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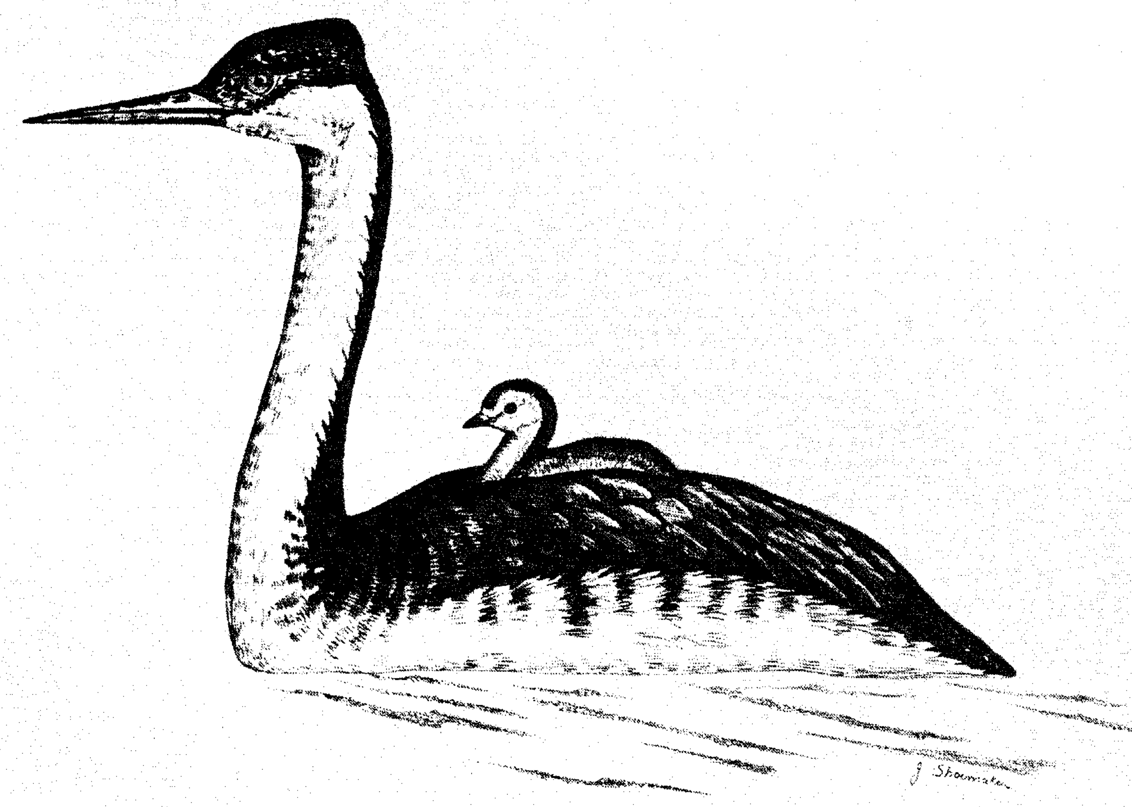
HABITAT SUITABILITY INDEX MODELS: WESTERN GREBE



Fish and Wildlife Service

S. Department of the Interior

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HABITAT SUITABILITY INDEX MODELS: WESTERN GREBE

by

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PREFACE

This document is part of the Habitat Suitability Index (HSI) Model Series (FWS/OBS-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. The habitat use information provides the foundation for HSI models that follow. In addition, this same information may be useful in the development of other models more appropriate to specific assessment or evaluation needs.

The HSI Model Section documents a habitat model and 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 application information includes descriptions of the geographic ranges and seasonal application of the model, its current verification status, and a listing of model variables with recommended measurement techniques for each variable.

In essence, the model presented herein is a hypothesis of species-habitat relationships and not a statement of proven cause and effect relationships. Results of model performance tests, when available, are referenced. However, models that have demonstrated reliability in specific situations may prove unreliable in others. For this reason, feedback is encouraged from users of this model concerning improvements and other suggestions that may increase the utility and effectiveness of this habitat-based approach to fish and wildlife planning. Please send suggestions to:

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WESTERN GREBE (*Aechmophorus occidentalis*)

HABITAT USE INFORMATION

General

The western grebe (*Aechmophorus occidentalis*) "breeds from southeastern Alaska, south-central British Columbia, central Alberta, central Saskatchewan and southwestern Manitoba south to southern California, north-central Utah, southwestern Colorado, southwestern and northeastern New Mexico, western Nebraska, northwestern Iowa, and western Minnesota; and locally in Mexico from Chihuahua and Durango south to northern Guerrero, Puebla and San Luis Potosi" (American Ornithologists' Union 1983:10).

The western grebe generally "winters along the Pacific Coast from southern British Columbia, and from Utah, Colorado, New Mexico, and western and southern Texas south to southern Baja California, northern Guerrero, Puebla and San Luis Potosi" (American Ornithologists' Union 1983:10).

The western grebe, within its breeding range, is considered in the guild context of Short (1983) to generally nest on the water surface layer and to feed within the water surface and water column layers of habitat.

Food

The western grebe is primarily a fish eating bird. The grebe apparently uses its rapier-like bill to pierce its largest prey (Lawrence 1950). Western grebes ate young herring (species unknown), shrimp (species unknown), sculpins (*Leptocottus* spp.), and small crabs (including *Spirontocaris* spp.) while foraging along the coast in British Columbia (Munro 1941). Herring (*Clupea* spp.), sea perch (*Cymatogaster* spp.), and fish of families Stichaeidae, Embiotocidae, and Cottidae appeared in the stomach contents of western grebes collected in Puget Sound (Phillips and Carter 1957). Fish constituted most of the stomach contents of birds collected in California, Oregon, Utah, and British Columbia (Wetmore 1924). Chubs (*Mylocheilus* spp; *Leuciscus* spp.), carp (*Cyprinus* spp.), suckers (*Catostomus* spp.), and smelt (*Atherinopsis* spp.) were the predominant fish identified.

