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HABITAT SUITABILITY INDEX MODELS: BEAVER

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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BEAVER (Castor canadensis)

HABITAT USE INFORMATION

General

The beaver (Castor canadensis) is a large, highly specialized aquatic rodent found in the immediate vicinity of aquatic habitats (Hoffman and Pattie 1968). The species occurs in streams, ponds, and the margins of large lakes throughout North America, except for peninsular Florida, the Arctic tundra, and the southwestern deserts (Jenkins and Busher 1979). Beavers construct elaborate lodges and burrows and store food for winter use. The species is active throughout the year and is usually nocturnal in its activities. Adult beavers are nonmigratory.

Food

Beavers are generalized herbivores; however, they show strong preferences for particular plant species and size classes (Jenkins 1975; Collins 1976a; Jenkins 1979). The leaves, twigs, and bark of woody plants are eaten, as well as many species of aquatic and terrestrial herbaceous vegetation. Food preferences may vary seasonally, or from year to year, as a result of variation in the nutritional value of food sources (Jenkins 1979).

Denney (1952) summarized the food preferences of beavers throughout North America and reported that, in order of preference, beavers selected aspen (Populus tremuloides), willow (Salix spp.), cottonwood (P. balsamifera), and alder (Alnus spp.). Although several tree species have often been reported to be highly preferred foods, beavers can inhabit, and often thrive in, areas where these tree species are uncommon or absent (Jenkins 1975). Aspen and willow are considered preferred beaver foods; however, these are generally riparian tree species that may be more available for beaver foraging but are not necessarily preferred over all other deciduous tree species (Jenkins 1981). Beavers have been reported to subsist in some areas by feeding on coniferous trees, generally considered a poor quality source of food (Brenner 1962; Williams 1965). Major winter foods in North Dakota consisted principally of red osier dogwood (Cornus stolonifera), green ash (Fraxinus pennsylvanica), and willow (Hammond 1943). Rhizomes and roots of aquatic vegetation also may be an important source of winter food (Longley and Moyle 1963; Jenkins pers. comm.). The types of food species present may be less important in determining habitat quality for beavers than physiographic and hydrologic factors affecting the site (Jenkins 1981).

Tree cutting may occur during any season of the year (Jenkins 1979). However, the most intensive amount of foraging on trees or shrubs by beavers typically occurs in late fall, after green vegetation has become dessicated, and during early spring, prior to the availability of green vegetation. Woody vegetation may be consumed immediately, although the majority of the branches and stems are hauled to a cache for storage and later use as winter food.

An adequate and accessible supply of food must be present for the establishment of a beaver colony (Slough and Sadleir 1977). The actual biomass of herbaceous vegetation will probably not limit the potential of an area to support a beaver colony (Boyce 1981). However, total biomass of winter food cache plants (woody plants) may be limiting. Low marshy areas and streams flowing in and out of lakes allow the channelization and damming of water, allowing access to, and transportation of, food materials. Steep topography prevents the establishment of a food transportation system (Williams 1965; Slough and Sadleir 1977). Trees and shrubs closest to the pond or stream periphery are generally utilized first (Brenner 1962; Rue 1964). Jenkins (1980) reported that most of the trees utilized by beaver in his Massachusetts study area were within 30 m (98.4 ft) of the water's edge. However, some foraging did extend up to 100 m (328 ft). Foraging distances of up to 200 m (656 ft) have been reported (Bradt 1938). In a California study, 90% of all cutting of woody material was within 30 m (98.4 ft) of the water's edge (Hall 1970).

Woody stems cut by beavers are usually less than 7.6 to 10.1 cm (3 to 4 inches) dbh (Bradt 1947; Hodgdon and Hunt 1953; Longley and Moyle 1963; Nixon and Ely 1969). Jenkins (1980) reported a decrease in mean stem size cut and greater selectivity for size and species with increasing distance from the water's edge. Trees of all size classes were felled close to the water's edge, while only smaller diameter trees were felled farther from the shore.

