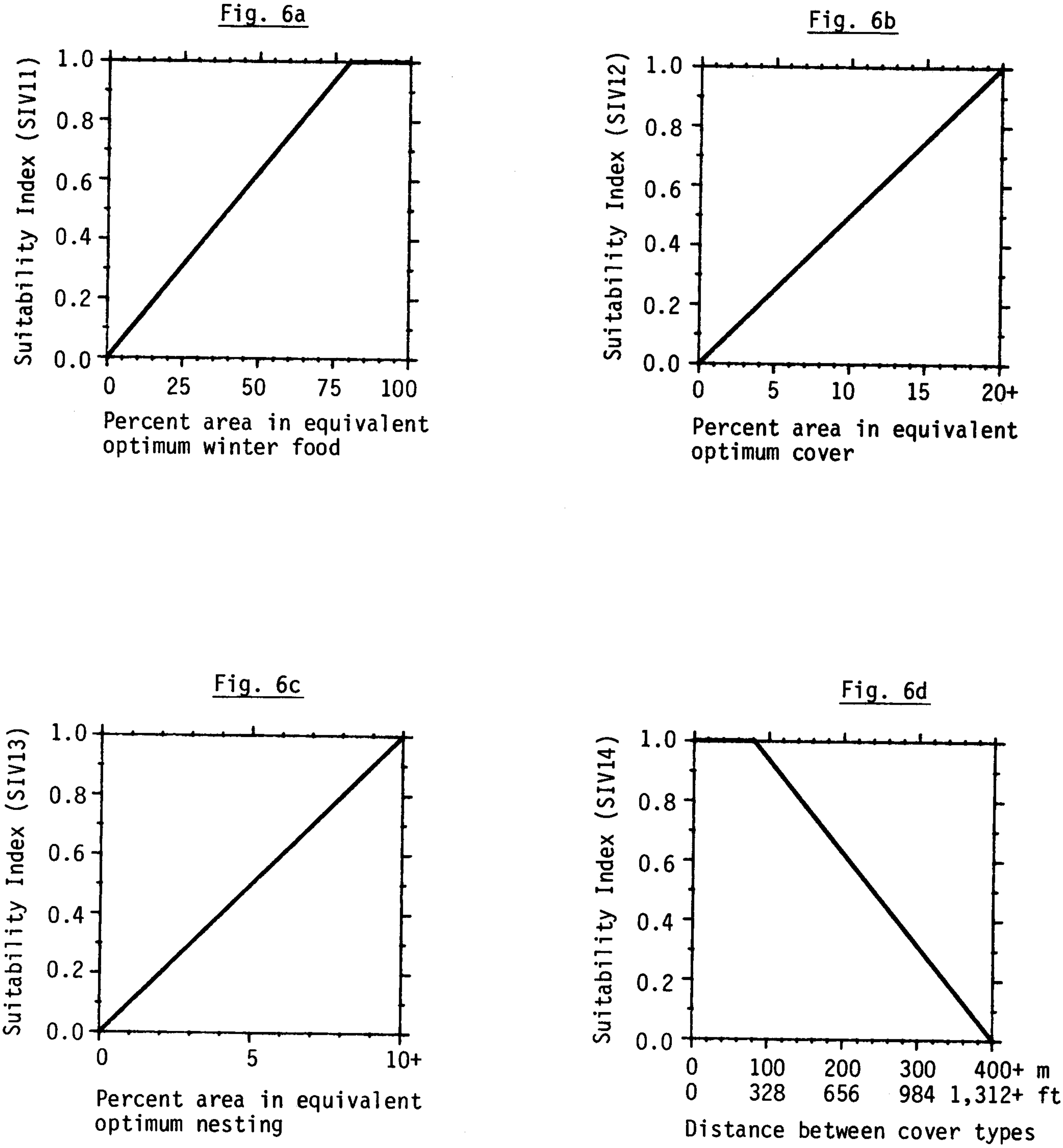


Figure 6. The relationship between variables used to assess habitat composition and interspersion, and suitability indices for the variables.

where $EOALR_j$ = the equivalent optimum area providing a given life requisite j

n = the number of cover types providing the life requisite

q_i = the quality of life requisite j in cover type i

a_i = the relative area of cover type i

d_i = the interspersion index for cover type i

Equation 5 can be solved by the following steps:

1. Determine if all life requisites are provided at some level greater than zero, considering all cover types under consideration. If any life requisite is not provided, the HSI will equal zero and no further calculations are necessary.