Insects constituted 17% and fish fragments 81% of the total food volume in the stomachs of western grebes collected on Clear Lake in Lake County, California (Lawrence 1950). Aquatic insects comprised from 32% of the diet in May to 8% of the diet in September. White catfish (*Ictalurus catus*), the Sacramento River perch (*Archoplites interruptus*), and the bluegill (*Lepomis macrochirus*) were the most common foodstuffs, with bluegills comprising 71% of the food volume. Fish averaged about 27 to 88 mm (about 1 to 3 1/2 inches) in length. Bent (1919) reported a salamander (Ambystoma spp.) as a noteworthy component in the stomach of a western grebe.

Water

The western grebe is dependent upon an aquatic environment that satisfies its physiological requirements for water.

Cover

The western grebe uses marshes, lakes, and bays while on summer range and sheltered seacoasts while migrating and overwintering (American Ornithologists' Union 1983). The grebe uses persistent emergent vegetation such as bulrushes (Scirpus spp.), cattails (Typha spp.), reed (Phragmites communis) and extensive rafts of floating vegetation, such as Potomageton spp., as protective cover on both winter and summer ranges. These cover types also provide nesting cover on suitable summer ranges.

Reproduction

The western grebe, in North Dakota, usually nests only on lakes and ponds that are 20 ha (50 acres) or more in area (Stewart 1975). Extensive beds of persistent emergent vegetation at edges of ponds or lakes provide favorable nesting sites and attract the largest nesting colonies of western grebes. Nest platforms are frequently located in and attached to persistent emergent vegetation (Bent 1919; Munro 1939, 1941; Nero 1959; Lindvall 1976). Large colonies of western grebes historically have occurred where islands of persistent emergent vegetation were interspersed with channels of open water. For example, the grebe formerly occurred in large colonies on bodies of water like lower Klamath Lake which was described by Finley (1907) as a body of water 40 km (25 mi) long and 16 to 19 km (10 to 12 mi) wide. Extensive beds of persistent emergent vegetation bordered the lake and extended out for miles. Floating nests of western grebes attached to the emergent vegetation were found every few feet within this herbaceous wetland.

Most colonies of western grebes within the Delta Marsh, Manitoba, were located within small coves and channels and along northern shorelines that provide wavebreaks from prevailing winds (Nuechterlein 1975). Nest platforms were supported by the densest clump of persistent emergent vegetation available and water depths under the nest platforms averaged 41 cm (16 inches) with a minimal depth of at least 25 to 30 cm (10 to 12 inches). The density of stems on one side of the nest was minimal so the grebe could dive to and from the nest platform.

Nests built early in the spring, before extensive regrowth of persistent emergent vegetation has occurred, may be constructed from mounds of bulrush protruding 15 cm (6 inches) above the water surface (Munro 1941). Platform nests are usually constructed later in the year after extensive regrowth of emergent vegetation has occurred.

The maintenance of a stable water depth of about 30 cm (12 inches) in the persistent emergent vegetation areas of the marsh during April through July is critical to nesting success (Feerer and Garrett 1977). It is assumed that drawdowns in water levels during the nesting season are deleterious to grebes because they tend to isolate the grebes from their nests. No nesting occurred on reservoirs in northern Colorado that failed to reach capacity and flood the protective cover along shorelines (Davis 1961).

The quantity and quality of available nesting habitat may be increased during periods of high water because areas of cattails and phragmites become flooded and therefore useable as nesting habitat for the western grebe. Reductions in the water levels may force the grebe to use other vegetation as nest substrates. For example, nest platforms have been found attached to small rose (*Rosa* spp.) and willow (*Salix* spp.) bushes standing in shallow water (Nero *et al*. 1958). Nests also have been reported in forbs and brush near shore, in a half-submerged mix of *Kochia* spp. and cocklebur (*Xanithium* spp.) 30 m (100 ft) from shore, in a small decadent stand of bulrushes, and in an open growth of half-submerged tamarisk (*Tamarix* spp.) bushes (Davis 1961). Stirling (1964) also found nests positioned at the edge of a dense growth of willows.

About 40% of the nests observed at the Bear River Migratory Bird Refuge in Utah were open water nests (Lindvall 1976). Nests were constructed from pondweed (*Potomageton* spp.) in areas where no persistent emergent vegetation occurred. These floating pondweed nests extended 30 cm (12 inches) below the surface to 10 cm (4 inches) above the surface. Floating raft nests were held together by the dense entangled pondweed.

A few nests of the western grebe have been observed away from water. Nero et al. (1958) discovered nests around a small pond on an isolated island in southern Saskatchewan. Nests were located as far as 15 m (50 ft) from water and were constructed of grass when distal to water and of sticks and feathers when proximal to water. It was apparent that the colony of grebes had previously used persistent emergent marsh vegetation along the lake. This vegetation was no longer available because of unfavorable water conditions. This nesting attempt was noteworthy and apparently unsuccessful. The western grebe is not considered to be a species that nests away from water, so dry land conditions are not considered in this model. The western grebe does nest on channel banks immediately adjacent to water-filled channels that allow the bird to swim directly to or from the nest site. Lindvall (1976) found that 5% of the nests of western grebes on the Bear River Migratory Bird Refuge were channel bank nests.

Interspersion

The literature (Finley 1907; Nuechterlein 1975) implies that the western grebe, in its breeding range, requires an interspersion of persistent emergent vegetation in sheltered coves or bays, shallow water suitable for the establishment of floating nests, and large areas of open water that support a suitable prey population and allow the bird to dive and successfully catch fish.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area. This model is applicable throughout the breeding range of the western grebe (Fig. 1). It is assumed that this model will be equally relevant to both the "light-phase" and "dark-phase" color morphs recognized by the American Ornithologists' Union (1983).

Season. This model will produce HSI values for the nesting habitat of the western grebe during the April-July nesting season. Field measurements should be taken during this season because important variables consider the quantity of edge between emergent vegetation and open water, and water fluctuations and wave heights during the nesting season.

Cover types. This model was developed for application in habitats described as herbaceous wetlands (HW) (U.S. Fish and Wildlife Service 1981) and more explicitly as palustrine persistent emergent wetlands by Cowardin et al. (1979).