Beavers rely largely on herbaceous vegetation, or on the leaves and twigs of woody vegetation, during the summer (Bradt 1938, 1947; Brenner 1962; Longley and Moyle 1963; Brenner 1967; Aleksiuk 1970; Jenkins 1981). Forbs and grasses comprised 30% of the summer diet in Wyoming (Collins 1976a). Beavers appear to prefer herbaceous vegetation over woody vegetation during all seasons of the year, if it is available (Jenkins 1981).

Aquatic vegetation, such as duck potato (Sagittaria spp.), duckweed (Lemna spp.), pondweed (Potamogeton spp.), and water weed (Elodea spp.), are preferred foods when available (Collins 1976a). Water lilies (Nymphaea spp.), with thick, fleshy rhizomes, may be used as a food source throughout the year (Jenkins 1981). If present in adequate amounts, water lily rhizomes may provide an adequate winter food source, resulting in little or no tree cutting or food caching of woody materials. Jenkins (1981) compared the rate of tree cutting by beavers adjacent to two Massachusetts ponds that contained stands of water lilies. A pond dominated by yellow water lily (N. variegatum) and white water lily (N. odorata), which have thick rhizomes, had low and constant tree cutting activity throughout the fall. Conversely, the second pond, dominated by water shield (Brasenia schreberi), which lacks thick rhizomes, had increased fall tree cutting activity by beavers. Tree cutting was particularly evident as the water shield leaves died.

Water

Beavers require a permanent supply of water and prefer a seasonably stable water level (Slough and Sadleir 1977). Beavers can usually control water depth and stability on small streams, ponds, and lakes; however, larger rivers and lakes where water depth and/or fluctuation cannot be controlled, are often partially or wholly unsuitable for the species (Murray 1961; Slough and Sadleir 1977). Beavers are absent from sizable portions of rivers in Wyoming, due to swift water and an absence of suitable dwelling sites during periods of high and low water levels (Collins 1976b).

In riverine habitats, stream gradient is the major determinant of stream morphology and the most significant factor in determining the suitability of habitat for beavers (Slough and Sadleir 1977). Retzer et al. (1956) reported that 68% of the beaver colonies recorded in Colorado were in valleys with a stream gradient of less than 6%, 28% were associated with stream gradients from 7 to 12%, and only 4% were located along streams with gradients of 13 to 14%. No beaver colonies were recorded in streams with a gradient of 15% or more. Valleys that were only as wide as the stream channel were unsuitable beaver habitat, while valleys wider than the stream channel were frequently occupied by beavers. Valley widths of 46 m (150 ft) or more were considered the most suitable. Marshes, ponds, and lakes were nearly always occupied by beavers when an adequate supply of food was available.

Cover

Lodges or burrows, or both, may be used by beavers for cover (Rue 1964). Lodges may be surrounded by water or constructed against a bank or over the entrance to a bank burrow. Water protects the lodges from predators and provides concealment for the beaver when traveling to and from food gathering areas and caches.

The lodge is the major source of escape, resting, thermal, and reproductive cover (Jenkins and Busher 1979). Mud and debarked tree stems and limbs are the major materials used in lodge construction although lesser amounts of other woody, as well as herbaceous vegetation, may be used (Rue 1964). If an unexploited food source is available, beavers will reoccupy abandoned lodges rather than build new ones (Slough and Sadleir 1977). On lakes and ponds, lodges are frequently situated in areas that provide shelter from wind, wave, and ice action. A convoluted shoreline, which prevents the buildup of large waves or provides refuge from waves, is a habitat requirement for beaver colony sites on large lakes.

Reproduction

Reproductive and cover requirements for the beaver are the same.

Interspersion

Suitable habitat for beavers must contain all of the following: (1) stable aquatic habitat providing adequate water; (2) channel gradient of less than 15%; and, (3) quality food species present in sufficient quantity (Williams 1965).

Beaver colony territories are distinct and nonoverlapping and are the fundamental units of a beaver population (Bradt 1938). A colonized area typically contains a series of ponds of various ages, sizes, and depths (Rutherford 1964). The beavers within each colony may establish and utilize several lodges or bank burrows, or both, within their territory. During periods of low population density, the territorial boundaries of one colony may expand to include the dams and lodges of adjacent vacant colony sites (Townsend 1953). During periods of low stream flows, floodplain populations of beavers reestablished dwelling sites and territories within the main river channel in Wyoming (Collins 1976b). The average distance moved was 262 m (286 yds).