2. Compute the life requisite values for each cover type by collecting field data for each variable, entering these data into the proper suitability index curve, and using the resulting index values in the appropriate life requisite equations.

3. Determine the relative area (%) of each cover type within the study area as follows:

$$\text{Relative Area (\%) for Cover Type A} = \frac{\text{Area of Cover Type A}}{\text{Total Area of All Cover Types used by the Species}} \times 100$$

   Only those cover types used by the species should be considered in determining this percentage.

4. Determine which cover types are not providing one or more life requisites. For each of these cover types, an interspersion index must be computed. This is accomplished as follows:

   a. Select random points on a map in each cover type missing a life requisite and measure the distance to the edge of the nearest cover type (or cover types, where two or more life requisites are missing) that provide(s) the missing life requisite(s).

   b. Enter each of these distance measurements into the suitability index curve for interspersion (Fig. 6d), record the individual interspersion indices, and use these to calculate the average interspersion index for each cover type. Where two or more life requisites are missing from a cover type, use the lowest average interspersion index in the next calculation.

5. Modify the relative area (from Step 3) of each cover type missing a life requisite by multiplying the relative area by the average interspersion index for that cover type. This determines the useable area (%) of each cover type. For those cover types that provide all life requisites the useable area (%) is the same as the relative area (%).

6. To determine the percent area in optimum condition for any life requisite, first multiply the useable area (%) for each cover type by the life requisite values for that cover type (from 2 above). Sum the products of this multiplication across all cover types for each life requisite. This sum for each life requisite is the equivalent percent of the area that provides that life requisite at optimum levels (this is actually an equivalent figure, i.e., 100% of the area at a 0.5 value is equal to 50% of the area at an optimum, 1.0 value).

7. To determine overall life requisite values enter the percent equivalent optimum area for each life requisite (EOALRj) (Step 6) into the appropriate life requisite composition Suitability Index curve (Fig. 6a-c). The index value obtained is the overall life requisite value. The HSI is equal to the lowest of the overall life requisite values.

Application of the Model

Summary of model variables. Ten habitat variables, three composition variables, and one interspersion variable are used in this model to determine life requisite values for the bobwhite. The general relationship between habitat variables, life requisites, cover types, and the HSI are illustrated in Figure 7.

Definitions of variables and suggested measurement techniques (Hays et al. 1981) are provided in Figure 8.