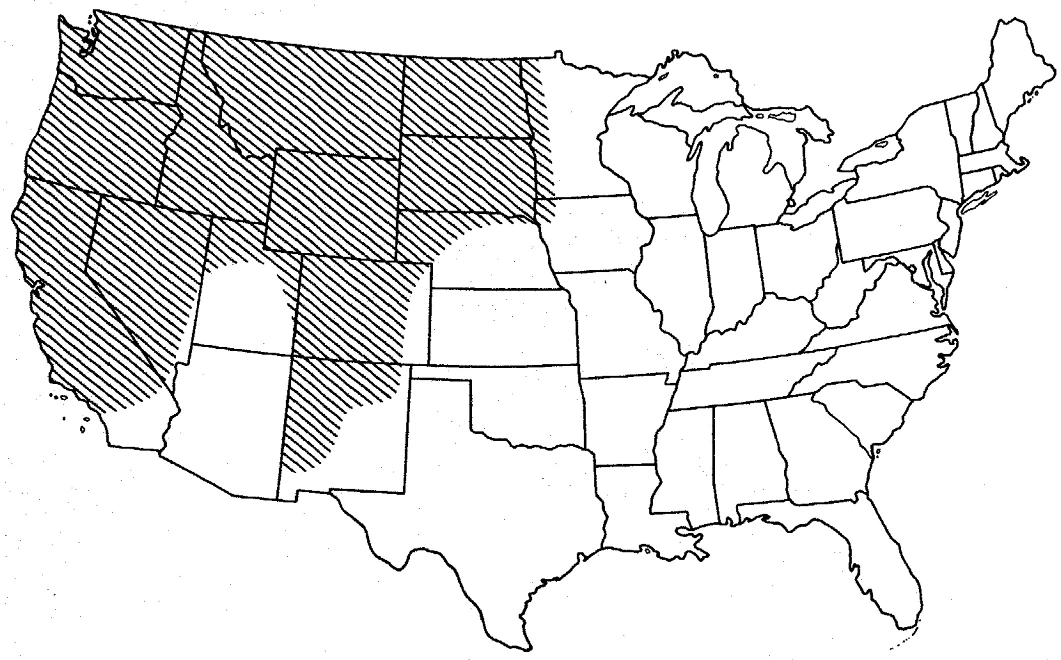


Figure 1. Distribution of the western grebe in its breeding range (shaded area) in the western United States (adapted from a map prepared by D. B. Inkley and C. M. Raley, Wyoming Coop. Fish. and Wildl. Unit, Laramie, from American Ornithologists' Union, 1983).

Minimum habitat area. The minimum area of breeding habitat is the quantity of habitat required before that area will be occupied by a wildlife species. The western grebe is a colonial nester. Its preferred nesting habitat is in flooded emergent vegetation in a backwater area contiguous to deeper open water where it can fish. A wave break of some sort is frequently located between the nest and open bays of water. The size of the nesting colony, all other factors being equal, seems dependent on the area of suitable persistent emergent vegetation. It is assumed that the water body must be 20 ha (50 acres) in size with about 70% open water. It should contain a stand of persistent emergent vegetation that is 0.4 ha (1 acre) or more in size interlaced with channels of open water in order to be considered potential breeding habitat for the western grebe. It also must contain a suitable fish population. Marshes where nesting occurs may be small percentages of the area of very large lakes (Nuechterlein pers. comm.).

Verification level. This model was developed from descriptive studies of nesting habitats of the western grebe that have been reported in the literature. The model was reviewed by Dr. Ronald A. Ryder, Colorado State University, and Dr. Gary Nuechterlein, University of Michigan. Their comments for improving the model have been incorporated into the text. Some limitations of this model are described below, under "Application of the Model".

Model Description

Overview. This HSI model for the western grebe describes the relationship between aquatic habitats and the reproductive life requisites of the grebe. The model assumes that dense stands of suitable persistent emergent vegetation, interspersed with channels of open water, and in proximity to areas of deeper water where fishing can occur, provide suitable conditions for nesting grebes.

The following sections provide documentation of the logic and assumptions used to translate habitat information for the western grebe into the variables selected for the HSI model. Specifically, these sections describe: (1) the variables used in the model; (2) the assumed suitability level of each variable; and (3) the assumed relationships between variables.

The logic used to develop the HSI model describing the quality of nesting habitat to the western grebe is illustrated in Figure 2. A tree diagram identifying the variables important to the western grebe is presented in Figure 3.

Reproductive component. Western grebes rarely fly except during migration, therefore water sources used as nesting habitats must provide a suitable and abundant fish prey base. Essentially, the grebe may eat any fish it can swallow. Small fish of the genera *Cyprinus* (carp), and *Lepomis* (sunfish and bluegills), are especially important food sources for the western grebe.

