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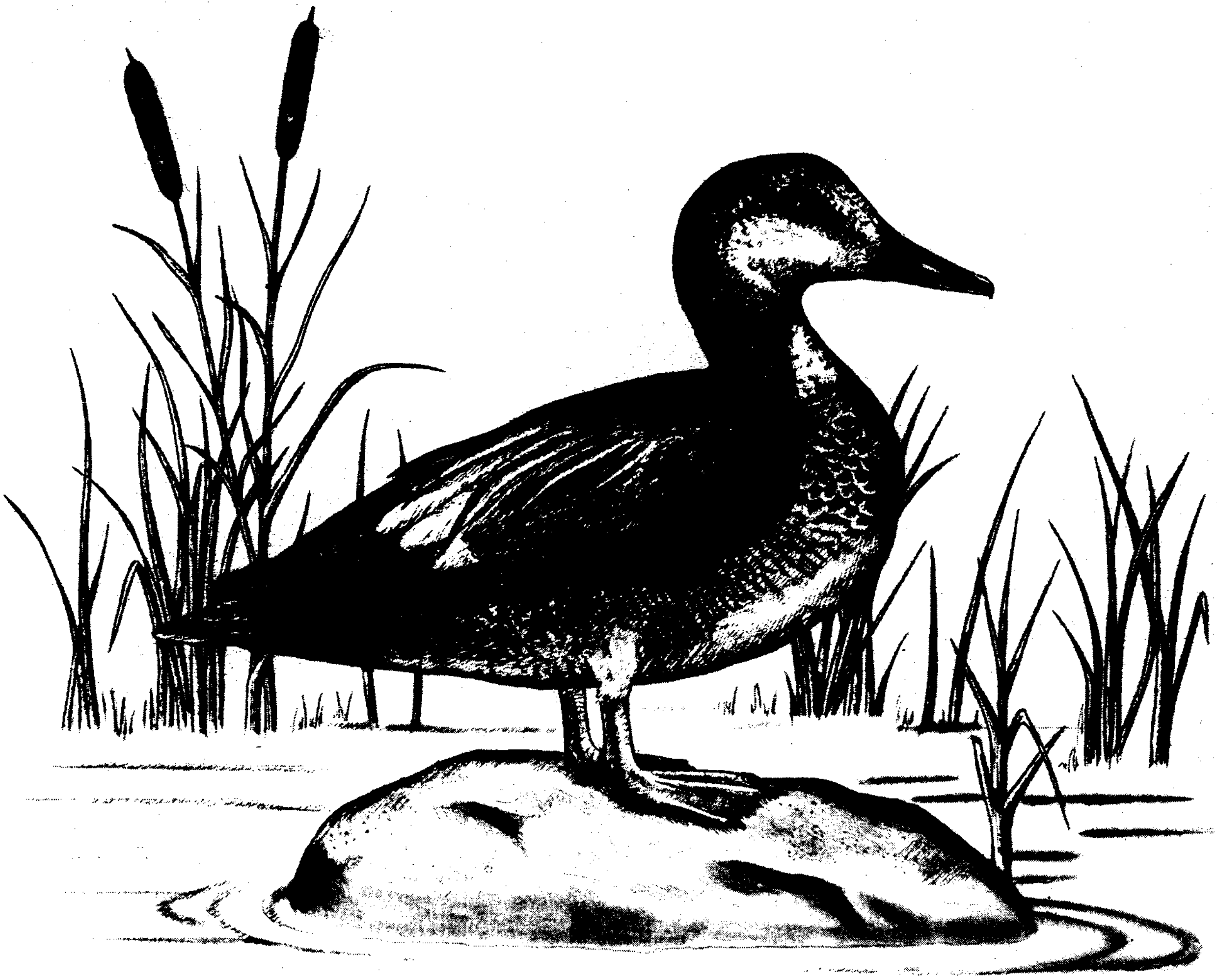
HABITAT SUITABILITY INDEX MODELS: GADWALL (BREEDING)



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HABITAT SUITABILITY INDEX MODELS: GADWALL (BREEDING)

by

Patrick J. Sousa
Habitat Evaluation Procedures Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
Drake Creekside Building One
2627 Redwing Road
Fort Collins, CO 80526-2899

Western Energy and Land Use Team
Division of Biological Services
Research and Development
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

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is a formalized synthesis of biological and habitat information published in the scientific literature and may include unpublished information reflecting the opinions of identified experts.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

Habitat Evaluation Procedures Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2627 Redwing Road
Ft. Collins, CO 80526-2899

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ACKNOWLEDGMENTS

The basis for this HSI model was developed in a workshop that included the following waterfowl biologists from the Northern Prairie Wildlife Research Center, Jamestown, ND: Leo Kirsch (retired), John Lokemoen, and George Swanson. These individuals contributed freely of their experience so that we could develop the most reasonable HSI model possible with the current knowledge of waterfowl habitat requirements. L. Kirsch, J. Lokemoen, and G. Swanson also reviewed the model that resulted from the workshop. L. Kirsch provided unpublished data that were used in the development of the nesting component portion of this model.

In addition to the waterfowl authorities, the following potential users of the models participated in the workshop and/or the model review: Michael McEnroe and Steven Young (U.S. Fish and Wildlife Service, Bismarck, ND); Richard McCabe and Robert Schultz (U.S. Bureau of Reclamation, Bismarck, ND); and Fred Ryckman and Terry Steinwand (North Dakota Department of Game and Fish, Bismarck, ND). The inputs of all these individuals contributed to the content of this model. Michael Armbruster and Arthur Allen (U.S. Fish and Wildlife Service, Ft. Collins, CO) served as facilitators for the modeling workshop.

The cover of this document was illustrated by Jennifer Shoemaker. Word processing was provided by Carolyn Gulzow, Dora Ibarra, and Elizabeth Graf. Kay Lindgren assisted with literature searches.

Funding for the development of this model was provided to the U.S. Fish and Wildlife Service's Habitat Resources Program (Region 6) by the U.S. Bureau of Reclamation under the provisions of the Fish and Wildlife Coordination Act. Additional funds were provided by the U.S. Bureau of Reclamation's Program Related Engineering and Scientific Studies (Environmental, Evaluation, and Planning Project).

GADWALL (Anas strepera)

HABITAT USE INFORMATION

General

Extensive breeding populations of the gadwall (Anas strepera) in the United States are limited to the northern prairies and to the marshes of the intermountain valleys of the western United States (Bellrose 1979). Isolated breeding populations exist along the Atlantic and Alaskan coasts and in other inland locations (Bellrose 1976). The largest numbers of breeding gadwalls occur in the mixed-grass prairies of the Dakotas and the Prairie Provinces of Canada. Range expansion to the eastern United States has apparently resulted from creation of suitable habitat in the form of impoundments on Federal refuges and state management areas (Henny and Holgersen 1974). Recent range expansion also has been noted west of the Cascades in the northwestern United States (Canning and Herman 1983).

Food

The diet of gadwalls during fall and winter is predominantly vegetation (Gates 1957; Landers et al. 1976; Paulus 1982). Vegetative material accounted for over 95% of the diet of gadwalls on a Louisiana wintering area and included algae, dwarf spikerush (Eleocharis parvula), common widgeongrass (Ruppia maritima), spiked watermilfoil (Myriophyllum spicatum), and baby pondweed (Potamogeton pusillus) (Paulus 1982). The two most prominent plants in the diet of gadwalls in South Carolina were fragrant flatsedge (Cyperus odoratus) and Carolina redroot (Lachnanthes caroliniana) (Landers et al. 1976). Important food plants in Utah during the fall were sago pondweed (P. pectinatus), widgeongrass, and inland saltgrass (Distichlis stricta) (Gates 1957).

Animal food makes up a larger proportion of the spring and summer diet of adult gadwalls (Serie and Swanson 1976) and ducklings (Sugden 1973). From early spring through late August, animal material accounted for 46% of the diet of adult gadwalls on saline wetlands in North Dakota (Serie and Swanson 1976). Crustaceans, especially those belonging to the order Anostraca, and insects, especially adult and larval chironomids (Chironomidae), were prominent in the animal portion of the diet. Hens ate more crustaceans and dipterans, and less vegetation, than their mates during the egg-laying period. The proportion of animal food in the diet reached a peak of 72% in females during the egg-laying period. Important plants during the spring and summer period were filamentous algae, widgeongrass, muskgrass (Chara spp.), and sago pondweed.

Recently hatched gadwall ducklings in Alberta predominantly fed on invertebrates, but were essentially herbivorous by 3 weeks of age (Sugden 1973). Major animal foods included adult and larval chironomids, water boatmen

(Corixidae), beetles (Coleoptera), and cladocerans (Cladocera). Important plants in the ducklings' diet were baby pondweed, green algae (Cladophoracea), duckweed (Lemna minor), and seeds of American sloughgrass (Beckmannia syzigachne).

Gadwalls typically feed by dabbling, tipping, surface picking, and filtering (Serie and Swanson 1976). Gadwalls in North Dakota concentrated their feeding activities in the littoral zones of deeper, permanent wetlands and throughout the entire basin of shallow wetlands (Serie and Swanson 1976). Ephemeral ponds may be important sources of accessible and abundant planktonic crustaceans early in the breeding season. Wintering gadwalls in Louisiana fed 96.7% of the time in water 15 to 67 cm deep (Paulus 1982). Broods in Alberta also avoided feeding in areas < 15 cm deep and concentrated their feeding activities in water 17 to 46 cm deep (Sugden 1973). Broods fed 86% of the time over areas of submerged vegetation,

Water

The distribution and density of waterfowl is influenced to a large degree by water permanence in available wetlands (Kantrud and Stewart 1977); wetlands are considered to be the primary factor in waterfowl production (Higgins 1977).