The basic composition of a beaver colony is the extended family, comprised of a monogamous pair of adults, subadults (young of the previous year), and young of the year (Svendsen 1980). Dispersal of subadults occurs during the late winter or early spring of their second year and coincides with the increased runoff from snowmelt or spring rains. Subadult beavers have been reported to disperse as far as 236 stream km (147 mi) (Hibbard 1958), although average emigration distances range from 8 to 16 stream km (5 to 10 mi) (Hodgdon and Hunt 1953; Townsend 1953; Hibbard 1958; Leege 1968).

The daily movement patterns of the beaver centers around the lodge or burrow and pond (Rutherford 1964). The density of colonies in favorable habitat ranges from 0.4 to 0.8/km² (1 to 2/mi²) (Lawrence 1954; Aleksiuk 1968; Voigt et al. 1976; Bergerud and Miller 1977 cited by Jenkins and Busher 1979). The mean distance between beaver colonies in an Alaskan riverine habitat was 1.59 km (1 mi) (Boyce 1981). The closest neighbor was 0.48 km (0.3 mi) away. The size of the colony's feeding range is a function of the interaction between the availability of food and water and the colony size (Brenner 1967). The average feeding range size in Pennsylvania, excluding water, was reported to be 0.56 ha (1.4 acre). The home range of beaver in the Northwest Territory was estimated as a 0.8 km (0.5 mi) radius of the lodge (Aleksiuk 1968). The maximum foraging distance from a food cache in an Alaskan riverine habitat was approximately 800 m (874 yds) upstream, 300 m (323 yds) downstream, and 600 m (656 yds) on oxbows and sloughs (Boyce 1981).

Special Considerations

Beavers will live in close proximity to man if all habitat requirements are met (Rue 1964). However, railways, roads, and land clearing often are adjacent to waterways and may be major limiting factors affecting beaver habitat suitability (Slough and Sadleir 1977).

Transplants of beaver may be successful on strip mined land or in new impoundments where water conditions are relatively stable (Nixon and Ely 1969). Highly acidic waters, which often occur in strip mined areas, are acceptable for beaver if suitable foods are present.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area. This HSI model was developed for application throughout the range of the beaver. However, preferred foods may vary throughout the range of the species, depending on local availability. The food component of this model assumes that woody vegetation potentially may limit the ability of an area to support beavers. Herbaceous vegetation is an important component of the summer diet of beavers and is believed to be preferred over woody vegetation during all seasons, if available. Because herbaceous vegetation is generally available throughout the year in the southern portion of the beaver's range, it may have a more important influence on the annual diet than is indicated in this model.

Season. This model has been developed to evaluate the quality of year-round habitat for the beaver.

Cover types. This model has been developed to evaluate habitat quality in the following cover types (terminology follows that of U.S. Fish and Wildlife Service 1981): Evergreen Forested Wetland (EFW); Deciduous Forested Wetland (DFW); Evergreen Scrub-Shrub Wetland (ESW); Deciduous Scrub-Shrub Wetland (DSW); Herbaceous Wetland (HW); Riverine (R); and Lacustrine (L).

Due to the foraging behavior of the beaver, the application of this model and determination of habitat units will vary by cover type. When evaluating beaver habitat in riverine, lacustrine, and wetland cover types, the model considers the area of the cover type plus a 200 m (656 ft) band of habitat on each side of the riverine channel or surrounding the water body or wetland. Figure 1 illustrates the relationship of cover types to the suggested evaluation area.

Minimum habitat area. Minimum habitat area is defined as the minimum amount of contiguous habitat that is required before an area will be occupied by a species. Information on minimum habitat area for beavers was not found in the literature. However, it is assumed that a minimum of 0.8 km (0.5 mi) of stream channel and 1.3 km^2 (0.5 mi^2) of lake or marshland habitat must be available before these areas are suitable for colonization by beaver. If this minimum amount of habitat is not present, the HSI is assumed to be 0.0.