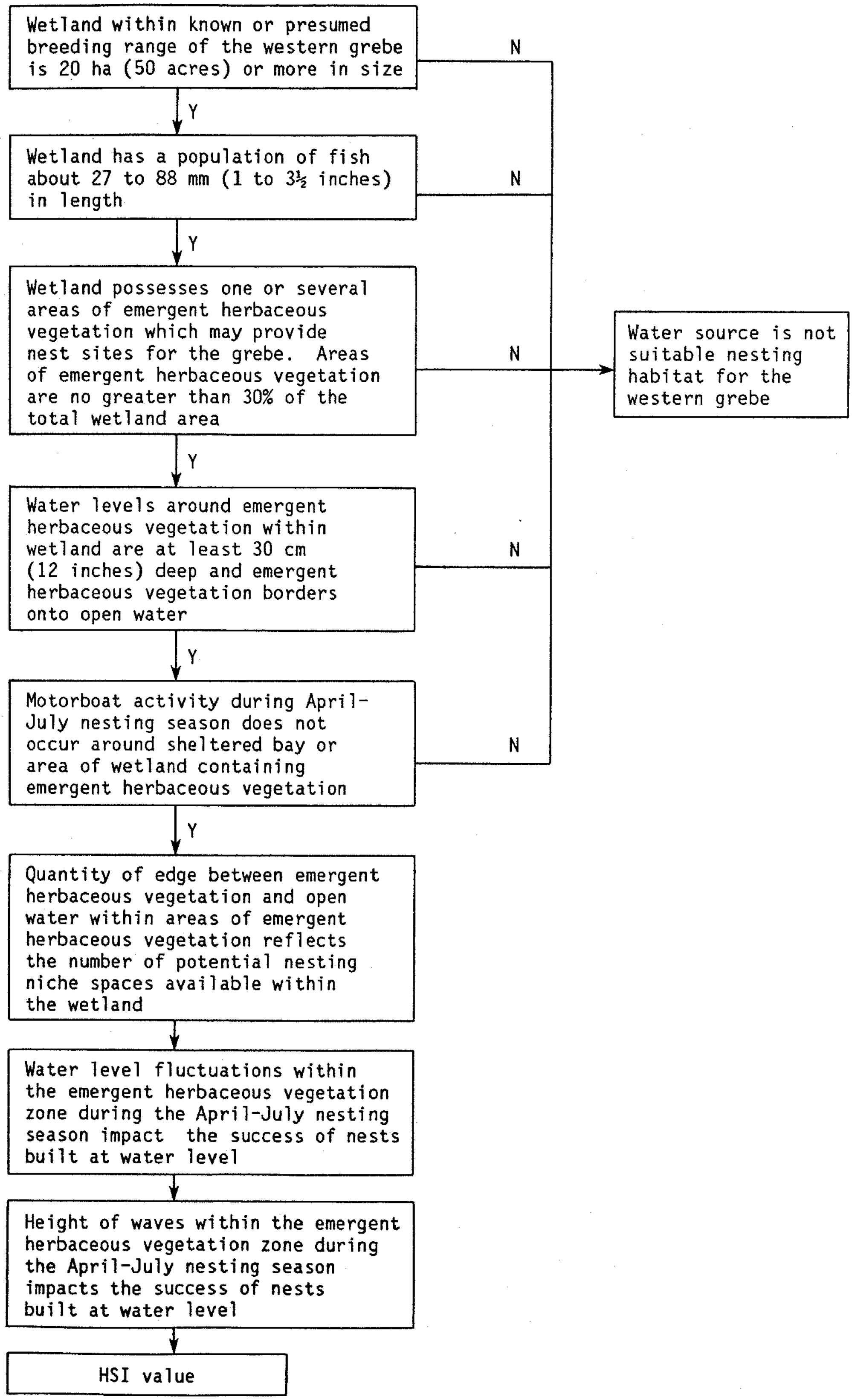


Figure 2. Logic used to develop the HSI model describing the quality of nesting habitat for the western grebe.