The use of stock ponds by gadwall broods in South Dakota primarily was influenced by the amount of open water (Mack and Flake 1980). Open water sites are preferred by gadwalls for loafing (Duebbert 1966) and as escape cover by broods (Evans and Black 1956, cited by Mack and Flake 1980) and adults (Flake et al. 1977, cited by Mack and Flake 1980). Gadwall pairs in Manitoba were found in greatest abundance when the ratio of open water to emergent vegetation was approximately 50:50, compared to wetlands with 30:70 and 70:30 ratios (Kaminski and Prince 1981). However, preference of gadwall pairs for habitats with a 50:50 ratio of water to cover was significant for only 1 year of the Z-year study. Trauger (1967) recommended that open water compose at least 40% of a wetland for brood use by dabbling ducks. Murkin et al. (1982) concluded that a water to vegetation ratio of 50:50 resulted in the maximum density of waterfowl pairs.

Cover

Gadwalls wintering in Texas utilized fresh water habitats and use was concentrated in the deeper waters (maximum water depth was 2.5 m; average water depth was 1.5 m) with abundant aquatic vegetation and sparse emergent vegetation (White and James 1978). In contrast, late summer molting cover in Manitoba was characterized by dense stands of cattail (Typha spp.) or bulrush (Scirpus spp.) (Oring 1969).

Reproduction

Pair habitat. Seasonal and semipermanent wetlands accounted for 54.6 and 35.4%, respectively, of use by gadwall pairs in North Dakota (Kantrud and Stewart 1977) and 33 and 18%, respectively, of the wetland area (Stewart and Kantrud 1973). A Z-year average of 61% of gadwall pairs in South Dakota used natural basin wetlands, which accounted for 75% of the area of all wetland basins (Ruwaldt et al. 1979). Semipermanent and seasonal wetlands accounted for a 2-year average of 43.7 and 13.0%, respectively, of gadwall pair use and 32.1 and 13.4% of the wetland area. Constructed wetlands (dugouts and stock ponds) in the same study accounted for a Z-year average of 15% of the wetland area and 32.4% of use by gadwall pairs. Gadwall pairs in South Dakota used ponds with scattered dense patches of emergents and avoided ponds with no emergent vegetation (Flake and Vohs 1979). Use of wetlands by gadwall pairs also was positively correlated with the presence of round-stem bulrushes (Scirpus spp.) and shoreline irregularity.

Numbers of gadwall pairs over a 15-year period in Saskatchewan were Positively correlated with the number of pairs present in the previous year (third-order, Spearman-rank, partial correlation coefficient = 0.31; $P < 0.10$) (Leitch and Kaminski 1985). Pair numbers were not significantly correlated with the number of wetlands available in May or in August of the previous year.

Nesting habitat. Gadwalls nest on islands, on dikes in marshes, and in fields and meadows, but rarely nest over water (Bellrose 1976). Fields of seeded native grasses supported the highest number of initiated nests of gadwalls in North Dakota, followed by seeded introduced grasses and unplowed prairie (Klett et al. 1984). Seeded native and seeded introduced grasses supported about the same number of initiated nests in South Dakota, followed by unplowed prairie. Ninety-five percent of gadwall nests in an intensively farmed area of North Dakota were in untilled uplands, with the remaining 5% in growing grains (Higgins 1977); summer fallow areas, mulched stubble, and standing stubble were not used. Nests may be placed in herbaceous vegetation (Duebbert and Lokemoen 1976; Kirsch et al. 1978) or on the ground under shrub clumps (Duebbert et al. 1983; J. T. Lokemoen, U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Jamestown, ND; pers. comm.). Most nests are located on the driest sites available (Miller and Collins 1954; Gates 1962; Oring 1969).

Presence of residual herbaceous vegetation may be an important habitat factor in nest site selection (Duebbert and Lokemoen 1976; Kirsch et al. 1978; Voorhees and Cassel 1980), although new growth may partially compensate for the lack of residual herbaceous vegetation (Martz 1967) because gadwalls begin nesting after new plant growth has begun (Kirsch et al. 1978; Giroux 198113; Hines and Mitchell 1983). Data (Table 1) provided by L. M. Kirsch (U.S. Fish and Wildlife Service, retired, Woodworth, ND; unpubl.) revealed an increase in gadwall nesting density with an increase in the average height and density of residual herbaceous vegetation as evaluated by a visual obstruction measurement (the height at which a round pole 3 x 150 cm is totally obscured by vegetation when viewed from a distance of 4.0 m) (Robel et al. 1970). Linear regression analysis of the data in Table 1 resulted in a regression equation of $Y = 1.68 + 2.42x$, a correlation coefficient (r) of 0.77 ($P < 0.05$), and a coefficient of determination (r^2) of 0.59. Nesting densities within a given class of visual obstruction measurements of residual vegetation varied widely, however, as indicated by the ranges in nesting density in Table 1, suggesting that other factors also had a major influence on nest density. One reason for the high variability in nest densities within given visual obstruction classes

Table 1. Gadwall nesting densities by classes of residual vegetation for fields on the Woodworth Study Area, North Dakota, 1974-1978 (data provided by L. Kirsch).

$\bar{x}$ visual obstruction measurement (range) in dm	Number of observations, in class	Mean number of gadwall nests/40.5 ha (range)
0.17 (0.12-0.24)	7	3.28 (0.00-14.28)
0.30 (0.25-0.34)	7	2.66 (0.00-8.33)
0.42 (0.35-0.49)	7	1.36 (0.00-3.33)
0.55 (0.50-0.60)	7	1.52 (0.00-5.00)
0.66 (0.62-0.72)	7	3.99 (0.00-9.09)
0.78 (0.74-0.83)	7	3.12 (0.00-8.33)
0.91 (0.86-0.98)	7	3.38 (0.00-8.33)
1.06 (1.01-1.14)	7	1.36 (0.00-4.21)
1.32 (1.18-1.44)	7	10.07 (0.00-25.00)
1.52 (1.45-1.60)	7	6.85 (0.00-16.67)
1.73 (1.62-1.91)	7	4.85 (0.00-13.04)
2.31 (2.01-2.86)	7	6.51 (2.17-13.04)
3.70 (3.18-4.22)	2	10.36 (6.06-14.67)

is that some nests may have been initiated after new growth had begun (Kirsch, pers. comm.), resulting in situations where residual vegetation was not a cue used in nest site selection. Kirsch (pers. comm.) and Lokemoen (pers. comm.) indicated that a field with an *average* visual obstruction measurement of residual vegetation ≥ 2.5 dm would be ideal nesting habitat for gadwalls.

A study on 15 *areas* in North Dakota, Saskatchewan, and Manitoba suggested a direct but weak ($P = 0.06$) relationship between gadwall nest density and average visual obstruction measurement of vegetation in late spring (late May-early June) (Shaffer et a?. 1985). Visual obstruction measurements, study area effects, and number of pairs explained 26% of the total variation in gadwall nest density. Shaffer et al. (1985) suggested the following model to determine the number of gadwall nests *(N)* to be found in a given field:

$$N = (0.0052 + 0.0045 \times X) \times P \times A$$

where X = the average visual obstruction measurement in late spring

P = the estimated number of gadwall pairs within 0.6 km of the center of a field

A = the area of the field

The above model was considered to be most useful when comparing fields that shared similar study area effects, i.e., fields that were located in close proximity to each other (Shaffer et al. 1985).

High densities of gadwalls nested on a North Dakota island where herbaceous vegetation averaged 15 to 25 cm tall at the initiation of nesting but 1.5 to 1.8 m tall during the late incubation stages (Duebbert 1966). Fifty-one percent of nests in North Dakota nesting fields *were* in herbaceous cover from 30 to 60 cm tall, while 47% were in cover > 60 cm tall (Duebbert and Lokemoen 1980). No nests were found in herbaceous cover < 15 cm tall. Most gadwall nests in a California study were in vegetation 33 to 91 cm tall that provided concealment on all sides, as well as from above (Miller and Collins 1954). Canopy cover at gadwall nests in Saskatchewan exceeded 25% in vegetation > 30 cm tall that provided lateral concealment on three or four sides (Hines and Mitchell 1983). Vegetation < 20.3 cm tall is considered too short for nest concealment (Martz 1967). Kirsch et al. (1978:492) stated that they "... have not found grassland vegetation that was too tall and dense for use by nesting ducks nor have ... [they] found evidence that such conditions exist in the prairies." Duebbert (1982:236) concluded that gadwall nesting cover on islands "... can consist of brush, forbs, or grasses if the vegetative structure is tal? and dense."

The highest nesting densities of gadwalls have been reported from island habitats (Hammond and Mann 1956; Duebbert 1966, 1982; Giroux 1981a; Duebbert et al.1983; Hines and Mitchell 1983), in response to the lack of mammalian predation on the islands (Duebbert et al. 1983). Nest success on islands is higher than reported for nests in mainland habitats (Duebbert et al. 1983; Hines and Mitchell 1983). For example, nest success on islands and isolated ditch banks in Saskatchewan was 65%, while no nests were successful on uplands (Hines and Mitchell 1983). High densities and success of gadwall nests in mainland habitat in North Dakota resulted from intensive control of mammalian predators (Duebbert and Lokemoen 1980).

Gadwall nests on islands in Alberta were in forbs and grass-forbs cover (Giroux 1981a), and gadwall nests on Miller Lake (North Dakota) islands were concentrated in patches of western snowberry (Symphoricarpos occidentalis) - woods rose (Rosa woodsii) (Duebbert et al. 1983). Gadwall nests on a 2.2 ha island in Saskatchewan were concentrated in patches of western snowberry and slim nettle (Urtica gracilis) (Hines and Mitchell 1983). Shrub clumps in nonisland habitats are readily used for nesting cover by gadwalls (Lokemoen, pers. comm.).