Cover type	Area for evaluation
Lacustrine [> 8 ha (20 acres)] HSI determined only for area contained within 200 m (660 ft) band around lake.	
Lacustrine [≤ 8 ha (20 acres)] HSI determined for area contained within 200 m band plus area of lake.	
Riverine HSI determined for area within 200 m band on both sides of river plus area of river.	
Palustrine (herbaceous wetland, forested wetlands, or shrub wetlands) HSI determined for area contained within cover type plus area within 200 m band around wetland cover type.	

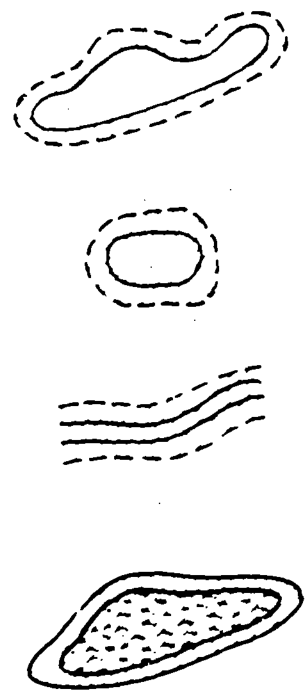


Figure 1. Guidelines for determining the area to be evaluated for beaver habitat suitability under various cover type conditions.

Special model considerations. Potential beaver habitat must contain a permanent source of surface water. Lakes and reservoirs that have extreme annual or seasonal fluctuations in the water level will be unsuitable habitat for beaver. Similarly, intermittent streams, or streams that have major fluctuations in discharge (e.g., high spring runoff) or a stream channel gradient of 15% or more, will have little year-round value as beaver habitat.

Assuming that there is an adequate food source available, small lakes [< 8 ha (20 acres) in surface area] are assumed to provide suitable habitat. Large lakes and reservoirs [> 8 ha (20 acres) in surface area] must have irregular shorelines (e.g., bays, coves, and inlets) in order to provide optimum habitat for the species.

Evaluation of potential beaver habitat must be centered in and around a suitable aquatic habitat. Therefore, the following factors must be taken into consideration in order to determine if this model is applicable to the habitat being evaluated:

If aquatic component of the cover type typically has extreme changes in water level or flow rate or has a channel gradient exceeding 15% -	Do not continue with model; HSI for beaver is assumed to be 0.0.
If aquatic component of the cover type has moderate or no fluctuation in water level or flow rate and channel gradient does not exceed 15% -	Continue with model to determine HSI values for water and food.

Verification level. This model was reviewed by Stephen H. Jenkins, Ph.D., Department of Biology, University of Nevada, and Rebecca J. Howard, Research Assistant, Department of Forestry and Wildlife Management, University of Massachusetts, Amherst. Improvements suggested by these reviewers were incorporated into this model.

Model Description

Overview. The HSI model for the beaver considers the quality of life requisites for the species in each cover type. Water and winter food are the only life requisites considered because the cover and reproductive needs of the species are assumed to be identical with water requirements. It also is assumed that all of the habitat requirements of the beaver can be provided within each cover type in which it occurs. Figure 2 illustrates how the HSI is related to cover types, life requisites, and specific habitat variables.

The following sections provide a written documentation of the logic and assumptions used to translate habitat information for the beaver to the variables and equations used in the HSI model. Specifically, these sections cover: (1) identification of the variables used in the model; (2) definition and justification of the suitability levels of each variable; and (3) description of the assumed relationships between variables.

Food component. Woody and herbaceous vegetation comprise the diet of the beaver. Herbaceous vegetation is a highly preferred food source throughout the year, if it is available. Woody vegetation may be consumed during any season, although its highest utilization occurs from late fall through early spring. It is assumed that woody vegetation (trees and/or shrubs) is more limiting than herbaceous vegetation in providing an adequate food source. Therefore, this model evaluates the potential of an area to provide an adequate winter food source.