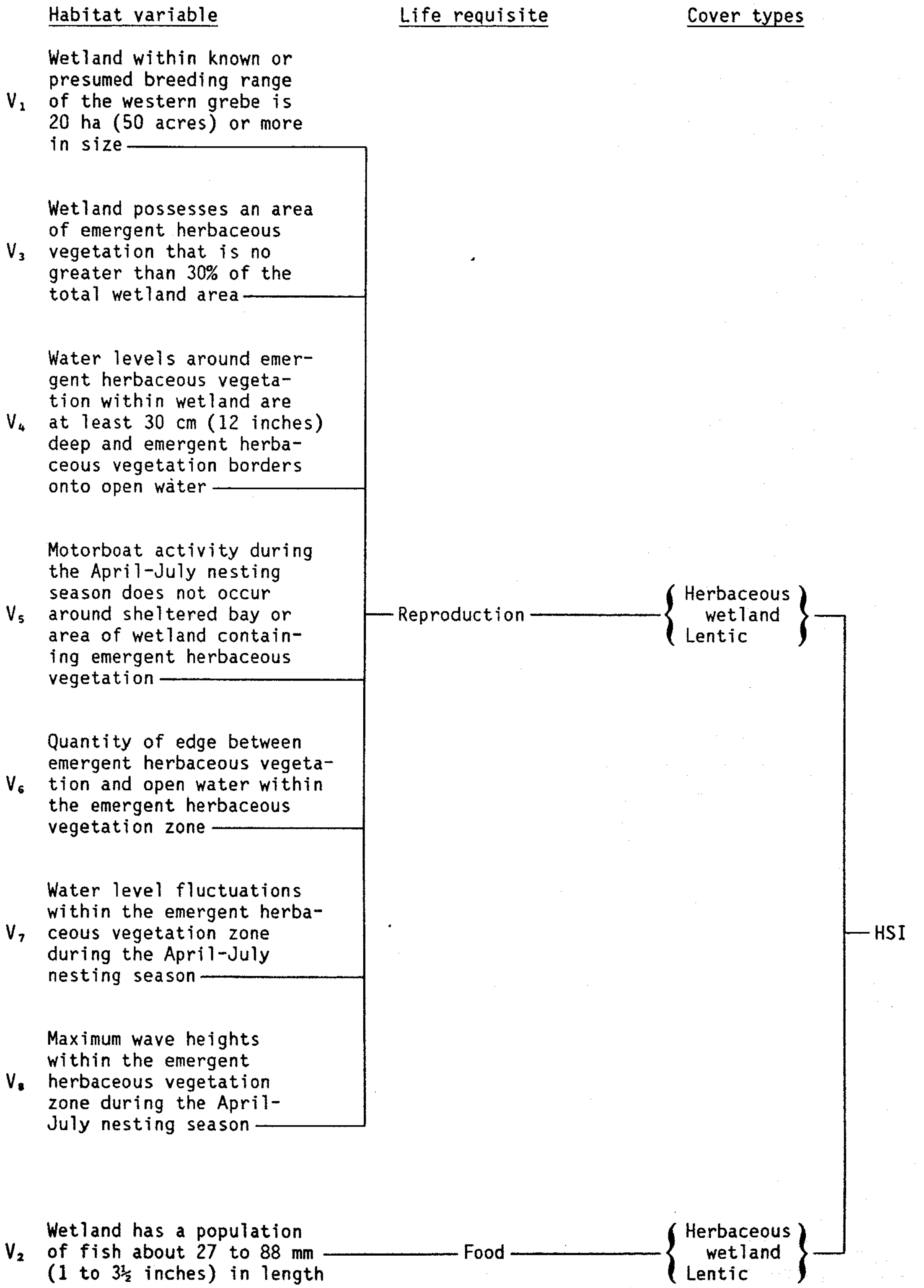


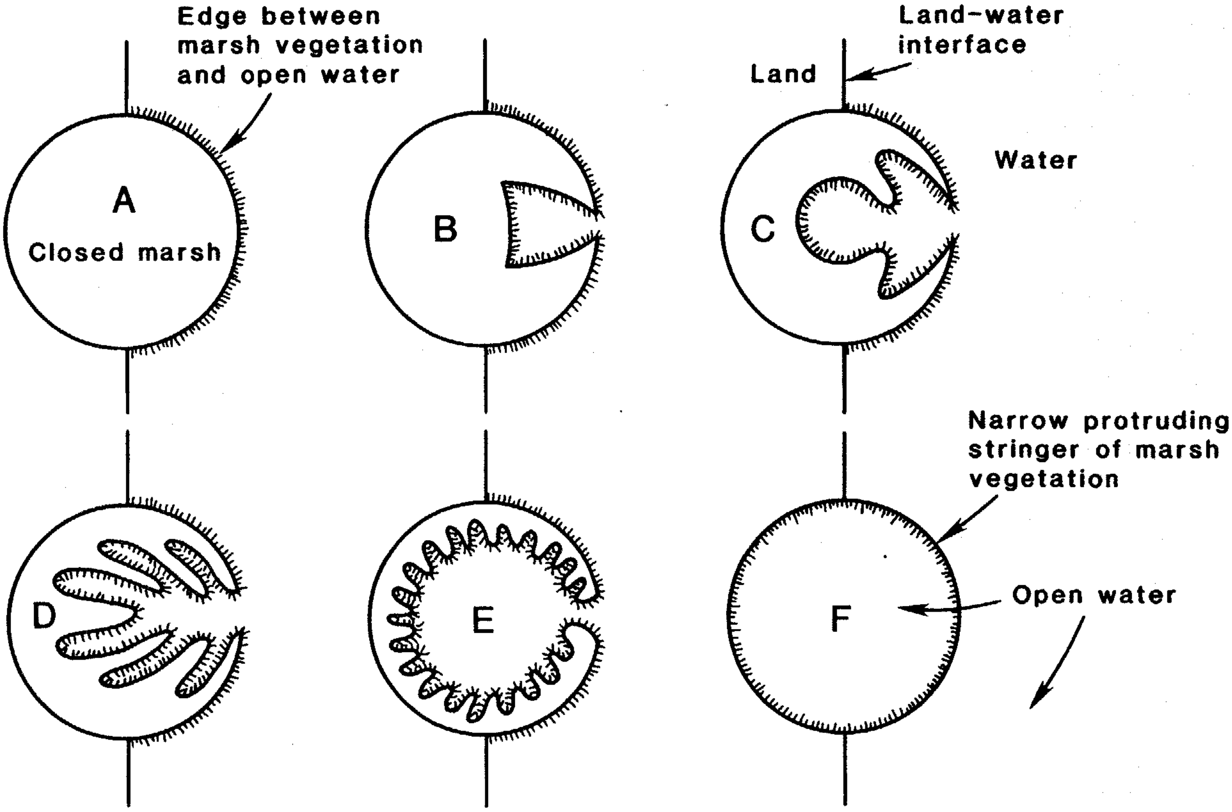
Figure 3. The relationship of habitat variables, life requisites, and cover types to an HSI for the western grebe.

Nesting habitats also must provide suitable cover so that successful reproduction can occur. Extensive beds of persistent emergent vegetation that border on sheltered bays or open water are good breeding habitat for the western grebe.

It is assumed that a wetland that is suitable breeding habitat for the western grebe will have no more than about 30% of the area in persistent emergent vegetation with the remaining area as open water. A critical habitat factor seems to be the amount of edge between the emergent vegetation and open water in flooded herbaceous wetlands. An edge measurement is relevant to this model for the western grebe because nests may occur at intervals as close as 2 m (6 ft) along the edge of emergent vegetation bordering open water (Davis 1961). Six illustrations demonstrating the variability in the amount of edge occurring between emergent herbaceous vegetation and open water within a herbaceous wetland of unit area are pictured in Figure 4. The illustrations depict that the quantity of edge available for nest placement in a closed herbaceous wetland bordering open water is minimal (Fig. 4A) and increases as the pattern of open channels within the herbaceous wetland becomes more complex. Presumably the quantity of potential nest sites within the herbaceous wetland increases as the quantity of edge increases. The quantity of edge and consequently of potential nest sites decreases as the herbaceous wetland becomes very open (Fig. 4F). The measure of edge between emergent vegetation and open water, as a surrogate measure of the relative number of potential nest sites, is Variable 6 in this HSI model.

A Suitability Index (SI) value describing the degree of interspersion of emergent herbaceous vegetation and open water within herbaceous wetlands is determined as follows. The SI value is calculated from a ratio which compares the edge measured within a 1.0 ha (2.5 acres) segment of a herbaceous wetland and the edge available within a closed circular herbaceous wetland 1 ha in area as illustrated in Figure 4A. The quantity of edge between emergent herbaceous vegetation and open water is measured for small herbaceous wetlands less than 1 ha and for 1 ha segments of large herbaceous wetlands. The quantity of edge measured for each 1 ha segment is divided by 177 m (580 ft) which is the quantity of edge between emergent herbaceous vegetation and open water for a totally closed circular herbaceous wetland that is 1 ha in area (Fig. 4A). The SI of that ha of herbaceous wetland is arbitrarily assigned a value of 1.0 if the edge ratio is 4 or above. Edge index values of 4 and above represent conditions of high degrees of interspersion of open water and emergent herbaceous vegetation (see Figs. 4D and 4E).

The denominator of the proportion used to calculate SI values for herbaceous wetlands less than 1 ha in area varies with the size of these smaller herbaceous wetlands. The area (x) of these small herbaceous wetlands is measured. This area is some proportion (1/x) of the area of a standard 1 ha herbaceous wetland. The denominator used to calculate the edge ration for predicting SI values for the small segment of herbaceous wetland is then $177 \div \sqrt{x}$.



Herbaceous wetland example	% area open water	% area closed herbaceous wetland	Length (m) of edge between herbaceous wetland vegetation and open water	Interspersion index. Quantity of measured edge to quantity of edge for closed herbaceous wetland
A	0.0	100.0	177	1.00
B	13.4	86.6	302	1.71
C	29.4	70.6	429	2.42
D	33.9	66.1	730	4.12
E	58.4	41.6	795	4.49
F	93.1	6.9	342	1.93

Figure 4. The quantity of edge between emergent vegetation and open water varies with the degree of openness and the pattern between open water and herbaceous wetland vegetation. Each example depicts a circular herbaceous wetland 1 ha in area.