Preferred nesting cover is eliminated by activities such as grazing (Kirsch 1969) or mowing (Martz 1967; Kirsch 1969; Voorhees and Cassel 1980). Although a strong relationship has been demonstrated between duck nesting densities and undisturbed cover (Kirsch et al. 1978), mowing may be useful for maintaining vegetative cover in earlier, more productive successional stages (Voorhees and Cassel 1980). Duebbert et al. (1981) recommended periodic disturbance to native and introduced grassland nesting habitat to maintain optimum conditions, although annual mowing or grazing was not recommended.

Brood habitat. Preferred escape cover for gadwall broods is large areas of open water, rather than water with emergents (Evans and Black 1956, cited by Mack and Flake 1980). Gadwall broods in Utah used deep-water marshes and the edges of large impoundments (Gates 1962); broods in Washington used large alkaline lakes with steep walls, as well as other wetlands (Yocom and Hansen 1960). Sixty-one percent of 1,073 gadwall broods observed over a 20-year period in North and South Dakota were in semipermanent wetlands (Class IV of Stewart and Kantrud 1971), 18% were in seasonal wetlands (Class III), and 9% were in permanent wetlands (Class V) (Duebbert and Frank 1984). The proportion of total wetland area accounted for by these wetland types in North Dakota in 1967 was 18% semipermanent, 36% seasonal (including 3% in tilled condition), and 3% permanent (Stewart and Kantrud 1973). However, wetland availability figures were for 1 year only, apparently reflected the availability of wetlands to pairs, and may not be a valid estimate of the wetland distribution available to broods. Amount of open water and number of wetland basins/0.65 km^2 plot were the primary factors that determined use of stock ponds by gadwalls in South Dakota (Mack and Flake 1980). The mean open water area on stock ponds used by gadwall broods was 1.4 ha, compared to a mean of 0.6 ha on ponds not used by gadwall broods. Wetland basins averaged 5.0/0.65 km^2 on study plots used by gadwall broods, but only 2.8/0.65 km^2 on plots not used by broods. Gadwall broods over a 15-year period in Saskatchewan were positively correlated with the number of pairs in the preceding spring (second-order, Spearman-rank, partial correlation coefficient = 0.56; $P < 0.01$) and the number of wetlands containing water in August (second-order, Spearman-rank, partial correlation coefficient = 0.43; $P < 0.05$) (Leitch and Kaminski 1985).

The gadwall is the primary waterfowl species in North Dakota that uses saline lakes for brood-rearing (Swanson et al. 1984). Brood use is closely tied to the presence of freshwater seeps or areas of lower salt content.

These areas provide fresh water for drinking and support dense emergent vegetation which provides cover for broods.

Interspersion

The average distance from nest sites to water was < 45.8 m in several studies of gadwalls (Miller and Collins 1954; Gates 1962; Vermeer 1970). Gadwall nests in North Dakota averaged 351 m from water (Duebbert and Lokemoen 1976), including some nests in fields up to 2.4 km from water (Duebbert and Lokemoen 1980). G. A. Swanson (U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Jamestown, ND; pers. comm.) suggested that selection of nesting habitat by gadwalls is based on proximity to pair feeding habitat rather than on proximity to brood-rearing habitat.

Gadwall hens in Utah moved their broods an average of 0.9 km and a maximum of 1.85 km from the nest to brood habitat (Gates 1962). Hens and broods in South Dakota dispersed into wetlands 1.6 to 3.2 km from the nests (Duebbert and Lokemoen 1980). Breeding home ranges for five hens in Utah averaged 27.1 ha (range 13.8 to 35.2 ha) and included at least one feeding pond and a ditch or channel used for loafing (Gates 1962).

Island-nesting gadwalls may reach high densities, for example: 494 nests/ha on a 0.32 ha island in North Dakota (Hammond and Mann 1956); 139 to 237 nests/ha in preferred island habitat in North Dakota (Duebbert et al. 1983); and 74 nests/ha on a 2.2 ha island in Saskatchewan (Hines and Mitchell 1983). Nest density in the latter study was 284 nests/ha in two patches of snowberry, totalling 0.5 ha (Hines and Mitchell 1984). Nest parasitism by other gadwalls (31 of 355 nests) at this high nest density reduced nesting success from 76 to 54%, egg success from 74 to 45%, and hatchability of eggs from 97 to 91% (Hines and Mitchell 1984). Parasitism by lesser scaup (Aythya affinis) reduced egg success from 74 to 67%. Nest densities elsewhere on the island ranged from 13 to 52 nests/ha; only one parasitized nest was found at the lower nest densities.

Nest densities in nonisland habitats are generally much lower than those observed on islands. For example, Kaiser et al. (1979) recorded only 0.67 nests/km^2 in native grasslands in South Dakota and 3.88 nests/km^2 in tame grasslands. The estimated number of initiated gadwall nests in North Dakota was 28/km^2 in seeded native grasses, 14/km^2 in seeded introduced grasses, and 4/km^2 in unplowed prairie (Klett et al. 1984). Gadwalls in South Dakota initiated an estimated 10 nests/km^2 in seeded native grasses, 11/km^2 in seeded introduced grasses, and 0/km^2 in unplowed prairie. Nest density in untilled uplands and growing grains in North Dakota was 4.33 nests/km^2 and 0.23 nests/km^2, respectively (Higgins 1977). A density of 7.5 nests/km^2 (61 nests on a 8.13 km^2 study area) was observed in an area of intensive predator control (Duebbert and-Lokemoen 1980).

Areas with diversified land uses are better for duck production than large expanses of tilled grain monocultures (Duebbert and Lokemoen 1976).

Special Considerations

Island-nesting waterfowl, such as gadwalls, require suitable wetlands for pair and brood-rearing habitat (Duebbert et al. 1983). Creation of nesting habitat in the form of small islands should consider the carrying capacity of surrounding wetlands for pairs (Hines and Mitchell 1983). Habitat management for waterfowl production must involve both wetland and upland habitat (Leitch and Kaminski 1985).

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area. This HSI model was originally developed for use in central and eastern North Dakota. It is considered applicable throughout the Prairie Pothole Region, where the greatest breeding densities of gadwalls occur (Fig. 1). Within the United States this region includes the mixed-grass prairie of North and South Dakota; the tallgrass prairie in western Minnesota, eastern North and South Dakota, and the sandhills of Nebraska: and the shortgrass prairie west of the Missouri River through Montana '(Bellrose 1976, 1979). The model also should be applicable within the Prairie Provinces of Canada and may be applicable in other portions of the breeding range of the gadwall

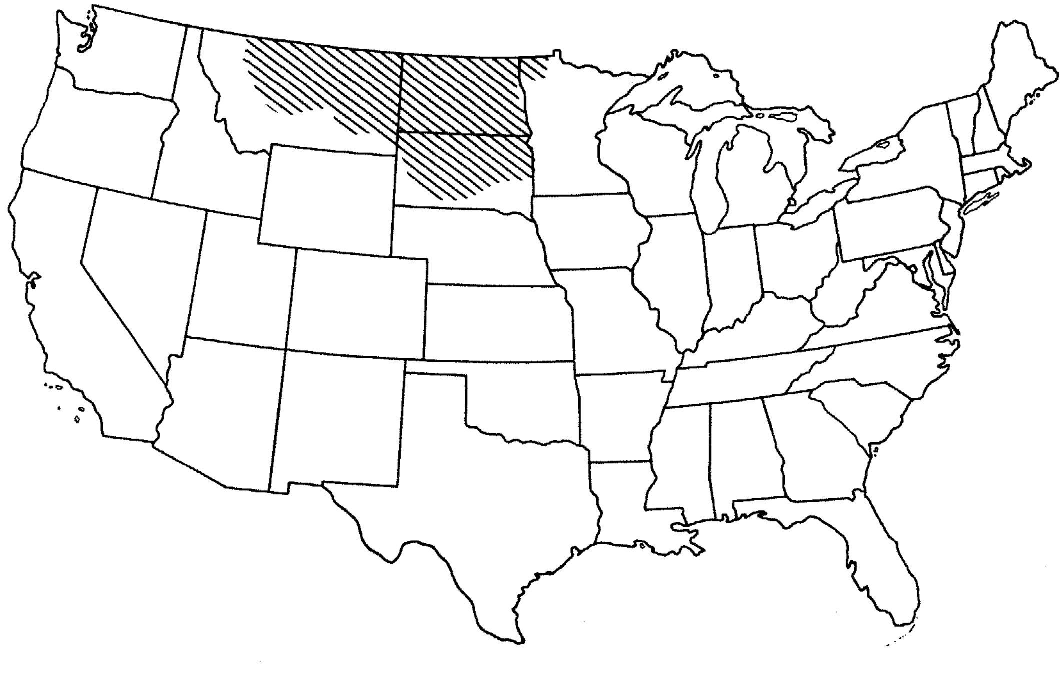

Figure 1. Geographic applicability of the gadwall HSI model within the United States (corresponds to areas of highest gadwall breeding densities, as shown in Bellrose 1976).

Season. This HSI model was developed to evaluate the quality of spring and summer habitat for gadwalls.