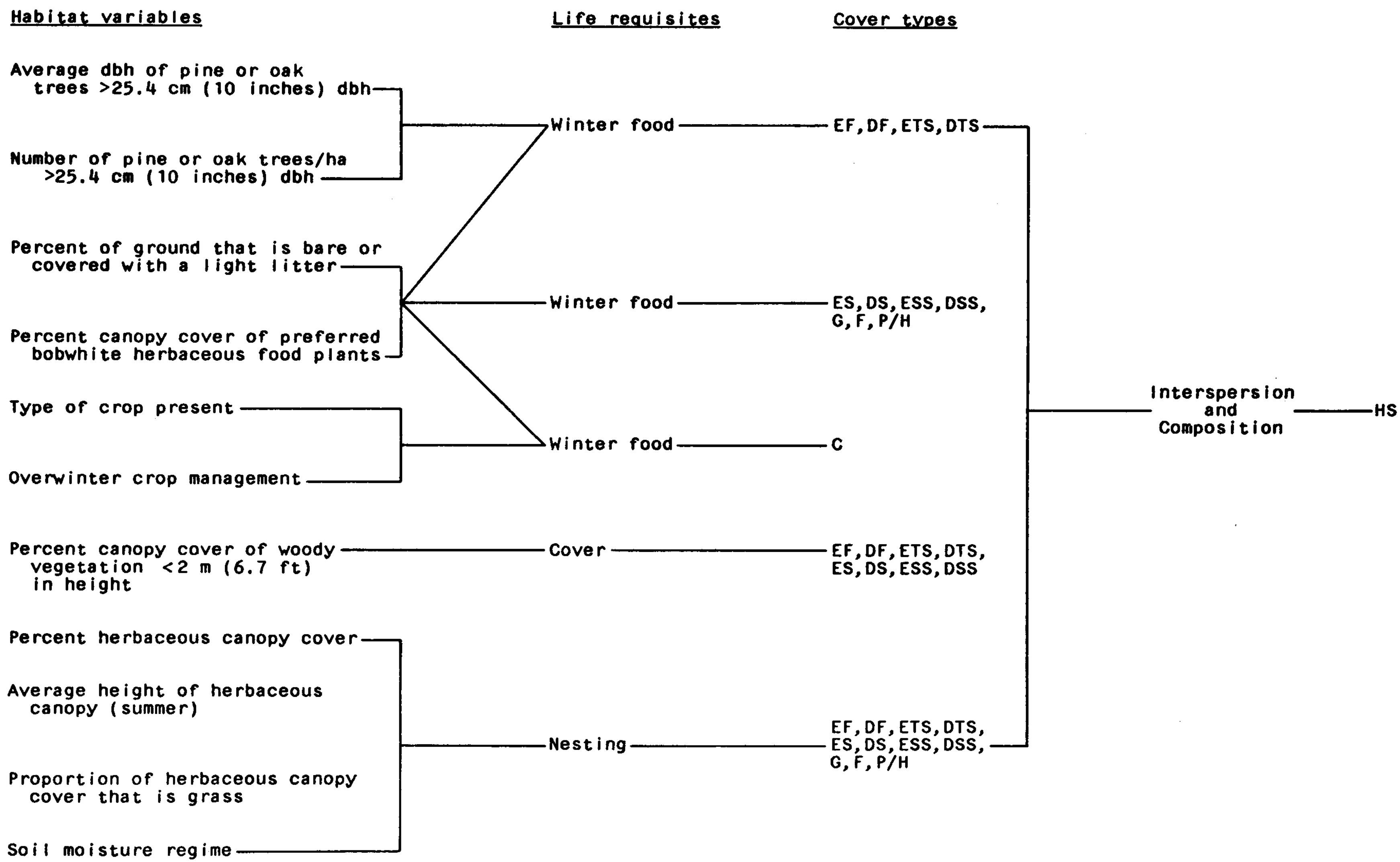


Figure 7. Relationships of habitat variables, life requisites, cover types, and the HSI in the bobwhite model.

Variable (definition)	Cover types	Suggested technique
Percent canopy cover of preferred bobwhite herbaceous food plants (the percent of the ground surface that is shaded by a vertical projection of herbaceous vegetation that is considered to be a preferred bobwhite food plant. See pp. 1-5 for specific information on preferred foods and consult local authorities).	EF,DF,ETS,DTS, ES,DS,ESS,DSS, G,F,P/H,C	Line intercept, quadrat, local information
Percent of ground that is bare or covered with a light litter [the percent of the ground surface that is nonvegetated or covered with vegetative litter that is less than 5.1 cm (2 inches) deep].	EF,DF,ETS,DTS, ES,DS,ESS,DSS, G,F,P/H,C	Line intercept, quadrat
Type of crop present [the present or last crop grown. Categories are: corn, soybeans, sorghum, cowpeas, or peanuts; other grain crops; vegetable, fruit, fiber crops, or tobacco].	C	Observation, local data
Overwinter crop management [an evaluation of the winter availability of agricultural crops based on management. Categories are: crop left unharvested; crop harvested, spring plowed; crop harvested, fall plowed].	C	Observation, local data

Figure 8. Definitions of variables and suggested measurement techniques.