Variable 6 estimates the suitability of the structure of herbaceous wetland vegetation to provide few or many potential nest sites for the western grebe. A variety of nest sites may actually be selected by grebes. Grebes nest on mounds of emergent vegetation or on nest platforms attached to emergent vegetation. In open wetland areas, floating masses of pondweed are used. All open water nests observed at the Bear River Migratory Bird Refuge in Utah occurred on rafts of *Potomageton* spp. (Lindvall 1976). Other masses of floating vegetation that did not form dense entangled rafts and which would, presumably, disintegrate from wave action, were not used as nest sites. The grebe also may construct nests on banks of dredged channels immediately adjacent to open water or on dried out islands of emergent herbaceous vegetation bordering flooded channels. Bank nests at the Bear River Migratory Bird Refuge were constructed from the surrounding emergent vegetation. Thirty-seven percent of the nests were in saltgrass (*Distichlis stricta*), 16% in hardstem bulrush (*Scirpus acutus*), 11% in cattail, 11% in a cattail-saltgrass mix, and most of the remaining nest sites occurred where there was no surrounding vegetation (Lindvall 1976). Eighty-nine percent of the nests were located near flowing water and the average distance of nests to water was 4 cm (< 2 inches) (Lindvall 1976) so grebes could swim to the nest site and hop onto the nest. These channel bank sites are successful only when disturbance by man, domesticated animals, or marsh predators are minimal. The grebe also has been reported to nest on floating platforms attached to emergent shrubs and forbs in habitats where persistent emergent wetland vegetation has occurred in the recent past but is presently lacking. Davis (1961) indicated low nest success in these habitats in north-central Colorado.

Nests of western grebes occur near the water level, thus, factors that influence water levels also may affect nests. Two additional variables, changing water levels within the herbaceous wetland (V_7), and wave action at the nest site (V_8) seem especially critical to nesting success. The impacts of V_7 and V_8 on nest sites within herbaceous wetland habitats can be considered by assuming that most nest sites in herbaceous wetlands occur on mounds of emergent vegetation or on floating platforms formed from masses of emergent vegetation that are entwined into standing emergent vegetation.

Drawdowns of even 20 or 30 cm (8 to 12 inches) in wetlands with gently sloping bottoms can produce large expanses of mudflats. Appreciable increases in water levels can flood out nests located on banks or nests that are built on hummocks or mounds protruding from the floor of herbaceous wetlands. Reductions in water levels may reduce the success of channel bank nests by making it difficult for grebes to swim to and hop onto nests. It is assumed that potential nest sites will not be affected by slight fluctuations [≤ 10 cm (4 inches)] but will be increasingly affected as the extent of water fluctuation increases. Thus, a fluctuation of 20 cm (8 inches) is assumed to reduce SI values to 0.5 and a fluctuation ≥ 30 cm (12 inches) is assumed to reduce SI values to 0.1.

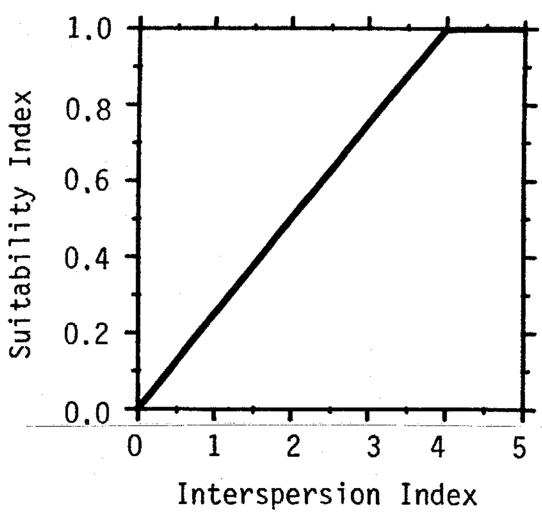
Wave action caused by strong winds or from man's recreational activities on lakes can destroy nests or wash eggs from nests. Water bodies or portions of water bodies subject to motorboat activities during the nesting season are considered unsuitable habitats in this model. The height of waves (produced by wind) at nest sites is a function of the distance across open water that wind can travel before reaching the nest sites. If nests are placed in sheltered coves and bays, then the distance across open water is diminished and wave heights at nest sites are moderated.

Wave heights less than or equal to 10 cm (4 inches) are assumed to moderately affect nests built on channel banks and mounds of emergent vegetation. But no impacts are expected on nests floating on pondweed rafts or nests attached to emergent vegetation. Waves greater than 20 cm (8 inches) are assumed to destroy nests built on channel banks and to moderately impact nests that are attached to or are built on mounds of persistent emergent vegetation. Waves greater than 30 cm (12 inches) are assumed to moderately impact nests built on floating rafts and to destroy nests attached to persistent emergent vegetation as well as nests built on mounds of emergent vegetation. Waves ≤ 10 cm (4 inches) are thus assumed not to affect SI values, while waves of 20 cm (8 inches) are assumed to reduce SI values to 0.5, and waves ≥ 30 cm (12 inches) are assumed to reduce SI values to 0.1.

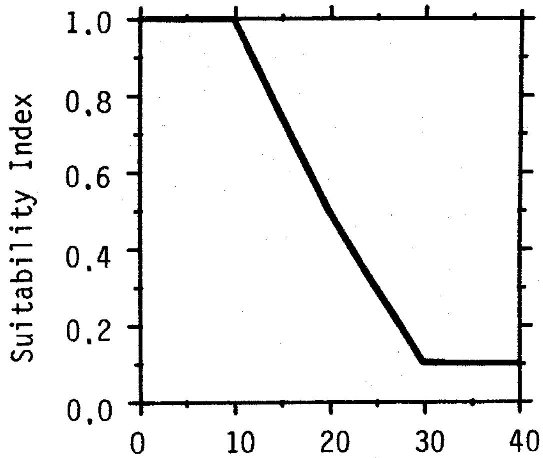
Model Relationships

Suitability Index (SI) values for habitat variables. This section contains estimated suitability index values for the habitat relationships described in the previous section.