Cover types. During the breeding season, gadwalls may use any of the following upland cover types for nesting (terminology follows that of U.S. Fish and Wildlife Service 1981): Cropland (C); Pasture and Hayland (P/H); Grassland (G); Forbland (F); Deciduous Shrubland (DS); and Deciduous Shrub Savanna (DSS). Gadwall pairs and broods use a variety of wetlands in the Palustrine and Lacustrine systems (terminology from Cowardin et al. 1979). The data that were used to develop the pair and brood components of this model, however, were based on the classification of Stewart and Kantrud (1971). Data presented in this model follow the Stewart and Kantrud (1971) classification used in the original references. The seven wetland classes defined by Stewart and Kantrud (1971) generally correspond to the water regime modifiers of Cowardin et al. (1979) (Table 2). The model can be used with either classification system using the relationships in Table 2. Definitions of the wetland classes and water regime modifiers listed in Table 2 are provided under Application of the Model. Constructed wetlands (stockponds, dugouts, and reservoirs) can be included in this model by classifying them into one of the wetland classes or water regime modifiers, based on a comparison of their physical and vegetational characteristics to the criteria used in the appropriate classification system.

Minimum habitat area. Minimum habitat area is defined as the minimum amount of contiguous suitable habitat that is required before an area will be occupied by a species. Specific information on the minimum habitat area for the gadwall was not located in the literature.

Verification level. The critical habitat requirements and associated habitat variables identified in this model resulted from a modeling workshop held April 13-16, 1982, in Fort Collins, Colorado. The purpose of the workshop was to develop habitat models for the blue-winged teal (*Anas discor*) and gadwall, based on the available literature and the expertise of the following individuals:

John Lokemoen, U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Jamestown, North Dakota.

George Swanson, U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Jamestown, North Dakota.

Leo Kirsch, U.S. Fish and Wildlife Service (retired), Woodworth, North Dakota.

Michael McEnroe, U.S. Fish and Wildlife Service, Ecological Services, Bismarck, North Dakota.

Richard McCabe, Bureau of Reclamation, Bismarck, North Dakota.

Table 2. Comparison of the wetland classes of Stewart and Kantrud (1971) with the water regime modifiers of Cowardin et al. (1979). (Modified from Cowardin et al. 1979)

Wetland class (Stewart and Kantrud 1971)		Water regime modifier (Cowardin et al. 1979)
I	Ephemeral ponds	None, not considered a wetland
II	Temporary ponds	Temporarily flooded
III	Seasonal ponds and lakes	Seasonally flooded
IV	Semipermanent ponds and lakes	Semipermanently flooded
	None[a]	Intermittently exposed
V	Permanent ponds and lakes	Permanently flooded (with mixohaline water)
VI	Alkali ponds and lakes	Intermittently flooded (with saline or hypersaline water)
VII	Fen (alkaline bog) ponds[b]	Saturated

[a] No corresponding wetland class exists for the intermittently exposed flooding regime.

[b] Fens are not included in the gadwall HSI model.

A meeting was held May 25-28, 1982 in Bismarck, North Dakota, to review the waterfowl models developed from the workshop. Results of the review indicated that the pair and brood components of the model appeared to meet perceptions of the participants about the suitability of several study areas for which data were available. The reliability of the nesting component of the model was questioned, but could not be evaluated with the available data. Participants in the review meeting were J. Lokemoen, L. Kirsch, M. McEnroe, R. McCabe, and F. Ryckman and M. Johnson (North Dakota Department of Game and Fish, Bismarck, North Dakota).

A review of the assumptions and limitations of the model was conducted May 24-25, 1983 in Jamestown, North Dakota. Participants in the review were J. Lokemoen, L. Kirsch, R. McCabe, R. Schultz (Bureau of Reclamation, Bismarck, North Dakota), S. Young (U.S. Fish and Wildlife Service, Ecological Services, Bismarck, North Dakota), and T. Steinwand (North Dakota Department of Game and Fish, Bismarck, North Dakota). Participants in the model review meeting concluded that the HSI model was realistic and as good as could be expected without further field testing and/or application. J. Lokemoen and L. Kirsch concluded that the model would adequately predict potential habitat quality for the gadwall in the Prairie Pothole Region. Data provided by L. Kirsch at this meeting were used to develop the nesting component portion of the current model.

A study was conducted on several study areas in North Dakota and Canada to further evaluate the relationship between average vegetative conditions of a field and attractiveness of the field to nesting gadwalls (Shaffer et al. 1985). Results of the study were used to modify the nesting component of the current model.

Model Description

Overview. Breeding habitat suitability for the gadwall can be evaluated by assessing the habitat requirements for pairs, nesting hens, and broods. Habitat suitability for pairs and broods is a function of the availability and distribution of wetlands; pairs are able to use all wetland types other than ephemeral wetlands, but broods are restricted to more permanent wetlands that will provide a reliable source of water during the brood-rearing period. Suitability of nesting habitat is dependent on the abundance of dense, tall herbaceous or shrub cover.

This HSI model provides a method to evaluate gadwall habitat suitability within the context of habitat suitability for all species of upland nesting waterfowl in the Prairie Pothole Region. The standards of comparison used in the pair, nesting, and brood components of this model are based on the needs of all upland nesting waterfowl. Evaluation of the habitat in a given area, however, is modified by the specific habitat requirements of the gadwall to obtain a Habitat Suitability Index for this species.

The following sections identify important habitat variables, describe suitability levels of the variables, and describe the relationships between variables.

Pair habitat component. Pairs use wetlands for feeding, loafing, and courtship prior to nesting. Data on the use of basin wetlands in the Prairie Pothole Region of North Dakota (Kantrud and Stewart 1977) and in South Dakota (Ruwaldt et al. 1979) indicate that various classes of wetlands (as defined by Stewart and Kantrud 1971) are used to different degrees by gadwall pairs. An index of preference for wetland classes can be developed, based on pair use compared to the availability of wetland classes. These indices are presented in Table 3, based on North Dakota data (Stewart and Kantrud 1973; Kantrud and Stewart 1977), and in Table 4, based on data from South Dakota wetlands (Ruwaldt et al. 1979). Based on this analysis, the highest quality natural wetlands for gadwall pairs in North Dakota are semipermanent wetlands, followed by temporary and seasonal wetlands (Table 3). Gadwall pairs in South Dakota also showed the highest preference for semipermanent wetlands, followed by seasonal and permanent wetlands (Table 4). Use of preference indices assumes that all wetlands within a given class have the same value for gadwall pairs. Variability in other factors, such as available food, open water to vegetation ratio, and shoreline length and irregularity, are not addressed in this model. Although variability within a wetland class certainly occurs, this model is intended for evaluation of large areas with numerous wetlands, rather than an evaluation of each wetland.

Gadwall pairs will use constructed wetlands. However, preference indices for gadwall pairs in constructed wetlands are not included in this model because the classification of constructed wetlands is not based on ecological characteristics. If constructed wetlands are to be included in an application of this model, preference indices must be developed by the model users. Similarities in water conditions and vegetation between constructed and natural wetlands can be used to assign pair preference indices to constructed wetlands. Data provided by Ruwaldt et al. (1979) for South Dakota may be useful in developing pair preference indices for stock ponds and dugouts.

Optimum conditions for waterfowl pairs, including gadwalls, in the Prairie Pothole Region are assumed to exist when a minimum of 150 optimum wetlands account for a minimum of 64.8 ha/259 ha. This assumption was based on the perceived need for a large number of small wetlands within a section (259 ha) in order to support the maximum number of waterfowl pairs, while still providing potentially optimum nesting and brood habitat (discussed below). The selection of 150/section as the standard of comparison for the density of optimum wetlands was based on the opinion of species experts in the modeling workshop that this is an attainable figure that represents optimum conditions.

A complete lack of wetlands provides no pair suitability. The value of wetlands to pairs is assumed to decrease in a linear relationship as the number and area of wetlands approaches zero. Pair densities on smaller wetlands are usually greater than on larger wetlands, because larger wetlands generally have large areas of open water that do not provide the required isolation for pair use. The conditions described as optimum for pairs (150 wetlands totalling 64.8 ha/section) equate to an average wetland size of 0.43 ha. If it is assumed that a few large wetlands will be present, then most of the wetlands will be < 0.4 ha, a condition considered by workshop participants to be optimum for pairs.

Table 3. Determination of a wetland preference index for gadwall pairs in the Prairie Pothole Region of North Dakota.

Wetland class[a]	Gadwall use (% total distribution)[b]	Availability of wetland class (% of total wetland area)[c]	Use/availability	Index[d]
Ephemeral (I)	0.0	1	0.00	0.00
Temporary (II)	3.6	3	1.20	0.61
Seasonal (III)	54.6	36	1.52	0.77
Semipermanent (IV)	35.4	18	1.97	1.00
Permanent (V)	2.0	3	0.67	0.34
Alkali (VI)	0.4	6	0.07	0.04

[a] The classification used is that of Stewart and Kantrud (1971), because data on waterfowl use presented by Kantrud and Stewart (1977) were based on this classification. See Table 2 and Application of the Model for guidelines on using other wetland classification systems.

[b] From Kantrud and Stewart (1977:247, Table 1).

[c] From Stewart and Kantrud (1973:45, Table 2). The number represents the proportion of the total wetland acreage accounted for by the individual wetland class. Total is 67% because only those wetland classes of the Stewart and Kantrud (1971) classification system referred to in Kantrud and Stewart (1977) were used. The remaining wetlands were undifferentiated tillage ponds (25%), streams and oxbows (5%), and constructed wetlands (≤ 3%).

[d] Determined by dividing the use/availability value by 1.97, the maximum use/availability value.

Table 4. Determination of a wetland preference index for gadwall pairs in South Dakota.

Wetland class[a]	Gadwall use (% total distribution)[b]	Availability of wetland class (% of total wetland area)[c]	Use/availability	Index[d]
Ephemeral (I)	0.0	14	0.00	0.00
Temporary (II)	1.8	11	0.16	0.12
Seasonal (III)	13.0	13	1.00	0.74
Semipermanent (IV)	43.7	32	1.36	1.00
Permanent (V)	2.6	4	0.65	0.48
Alkali (VI)	-	-	-	-

[a] The classification used here is that of Stewart and Kantrud (1971). See Table 2 and Application of the Model for guidelines on using other wetland classification systems.