Variable (definition)	Cover types	Suggested technique
Average dbh of pine or oak trees > 25.4 cm (10 inches) dbh [the average diameter of all pine or oak trees > 25.4 cm (10 inches) diameter at breast height (1.4 m/4.5 ft)].	EF,DF,ETS,DTS	Quadrat; Biltmore stick or diameter tape
Number of pine or oak trees/ha > 25.4 cm (10 inches) dbh [actual or estimated number of pine or oak trees/ha > 25.4 cm (10 inches) diameter at breast height (1.4 m/4.5 ft)].	EF,DF,ETS,DTS	Quadrat
Percent canopy cover of woody vegetation < 2.0 m (6.7 ft) in height [the percent of the ground surface that is shaded by a vertical projection of all woody vegetation in the specified height zone, including the lower, branching portions of woody vegetation whose total height exceeds 2.0 m (6.7 ft)].	EF,DF,ETS, DTS,ES,DS, ESS,DSS	Line intercept, quadrat, graduated rod
Percent herbaceous canopy cover [the percent of the ground surface that is shaded by a vertical projection of all nonwoody vegetation (grasses, forbs, sedges, etc)].	EF,DF,ETS,DTS, ES,DS,ESS,DSS, G,F,P/H	Line intercept quadrat

Figure 8. (continued).

Variable (definition)	Cover types	Suggested technique
Average height of herbaceous canopy (summer) (the average vertical distance from the ground surface to the dominant height stratum of the herbaceous canopy in the summer).	EF,DF,ETS,DTS ES,DS,ESS,DSS, G,F,P/H	Line intercept, graduated rod
Proportion of herbaceous canopy cover that is grass (the relative percent of all herbaceous cover that is comprised of grasses).	EF,DF,ETS,DTS, ES,DS,ESS,DSS, G,F,P/H	Line intercept
Soil moisture regime [the soil moisture on the ground surface during average spring/ early summer conditions. Categories are: Soils typically moist to saturated; soils moderately dry to moist; soils typically dry].	EF,DF,ETS,DTS, ES,DS,ESS,DSS, G,F,P/H	Observation, local data

Figure 8. (concluded).

Model assumptions. Numerous assumptions were made in the transformation of the published habitat information on bobwhites to the suitability index relationships and formulas used in this model. The major assumptions in the model are listed below.

1. The habitat variables and life requisite relationships apply to the entire geographic range of the bobwhite.

2. Winter foods are similar to fall and spring foods and are always more limiting than summer foods.

3. Water is not a limiting factor over most of the range of the bobwhite, and the presence of water is accounted for by the vegetative structure in arid habitats.

4. Optimal winter food values may be provided by crops alone, by the combined value of crops, herbaceous food plants, and mast, or by the combined value of herbaceous food plants and mast.

5. Herbaceous plant foods are more valuable than mast foods.

6. Interspersion of life requisites (winter food, cover, and nesting) is only a concern when a cover type does not provide one or more of these life requisites.

7. For individual life requisites, optimal overall conditions are provided by a specific mix of both quantity and quality of an area providing the life requisite. It is assumed that optimum overall conditions for a life requisite may still exist even if individual cover types contain lower than optimum quality, if the lack of quality is made up for by an increased quantity of the resource being present.

Other model assumptions are described for each variable and formula in the model. A thorough understanding of these assumptions is essential for both proper application of this model or to revise the model appropriately when the assumptions do not apply.

SOURCES OF OTHER MODELS

An index based on the interspersion of vegetative types was developed to evaluate bobwhite habitat in Nebraska (Baxter and Wolfe 1972). The model produced an output with a significant correlation ($r = 0.976$) to bobwhite numbers.

Urich et al. (1983) developed an additive habitat model for the bobwhite in Missouri. The model assesses various habitat characteristics in bottomland hardwoods, upland hardwoods, old fields, croplands, and pasture and haylands, and determines a numerical value for each of these cover types. The model does not provide a method to determine a single value for a composite of several different cover types.

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A review and synthesis of existing information were used to develop a Habitat Suitability Index (HSI) model for the northern bobwhite (Colinus virginianus). 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.

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