Cover type	Variable		Suitability index values
Lentic	V_1	Wetland within known or presumed breeding range of the western grebe is 20 ha (50 acres) or more in area.	SI = 1.0 if wetland is 20 ha or more in area = 0.0 if wetland is less than 20 ha in area
Herbaceous wetlands (HW) or lentic	V_2	Wetland has a population of fish about 27 to 88 mm (1 to 3½ inches) in length	SI = 1.0 if wetland possesses a population of fish of this size = 0.0 if fish of this size do not exist in the wetland

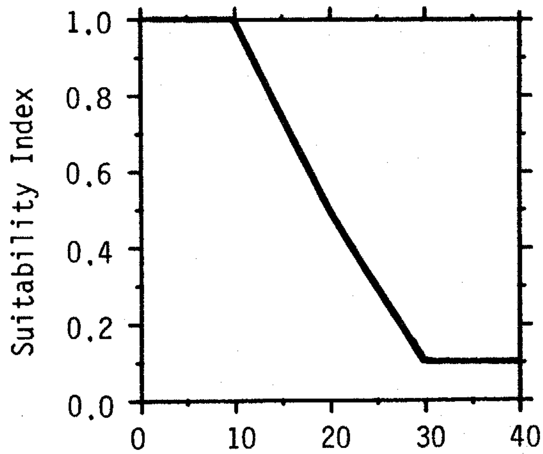
HW	V_3	Wetland possesses an area of emergent herbaceous vegetation that is no greater than 30% of the total wetland area.	SI = 1.0 if emergent herbaceous vegetation zone within the wetland is of this configuration = 0.0 if no zone of emergent herbaceous vegetation occurs within wetland or if such a zone is more than 30% of the wetland area
HW	V_4	Water levels around emergent herbaceous vegetation within the wetland are at least 30 cm (12 inches) deep and emergent herbaceous vegetation borders on open water.	SI = 1.0 if water levels are 30 cm or more in depth and if emergent vegetation zone borders on open water = 0.0 if water levels are less than 30 cm deep or if the emergent vegetation zone does not border on open water
HW	V_5	Motorboat activity during the April-July nesting season does not occur around sheltered bay or area of wetland containing emergent herbaceous vegetation.	SI = 1.0 if this condition is fulfilled = 0.0 if this condition is not fulfilled
HW	V_6	Quantity of edge between emergent herbaceous vegetation and open water within the emergent herbaceous vegetation zone.	

HW V_7 Water level fluctuations within the emergent herbaceous vegetation zone during the April-July nesting season.



Water level fluctuations (cm) during the nesting season

HW V_8 Maximum wave heights within the emergent herbaceous vegetation zone during the April-July nesting season.



Maximum wave heights (cm) during the nesting season

Equations. Each model variable, 1 through 5, represents a dichotomous condition wherein a fulfilled condition receives an SI of 1.0 and an unfulfilled condition receives an SI of 0.0. SI values for Variables 1-5 are simply multiplied together. If the product is 0.0, then one or more conditions were unfulfilled and the suitability of the habitat is considered to be 0.0. If the product from multiplying Variables 1-5 together is 1.0, then the final estimate of Habitat Suitability equals the cube root of the product of Variables 6-8. This approach suggests that Variables 6-8 are equally important in developing a final estimate of the utility of herbaceous wetlands within a lake as reproductive habitat for the western grebe. The suggested equation is:

$$(V_1 \times V_2 \times V_3 \times V_4 \times V_5)\,(V_6 \times V_7 \times V_8)^{1/3}$$

More western grebes may be produced in habitats with high HSI values than in habitats with low values. This may occur because both the density of nests of western grebes and the probability of nesting success may be higher in preferred habitats. One cannot equate nesting success with habitat quality, however, because non-habitat related factors can drastically influence animal populations. For example, the administration of large quantities of DDT to Clear Lake in Northern California from 1949-1957 resulted in the death of many western grebes and contributed to a general population decline of the grebe (Herman et al. 1969) even though physical habitat features were unchanged. The presence and numerical status of the bird in certain habitats thus may be independent of the quality of the structure of those habitats. It is emphasized that the SI values of habitats cited in this model are estimates based on descriptive data published in the literature.

Application of the Model

A biologist applying this model to determine if a lake provides the reproductive life requisites of the western grebe should first ask the following questions: (1) Is the area being studied within the known or presumed breeding range of the western grebe (Fig. 1)? (2) Is the wetland to be evaluated 20 ha (50 acres) or more in area? (3) Does the wetland have populations of small fish? (4) Is the herbaceous wetland area, which may provide nesting habitat for the western grebe, sheltered from wakes produced by motorboat activities (if motorboat activity occurs during the nesting season)? (5) Does the wetland possess a herbaceous wetland area that is no greater than 30% of the total wetland area and does this herbaceous wetland area border on open water? and (6) Does permanent water at least 30 cm (12 inches) deep occur around and throughout this herbaceous wetland area during the nesting season? If the answer to any of these six questions is no, then the wetland is probably not suitable nesting habitat for the western grebe.

If the answers to the six questions are affirmative, then the biologist can proceed to estimate the suitability of the lake as breeding habitat for the western grebe. A recommended approach is to interpret current, good quality, low altitude aerial photographs. Less accurate procedures would be to map herbaceous wetland boundaries from boat or by wading. The perimeters of the herbaceous wetland area can be delineated on the aerial photograph and the areas of those herbaceous wetland areas are thus determined. If herbaceous wetland areas are less than 1 ha (2.5 acres) in area, then the biologist should proceed directly to determining the quantity of edge between emergent herbaceous vegetation and open water occurring within the herbaceous wetland. If herbaceous wetland areas are greater than 1 ha in area, then the biologist should grid the aerial photograph into 1 ha quadrats and determine the quantity of edge between emergent herbaceous vegetation and open water occurring within each quadrat of herbaceous wetland habitat. One can, after calculating the quantity of edge, determine the SI value by calculating the ratio of actual edge within herbaceous wetlands to the quantity of edge that would occur in the standardized herbaceous wetland; i.e., the quantity of edge between emergent vegetation and open water in a closed circular herbaceous wetland 1 ha in area (Fig. 4A).