[b] From Ruwaldt et al. (1979:378, Table 3). Figures represent the average of use data provided for 1973 and 1974. Use of natural wetland basins equals 61.1%; remaining use was on streams and constructed wetlands.

[c] From Ruwaldt et al. (1979:376, Table 1). Total of natural basin wetlands equals 74%; remaining area was in streams and constructed wetlands.

[d] Determined by dividing the use/availability value by 1.36, the maximum use/availability value.

The number of wetlands on a study area can be converted to an equivalent number of optimum wetlands by weighting the number of wetlands in each class by the wetland preference indices for pairs (Table 3 or Table 4):

$$\mathrm{EONWP} = \sum_{i=1}^{n} (w_i p_i) \tag{1}$$

where EONWP = number of equivalent optimum wetlands/259 ha (i.e., weighted by preference indices) for pairs

n = the number of wetland classes available

w_i = the number of wetlands of wetland class i/259 ha

p_i = preference index for gadwall pairs for wetland class i

Equation 1 determines the sum of the number of wetlands per section weighted by the quality of the wetland classes for gadwall pairs. The relationship between the number of equivalent optimum wetlands/259 ha and a suitability index (SIV1) for gadwall pairs is presented in Figure 2a.

A value for equivalent optimum area of available wetlands can be determined by:

$$\mathrm{EOAWP} = \sum_{i=1}^{n} (a_i p_i) \tag{2}$$

where EOAWP = the equivalent optimum area of wetlands/259 ha for pairs

a_i = the area of wetlands of class i/259 ha

The resulting sum from Equation 2 is the total area of wetlands available per section weighted by the quality of the available wetlands to gadwall pairs. The relationship between this value and a suitability index (SIV2) for gadwall pairs is shown in Figure 2b.

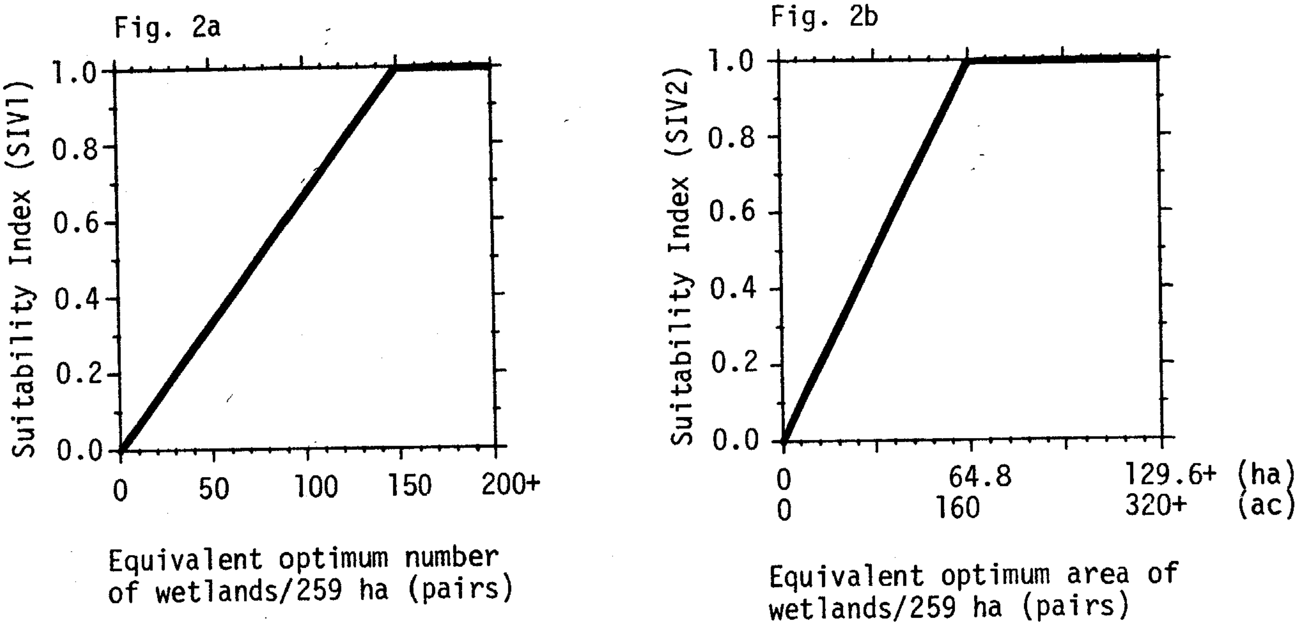

Figure 2. The relationships between values of variables used to evaluate gadwall pair habitat and suitability indices for the variables.

Number and area of wetlands are assumed to be of equal importance in determining habitat suitability for gadwall pairs. These two variables are not entirely independent. For example, an increase in the number of equivalent optimum wetlands will likely result in an increase in equivalent optimum area of wetlands for gadwall pairs. Although area and number of wetlands are not independent, the variable with the lowest suitability level is considered to have the greatest influence on the final index for pair habitat suitability (SIP). This relationship is best expressed by a geometric mean of the suitability indices for the two variables:

$$SIP = (SIV1 \times SIV2)^{1/2} \qquad (3)$$

Nesting habitat component. Gadwalls typically select the tallest, densest, herbaceous or shrubby vegetation available in which to nest. As vegetative cover (i.e., height and density of herbaceous vegetation or shrubs) increases, the potential for nest establishment and success increases. Residual vegetative cover (i.e., vegetation available before the growing season begins) is a particularly important source of suitable nest cover. Height and density of vegetation are assumed to be more important than vegetative composition.

A visual obstruction measurement that incorporates height and density into a single descriptor of vegetative structure (Robel et al. 1970) can be used to determine an index of the quantity and quality of residual vegetative cover. A visual obstruction measurement is the height, to the nearest 0.5 dm, at which a round pole 3 x 150 cm is totally obscured by vegetation when viewed from a distance of 4 m (see Robel et al. 1970 for further details). Data provided by Kirsch (unpubl.) can be used to determine the relationship of nesting density to residual vegetation. Table 1 displays the mean gadwall nesting density by visual obstruction classes from 1974 to 1978 on the Woodworth Study Area, Woodworth, North Dakota. Workshop participants believed that a field with a mean visual obstruction measurement of ≥ 2.5 dm represented ideal nesting conditions. Therefore, a mean visual obstruction measurement of ≥ 2.5 dm is considered equal to optimum nesting quality (corresponding to a 1.0 Suitability Index). The regression equation determined for the data in Table 1 is:

$$Y = 1.68 + 2.42x \tag{4}$$

where Y = gadwall nests/40.5 ha

x = mean visual obstruction measurement (dm) for a given field

Equation 4 can be modified to provide an output that is an index of nesting suitability of a habitat. This is accomplished by first assuming that a mean visual obstruction measurement ≥ 2.5 dm equals a suitability index of 1.0. The nest density predicted from Equation 4 when the mean visual obstruction measurement (i.e., nest density equals 7.73) is used as the maximum nest density. The predicted nest density of 1.97 nests/40.5 ha when the mean visual obstruction measurement equals 0.12 (the lowest observed value reported by Kirsch's data) can be compared to the maximum nest density. The resulting index value for this predicted nest density is 0.25 [i.e., (1.97 nests/40.5 ha)/(7.73 nests/40.5 ha)]. The same approach when the mean visual obstruction measurement equals 0.0 yields a suitability index of 0.22. However, sites that have a visual obstruction measurement of 0.0 throughout the nesting season (e.g., summer fallow) will not provide any cover for nests. Therefore, a mean visual obstruction measurement of 0.0 prior to spring vegetative growth is assigned a suitability index of 0.0. This approach may underestimate areas of growing grain or alfalfa that may provide some nesting cover later in the nesting season. Gadwalls may benefit from these habitats because they are relatively late nesters. Far fewer nests are placed in uplands (Higgins 1977), however, and a total failure of nests in croplands has been reported (Hines and Mitchell 1983). Therefore, assigning a 0.0 suitability to areas with a mean of 0.0 for the visual obstruction measurement of residual vegetation may not be a significant underestimate of habitat suitability for the gadwall.

Gadwalls are late nesters and the average conditions of residual vegetation may not be as appropriate a measure of the suitability of a field for nesting as conditions later in the spring. Shaffer et al. (1985) developed a model to predict the number of nests (N) that could be expected in a field based on the availability of pairs (P), a late-spring average visual obstruction measurement (X), and field size (A), as follows:

$$N = (0.0052 + 0.0045 \times X) \times P \times A \tag{5}$$

The above model did not include an estimate of an optimum nesting density and, therefore, cannot be used to estimate an index of habitat suitability.

The relationship between an average visual obstruction measurement in a given field and a suitability index (SIV3) for nesting gadwalls is shown in Figure 3a. The index obtained from Figure 3a represents the potential of a cover type to support maximum gadwall densities based on residual vegetation conditions.