The biologist, after estimating the potential availability of nest sites within hectare segments of the herbaceous wetland should then determine the extent of water level fluctuations and the height of wind-produced waves within the wetland during the nesting season. Wave heights can be calculated by determining from the aerial photograph the distance over surface water that prevailing winds will travel to different herbaceous wetland sites and applying the formula listed in Figure 5. The SI values for each of the eight variables can then be combined to estimate an HSI for each hectare of herbaceous wetland. The calculations may provide different HSI values for each hectare of herbaceous wetland within a large lake.

HSI determinations of habitat potential are values determined at a point in time and these values, especially in herbaceous wetlands, may fluctuate greatly between seasons and between years. Weller and Fredrickson (1973), for example, studied the dynamics of vegetation and the avian use of habitats in a glacial marsh in Iowa. They determined that seed produced a sparse stand of diverse semi-aquatic and terrestrial plants in the central unvegetated herbaceous wetland when water levels were diminished because of natural or artificial drawdowns. Subsequent flooding reduced those terrestrial and shallow herbaceous wetland plants and encouraged the growth of semi-aquatic perennials such as cattails. The result was a stand of emergents of increasing density but decreasing species diversity. Subsequent variations in plant density were dependent upon water depth and nutrient cycling. The area of emergent vegetation would thus vary in a cyclical nature if water levels varied cyclically between years and different HSI values would be obtained perhaps seasonally, certainly annually, dependent on recent fluctuations in water levels in the herbaceous wetland or lake. Therefore, herbaceous wetlands may yield different HSI determinations over short time periods and this should be considered when evaluating these habitats.

Definitions of variables and suggested field measurement techniques are presented in Figure 5.

SOURCES OF OTHER MODELS

Nuechterlein (1975) described a model that listed habitat criteria important to the way that western grebes selected habitats on the Delta Marsh, Manitoba. Optimal nesting habitats would have the following characteristics. A nest site would be located over water that was at least 30 cm deep, and would be situated near other western grebe nests (social attraction) yet would be a definitive distance from those nests (territoriality). The nest would be supported by the densest clump of persistent emergent vegetation available and would be situated on one side of that clump of emergents in a way that would leave an easy underwater access route to the nest. A wavebreak of some kind would be located between the nest and open bays of water. Nuechterlein's nest criteria were developed from an intensive study of the grebe on the Delta Marsh. His habitat criteria for optimal nest sites have been incorporated into the present HSI model. No other models of the habitat requirements of the western grebe were found in the literature.

Variable (definition)		Cover type	Suggested technique
V_1	Wetland within known or presumed breeding range of the western grebe is 20 ha (50 acres) or more in area.	Lentic	Determine area of wetlands identified from current, good quality aerial photographs. Area can be determined with either a dot grid (Hays et al. 1981) or a planimeter. Consult local naturalist groups to determine if the lake is presently or has in the past been used as breeding habitat by the western grebe.
V_2	Wetland has a population of fish about 27 to 88 mm (1 to 3½ inches) in length.	Lentic and Herbaceous Wetland (HW)	Seine to determine the presence of a population of small fish.
V_3	Wetland possesses an area of emergent herbaceous vegetation that is no greater than 30% of the total wetland area.	HW	Determine area of emergent herbaceous vegetation in wetland either with a dot grid (Hays et al. 1981) or with a planimeter. Compare to wetland area identifed for V_1 to determine the proportion of the wetland covered by emergent herbaceous vegetation.
V_4	Water levels around emergent herbaceous vegetation within wetland are at least 30 cm (12 inches) deep and emergent herbaceous vegetation borders on open water.	HW	Measured rule and on-site observations.

Figure 5. Definitions of variables and suggested measurement techniques.

Variable (definition)		Cover type	Suggested technique
V_5	Motorboat activity during April-July nesting season does not occur around sheltered bay or area of wetland containing emergent herbaceous vegetation.	HW	Review records of the recreational use of the lake to determine the likelihood of motorboat activities around emergent herbaceous vegetation during the nesting season.
V_6	Quantity of edge between emergent herbaceous vegetation and open water within the emergent herbaceous vegetation zone.	HW	Determine, for herbaceous wetlands that are less than 1 ha (2.5 acres) in area, the extent of the edge interface between emergent herbaceous vegetation and open water. Use map measurer (Hays et al. 1981) on the aerial photograph to determine the length of edge in meters. Calculate the edge index value for small herbaceous wetlands by dividing the quantity of edge measured in the small herbaceous wetland by $177 \div \sqrt{x}$. The value of (x) is the area of the small herbaceous wetland expressed as a proportion of a standard 1 ha area of herbaceous wetland. If areas of herbaceous wetlands are greater than 1 ha then grid the herbaceous wetland area on the aerial photograph into 1 ha quadrats, label each quadrat, and determine the length of the edge interface (using the map measurer) between emergent

Figure 5. (continued).

Variable (definition)		Cover type	Suggested technique
			herbaceous vegetation and open water within each quadrat. Treat quadrats that are a fraction of a 1 ha area as a small herbaceous wetland (above). Calculate the edge index value for each 1 ha quadrat of herbaceous wetland by dividing the quantity of edge measured for that quadrat segment by 177 m.
V_7	Water level fluctuations within the emergent herbaceous vegetation zone during the April-July nesting season.	HW	Direct observations of changes in water levels throughout the April-July nesting period. Historical records may describe magnitude of water fluctuations or manipulations within the water body.
V_8	Maximum wave heights within the emergent herbaceous vegetation zone durign the April-July nesting season.		Determine the position of potential nesting cover in relation to the direction of prevailing spring-summer winds. Determine from aerial photos the distance over which prevailing wind blows uninterrupted by land surface to the location of ha quadrats of herbaceous wetland vegetation. Calculate for each quadrat the maximum wave height from the following empirical formula:

Figure 5. (continued).

Variable (definition)	Cover type	Suggested technique
		$h_w = 0.105\sqrt{X}$ where h_w is height of the highest waves (cm) and X is the distance from the edge of the lake to the point of measurement downwind (cm) (Hutchinson 1957:356)

Figure 5. (concluded).

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This document is part of the Habitat Suitability Index (HSI) Model Series, which provides habitat information useful for impact assessment and habitat management for the Western grebe (Aechmophorus occidentalis). Several types of habitat information are provided. A Habitat Use Information Section can be used to derive quantitative relationships between key environmental variables and habitat suitability.

The HSI Model Section documents a habitat model and 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).

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