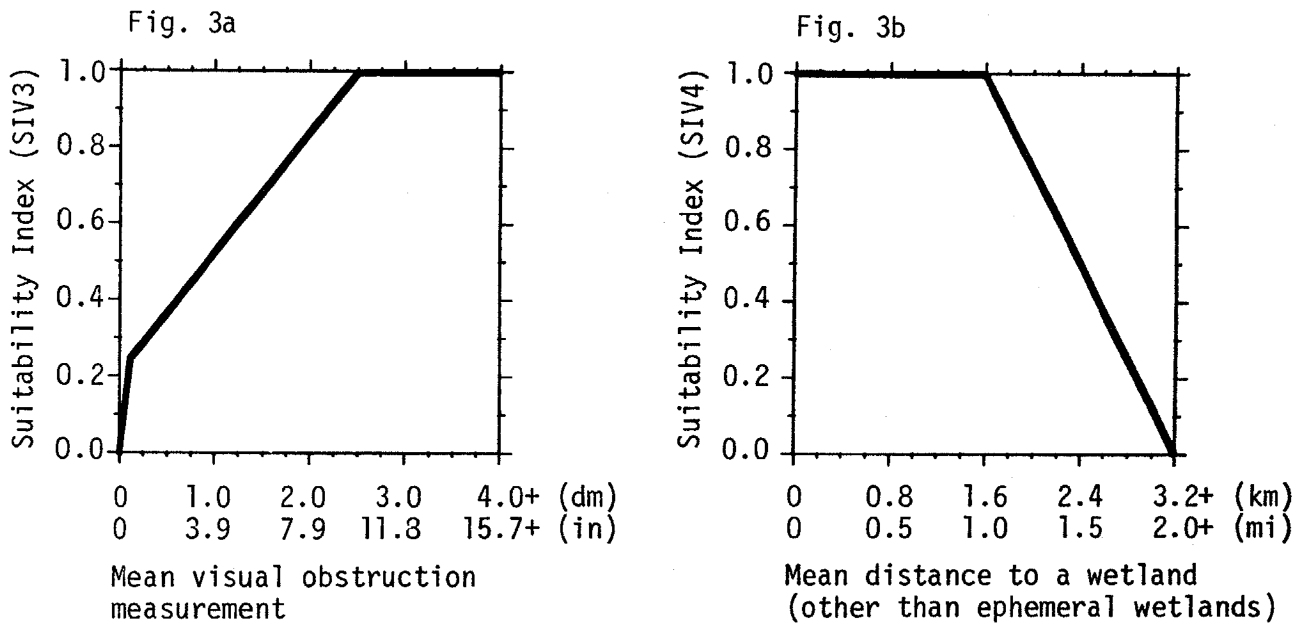

Figure 3. The relationships between values of variables used to evaluate gadwall nesting habitat in a given field and suitability indices for the variables.

Distance from nesting cover to suitable wetland habitat may influence the value of potential nesting cover. Gadwall hens and broods have been reported to disperse 1.6 to 3.2 km from the nest. However, selection of nesting habitat is influenced more by proximity of wetlands available to pairs than by proximity of larger brood wetlands (Swanson, pers. comm.). It is assumed that nesting cover within 1.6 km of any wetland other than ephemeral wetlands (if the classification system of Stewart and Kantrud 1971 is used) is optimally interspersed with suitable wetlands. Potential nesting cover located > 3.2 km from a nonephemeral wetland is considered unavailable to nesting gadwall hens. The relationship between these assumptions and a suitability index (SIV4) is depicted in Figure 3b. Virtually all the nesting cover in the Prairie Pothole Region is within 1.6 km of a suitable wetland; therefore, interspersion is not a factor in many habitat evaluations for the gadwall. It is included in this model, however, for use in situations where interspersion of suitable wetlands and nesting cover is less suitable as the result of major land use changes or from naturally existing conditions.

The physical suitability of a cover type for gadwall nesting is based on the suitability index obtained for the mean visual obstruction measurement for the cover type (SIV3). This suitability is directly modified by the availability of the cover type for nesting, which is evaluated by the suitability index obtained for distance to a wetland from the cover type (SIV4) to yield a suitability index for nesting (SIN). This relationship is expressed as:

$$SIN_i = SIV3_i \times SIV4_i \qquad (6)$$

Equation 6 determines the nesting suitability of a given cover type. In order to be directly comparable to the suitability of pair habitat and brood habitat (discussed below), the suitability values for each cover type must be combined to obtain an overall estimate of the suitability of available nesting habitat. The contribution of each cover type to nesting quality is a function of quality and area. The sum of the products of quality and area across all cover types yields an estimate of the equivalent optimum area of nesting habitat available to the gadwall (EOAN). This value can be determined by:

$$EOAN = \frac{259}{S} \sum_{i=1}^{m} (A_i SIN_i) \qquad (7)$$

where EOAN = the equivalent optimum area of gadwall nesting habitat/259 ha

S = size of the total study area in hectares

m = the number of cover types potentially providing gadwall nesting cover

A_i = the area of cover type i

SIN_i = the nesting suitability index for cover type i (from Equation 6)

The estimate obtained from Equation 7 must be compared to an optimum condition in order to obtain an overall index of nesting habitat quality for the area being evaluated. Optimum wetland habitat for pairs and broods is considered in this model to equal 64.8 ha of optimum wetlands/259 ha. Under the best wetland conditions, therefore, 194.2 ha of the section could be managed for optimum nesting habitat for gadwall. Optimum conditions, therefore, are assumed to exist if there are 64.8 ha of optimum wetlands and 194.2 ha of optimum nesting habitat/259 ha. If no nesting habitat is available, the index of nesting quality is 0.0. A linear relationship is assumed to exist for values of equivalent optimum area of nesting habitat per section between 0 and 194.2 ha (Fig. 4). The estimated equivalent optimum nesting habitat per section from Equation 7 can be compared to Figure 4 to obtain an index of nesting habitat quality (SIN) for a given study area.

Brood habitat component. Habitat suitability for gadwall broods is a function of wetland availability and distribution. Workshop participants believed that different wetland classes have different potentials to support gadwall broods. Indices that indicate the relative value of each wetland class to gadwall broods were assigned (Table 5). These values were based on the experiences of workshop participants and considered several factors, including water permanence, vegetative cover, water depth, potential food resources, and observed brood usage of the wetland classes. Semipermanent wetlands were considered the preferred natural wetland type for gadwall broods,

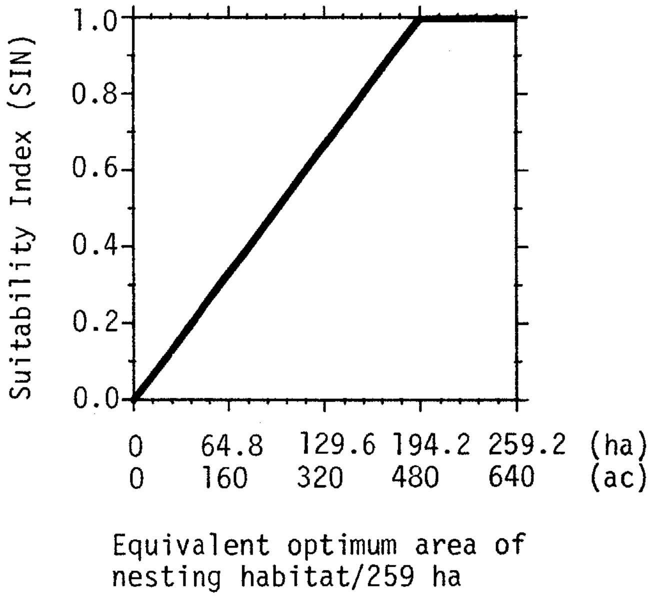

Figure 4. The relationship between the equivalent optimum area of gadwall gadwall nesting habitat and an overall nesting habitat suitability index.

Table 5. Wetland preference indices for gadwall broods in the Prairie Pothole Region.

Wetland class[a]	Preference index[b] (expert opinion)	Preference index[c] (use/availability)
Ephemeral (I)	0.00	--
Temporary (II)	0.00	< 0.001
Seasonal (III)	0.25	0.15
Semipermanent (IV)	1.00	1.00
Permanent (V)	0.80	0.89
Alkali (VI)	0.40	< 0.001

[a] Terminology from Stewart and Kantrud (1971). See Table 2 and Application of the Model for guidelines on using other classification systems.

[b] Based on input from model workshop participants; recommended for use in model applications.

[c] Based on brood use data from Duebbert and Frank (1984) and wetland availability data from Stewart and Kantrud (1973).

followed by permanent, alkaline, and seasonal wetlands. Ephemeral and temporary wetlands were assigned a value of 0.0 because they typically are unavailable during the brood-rearing period. Support for these wetland rankings for gadwall brood use is presented in Table 5, based on observed gadwall brood use (Duebbert and Frank 1984) and the availability of wetlands (Stewart and Kantrud 1973). The only major discrepancy in the two brood indices is for alkali wetlands. This difference may be due to the low number of observed broods (n = 5 over 20 years; Duebbert and Frank 1984) that may have a function of the large size of alkali wetlands (6% of wetland area, < 0.05% of wetland numbers; Stewart and Kantrud 1973). Swanson et al. (1984) found that gadwalls were the most prevalent waterfowl species using saline lakes for brood habitat; use was concentrated in areas of freshwater seeps that supported emergent vegetation for cover and provided fresh water for drinking. The indices proposed by workshop participants are recommended for use in model applications because the use/availability indices are based on a limited amount of wetland data.

Gadwall broods also use constructed wetlands (e.g., stockponds and dugouts). Preference indices for gadwall broods in constructed wetlands are not included in this model because the classification of constructed wetlands is not based on ecological characteristics. If constructed wetlands are considered in a given application of this model, preference indices must be developed by model users. Similarities in water conditions and vegetation between constructed and natural wetlands can be used to assign brood preference indices to constructed wetlands.

Use of preference indices (Table 5) implies that all wetlands within a given wetland class or water regime are of the same value to gadwall broods. While differences in suitability for broods exist between wetlands of a given class or water regime, this model is intended for evaluation of large areas with numerous wetlands, rather than an evaluation of each wetland.

Optimum habitat conditions for waterfowl broods, including gadwalls, are assumed to exist when at least 20 ha of equivalent optimum wetlands and at least six equivalent optimum wetlands are present per section. A total lack of wetlands provides no brood suitability. The value of wetlands to waterfowl broods is assumed to decrease in a linear relationship from optimum conditions as the number and area of optimum wetlands approaches zero. The selection of 20 ha as the standard of comparison was based on the opinion of Lokemoen (pers. comm.) that 100 waterfowl broods/259 ha was an attainable production level. Further, he assumed that a semipermanent wetland (optimum brood habitat as defined by this model) could support 2 broods/0.4 ha. Therefore, 20 ha of optimum wetlands could support the maximum production of 100 broods/259 ha. The selection of a minimum of six optimum wetlands/259 ha is based on the experiences of workshop participants.

The number of wetlands on a study area can be converted to the number of equivalent optimum wetlands available for brood-rearing by weighting the number of wetlands in each class by the preference indices for broods (Table 5), as follows:

$$\mathrm{EONWB} = \sum_{i=1}^{n} (w_i b_i) \qquad (8)$$

where EONWB = equivalent optimum number of wetlands/259 ha available for gadwall brood rearing

n = the number of wetland classes available

w_i = the number of wetlands of class i/259 ha

b_i = preference index for gadwall broods for wetland class i (from Table 5)

Equation 8 determines the sum of the number of wetlands per section weighted by the quality of the classes of wetlands available for gadwall broods. The relationship between the number of equivalent optimum wetlands per section and a suitability index (SIV6) for gadwall broods is presented in Figure 5a.

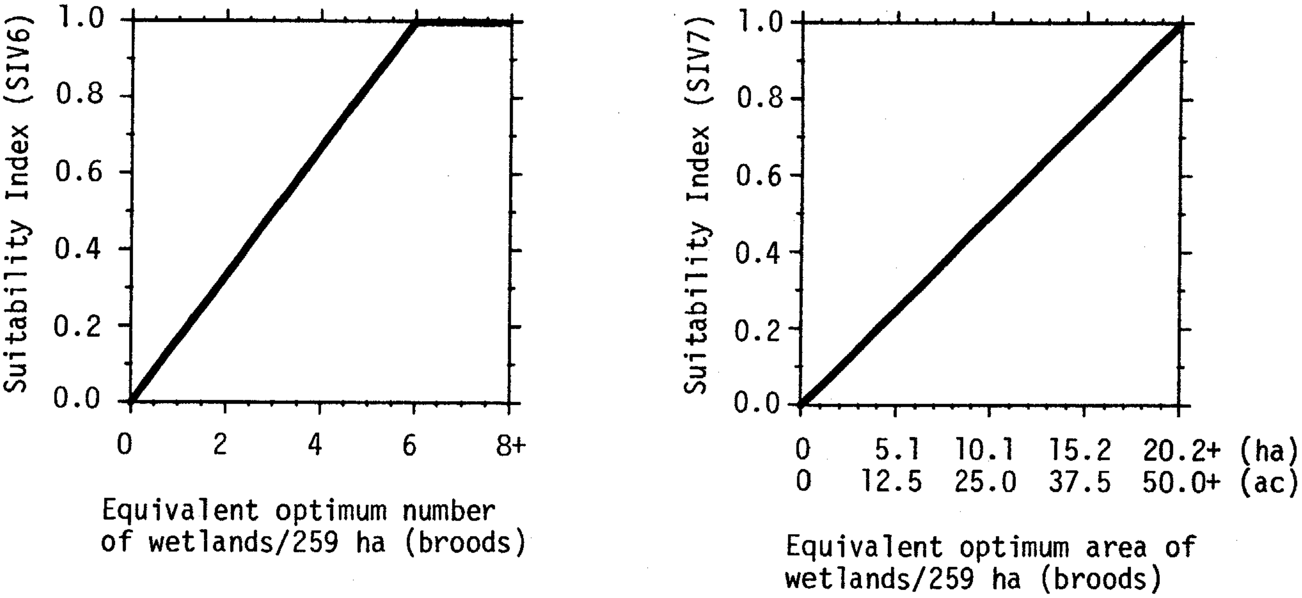
Fig. 5a

Fig. 5b

Figure 5. The relationships between values of variables used to evaluate gadwall brood habitat and suitability indices for the variables.

A value for the equivalent optimum area of wetlands/259 ha for broods can be determined by:

$$\text{EOAWB} = \sum_{i=1}^{n} (a_i b_i) \qquad (9)$$

where EOAWB = equivalent optimum area of wetlands/259 ha available for gadwall brood-rearing

a_i = the area of wetlands in wetland class i/259 ha

Equation 9 determines the sum of the area of wetlands per section weighted by the quality of the wetlands available for gadwall broods. The relationship between this value and a suitability index (SIV7) for gadwall broods is shown in Figure 5b.

The two variables selected for evaluating brood cover are not entirely independent. For example, an increase in the number of equivalent optimum wetlands will likely result in an increase in equivalent optimum area for gadwall broods. Although the variables are not independent, the variable with the lowest suitability level will have the greatest influence on the final value for brood-rearing habitat suitability (SIB). This relationship is best expressed by a geometric mean of the suitability indices for the two variables:

$$\text{SIB} = (\text{SIV6} \times \text{SIV7})^{1/2} \qquad (10)$$

HSI determination. The calculation of life requisite values considered composition and interspersion needs. The production of gadwalls on a particular area is assumed to be ultimately determined by the component with the lowest potential to support the needs of the species. The Habitat Suitability Index is based on the limiting factor theory and equals the lowest of the suitability indices determined for pair (SIP), nesting (SIN), or brood habitat (SIB).

Application of the Model

Summary of model variables and equations. A number of habitat variables and equations are used in this model to evaluate pair, nesting, and brood-rearing habitat for the gadwall (Fig. 6). The relationships between the habitat variables, derived variables, and life requisites used in this model and an HSI for the gadwall are summarized in Figure 7. The definitions and suggested measurement techniques for the variables used in this model are listed in Figure 8.

Pair Component		Page
Equation (1)	$\text{EONWP} = \sum_{i=1}^{n} (w_i p_i)$	15
(2)	$\text{EOAWP} = \sum_{i=1}^{n} (a_i p_i)$	15
(3)	$\text{SIP} = (\text{SIV1} \times \text{SIV2})^{1/2}$	16

Nesting Component		Page
Equation (4)	$Y = 1.68 + 2.42x$	17
(6)	$\text{SIN}_i = \text{SIV3}_i \times \text{SIV4}_i$	19
(7)	$\text{EOAN} = \frac{259}{S} \sum_{i=1}^{m} (A_i \text{SIN}_i)$	19

Brood Component		Page
Equation (8)	$\text{EONWB} = \sum_{i=1}^{n} (w_i b_i)$	23
(9)	$\text{EOAWB} = \sum_{i=1}^{n} (a_i b_i)$	24
(10)	$\text{SIB} = (\text{SIV6} \times \text{SIV7})^{1/2}$	24

Figure 6. Summary of equations used in the gadwall HSI model (equation variables are defined on the pages indicated).

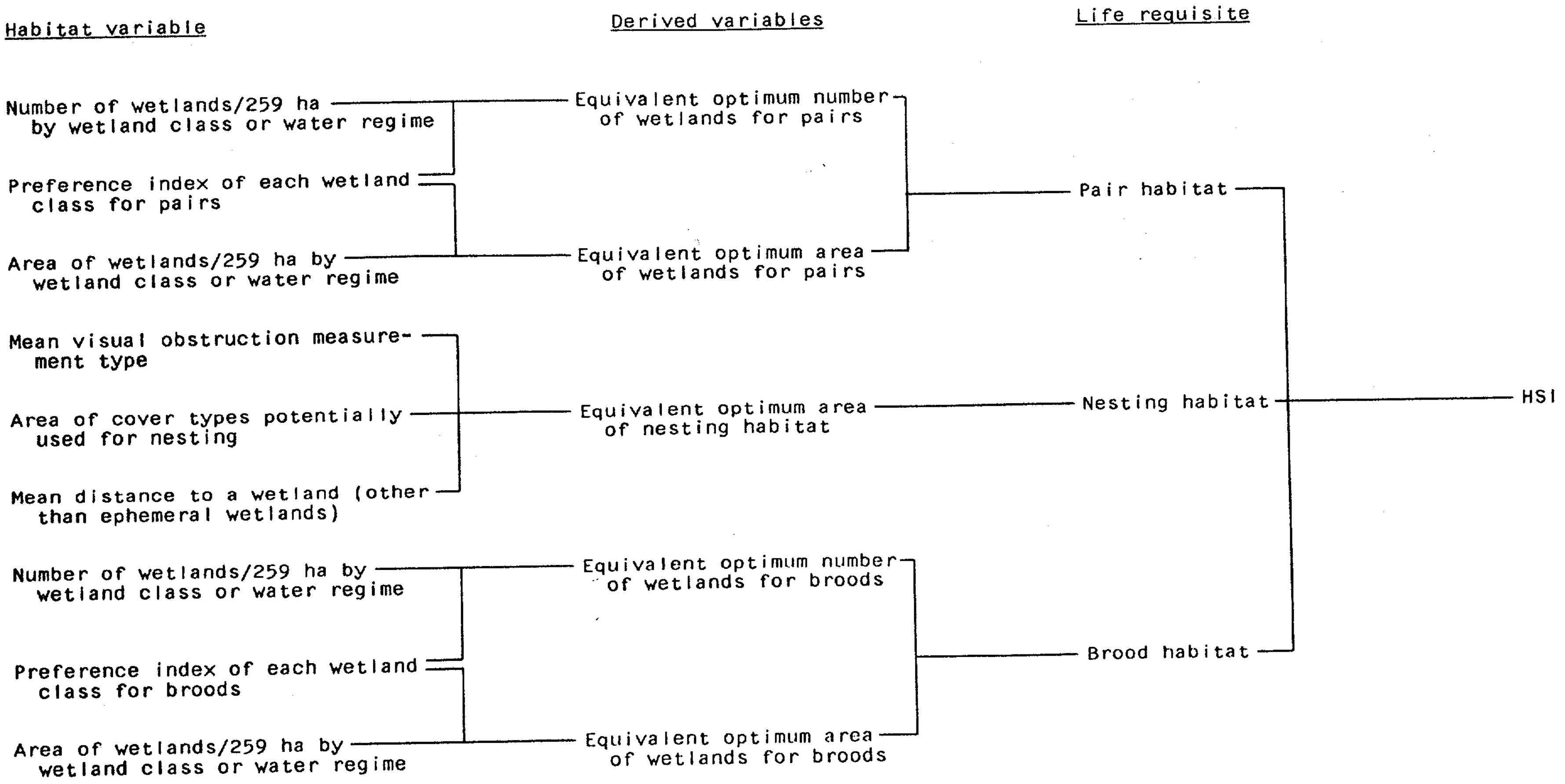

Figure 7. The relationship between habitat variables, derived variables, life requisites, and an HSI for the gadwall.

Variable (definition)	Cover types	Suggested technique
Number of wetlands/ 259 ha (640 ac) by wetland class or water regime.	Entire study area	Classify wetlands and tally number within each wetland class (Stewart and Kantrud 1971) or water regime (Cowardin et al. 1979); convert density for each class or water regime to number/259 ha.
Area of wetlands/ 259 ha (640 ac) by wetland class or water regime.	Entire study area	Classify wetlands and determine area of each wetland; sum the areas of all wetlands in each wetland class or water regime; convert total area of each class or water regime to ha/259 ha.
Mean visual obstruction measurement of residual vegetation [an estimate of the amount of cover provided by residual vegetation within a cover type; measured as the height at which a pole is totally obscured by vegetation when viewed from a distance of 4 m (13.1 ft)].	C,P/H,G,F, DS,DSS	Transect.
Mean distance to a wetland (other than ephemeral wetlands) (an average of the distances from randomly selected points within a cover type to the edge of the nearest wetland, other than ephemeral wetlands).	C,P/H,G,F, DS,DSS	Aerial photographs, ruler.

Figure 8. Definitions of variables and suggested measurement techniques.

Data collection and analysis. Values for habitat variables used to evaluate pair and brood habitat can be estimated through wetland classification and measurement using aerial photographs. Evaluation of nesting cover with this model requires the collection of field data for visual obstruction measurements, as well as determination of the average distance to the nearest wetland for each cover type that provides potential nesting habitat. Indices for these two variables are combined with the area of each nesting cover type to determine an equivalent optimum area of nesting habitat per section (Equation 7).

Although the variables used in this model are based on an area of 259 ha, any size study area can be evaluated as long as all variable estimates are standardized to 259 ha before suitability indices are determined.

Use of other wetland classification systems. In order to use this model without modification, wetlands on a study area must be classified according to the system developed by Stewart and Kantrud (1971). Other classifications that are generally available include those of Shaw and Fredine (1956) and Cowardin et al. (1979). When this model is used where wetlands are classified by a system other than that of Stewart and Kantrud (1971), the terminology of the classification system used must be equated to that used in this model. Guidelines relating the system of Shaw and Fredine (1956) to Stewart and Kantrud (1971) are provided in the latter publication. Equivalent terminology from Cowardin et al. (1979) is presented in Table 2 (p.10). The primary discrepancy between the two systems is that ephemeral wetlands of Stewart and Kantrud (1971) are not considered wetlands by Cowardin et al. (1979). In practice, this will not have any impact on the outputs of this model because emphemeral wetlands have preference indices of 0.0 for pairs (Tables 3 and 4) and broods (Table 5).

The wetland classes of Stewart and Kantrud (1971) are "... distinguished by the vegetational zone occurring in the central or deeper part and occupying 5 percent or more of the total wetland area being classified" (Stewart and Kantrud 1971:7). Definitions of the wetland classes are as follows (Stewart and Kantrud 1971:7-8):

> Class I - emphemeral ponds. The wetland-low-prairie zone dominates the deepest part of the pond basin.
>
> Class II - temporary ponds. The wet-meadow zone dominates the deepest part of the wetland area. A peripheral low-prairie zone is usually present.
>
> Class III - seasonal ponds and lakes. The shallow-marsh zone dominates the deepest part of the wetland area. Peripheral wet-meadow and low-prairie zones are usually present.
>
> Class IV - semipermanent ponds and lakes. The deep-marsh zone dominates the deepest part of the wetland area. Shallow-marsh, wet-meadow, and low-prairie zones are usually present, and isolated marginal pockets of fen zones occasionally occur.

Class V - permanent ponds and lakes. The permanent-open-water zone dominates the deepest part of the wetland area. Peripheral deep-marsh, shallow-marsh, wet-meadow, and low-prairie zones are often present, and isolated marginal pockets of fen zone occasionally occur.

Class VI - alkali ponds and lakes. The intermittent-alkali zone dominates the deepest part of the wetland area. Peripheral shallow-marsh, wet-meadow, and low-prairie zones are usually present. A deep-marsh zone is normally absent except occasionally for isolated patches near marginal seepage areas. A few isolated pockets of fen zone are normally present along the margins.

Class VII - fen (alkaline bog) ponds. The fen zone dominates the deepest part of the wetland area. Peripheral wet-meadow and low-prairie zones are often present.

The water regime modifiers of Cowardin et al. (1979) that are used in this model (Table 2) are described below (Cowardin et al. 1979:24);

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.

Saturated. The substrate is saturated to the surface for extended periods during the growing season, but surface water is seldom present.

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. Plants that grow both in uplands and wetlands are characteristic of the temporarily flooded regime.

Intermittently Flooded. The substrate is usually exposed, but surface water is present for variable periods without detectable seasonal periodicity. Weeks, months, or even years may intervene between periods of inundation. The dominant plant communities under this regime may change as soil moisture conditions change.

Use of the model on islands. Gadwalls reach much higher nesting densities on islands than in nonisland habitats. These high densities apparently result from an absence of predation which results in high success rates, and subsequent homing to island habitats. However, the available literature does not indicate any significant differences between island and mainland nesting habitat. In both island and nonisland habitat, gadwalls select tall, dense herbaceous vegetation or shrub cover. This model does not consider factors such as predation, nesting success, or homing; therefore, island nesting habitat is evaluated in the same way as nonisland nesting habitat. The model user should be aware, however, that in terms of absolute production, significantly more gadwalls can potentially be produced on islands. This difference should be considered when management recommendations or mitigation plans are being developed.

Model assumptions. An abundance of literature exists on waterfowl in the Prairie Pothole Region. The majority of published literature concentrates on individual facets of waterfowl ecology, such as feeding habitat or nesting habitat, and very few studies attempt to evaluate the total habitat needs of individual species. As a result, numerous unifying assumptions were necessary to develop a model that attempts to evaluate overall habitat suitability. Another reason numerous assumptions were necessary in model development is that the purpose of the HSI model is to provide a tool that can be used to evaluate large areas of habitat in relatively short periods of time with limited data. As a result, simplification was necessary to develop a practical model to be used in habitat evaluation by field biologists. Increased practicality is generally made at the expense of complexity and predictive capabilities.

The major assumptions in this HSI model are:

1. Semipermanent wetlands (semipermanently flooded water regime) provide optimal habitat for pairs and broods and can be used as a standard against which to measure the suitability of other wetlands.

2. All wetlands within a given wetland class or water regime have the same level of suitability for gadwall pairs and broods.

3. Under optimal conditions for pair, nesting, and brood habitat, the optimal ratio of upland to wetland habitat is 3 to 1.

4. Average conditions for the height and density of residual vegetation in upland habitat are suitable for predicting the quality of nesting habitat for gadwalls.

5. The distance between potential nesting habitat and brood habitat is less of a factor in nest site selection than the distance between potential nesting habitat and pair habitat.

Regarding the assumption that average conditions of residual vegetation in an upland cover type are adequate predictors of nesting suitability, evidence suggests that the predictive capability of average vegetative conditions is limited (Shaffer et al. 1985). This most likely results from simplifying complex relationships to produce a practical model. Other variables potentially important in nest site selection and nesting density include "...the quality of nearby wetlands, the attractiveness of competing nesting habitats, and the extent to which homing influences nest density in a particular field" (Shaffer et al. 1985:16). Other factors are probably involved in determining the overall attractiveness of a given habitat to nesting hens.

SOURCES OF OTHER MODELS

No other habitat models to predict overall habitat suitability for the gadwall were located in the literature. Hines and Mitchell (1983) developed the following regression equation to predict the number of gadwall nests expected on 10.0 by 30.0 m artificial islands in Waterhen Marsh, Saskatchewan:

$$Y = 0.085C + 0.177H - 1.813$$

where Y = predicted number of nests on an island

C = % forb canopy cover

H = vegetation height (cm)

The multiple correlation coefficient (R) was 0.96 ($p < 0.01$) with an R^2 value of 0.92.

Johnson (1982, cited by Shaffer et al. 1985) developed a model to predict pair densities from wetland area. Density of gadwall pairs was estimated to be 0.128 pairs/ha of wetland. Shaffer et al. (1985) proposed a model to predict nest density based on available pairs, field size, and a visual obstruction measurement under late spring conditions (Equation 5). Both of these models estimate specific population parameters; neither attempts to estimate overall habitat suitability.

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A review and synthesis of existing information were used to develop a Habitat Suitability Index (HSI) model for the gadwall (Anas strepera). 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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