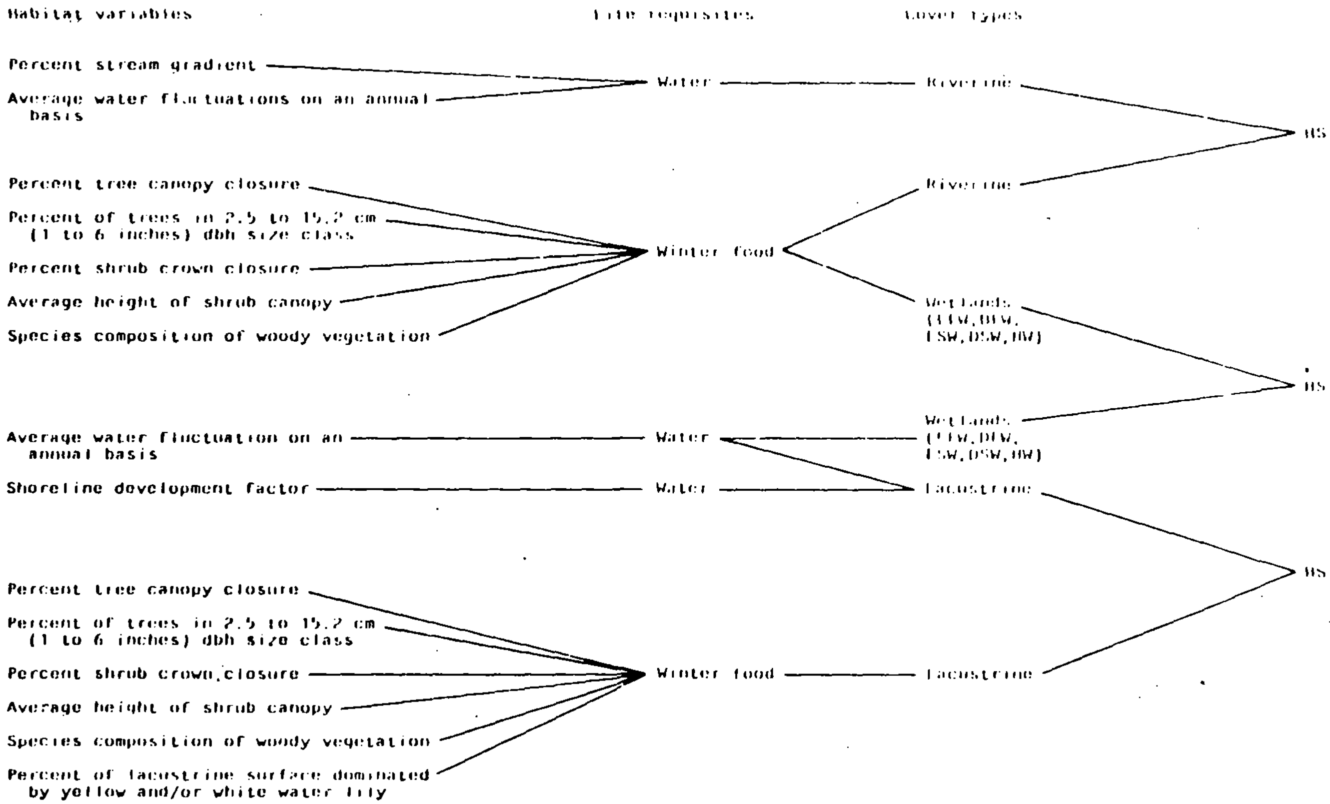


Figure 2. Tree diagram illustrating the relationships of habitat variables, life requisites, and cover types to the HSI for the beaver.

Several tree and shrub species (willow, aspen, cottonwood, and alder) have often been reported to be preferred foods; however, highly preferred species may vary in different geographic regions. Although coniferous trees and shrubs may be consumed, they are a less desirable food source for beavers than are deciduous tree species. Local variations in food preference and availability should be taken into consideration when evaluating the food component of this model.

Although beavers forage at distances up to 200 m (656 ft) from water, the majority of foraging occurs within 100 m (328 ft) of the water's edge. Even though woody vegetation may be within the optimum density and size classes, it is assumed that potential food sources farther than 100 m (328 ft) from water will be of less value than woody vegetation within 100 m (328 ft). Woody vegetation in excess of 200 m (656 ft) is assumed to have no value as a potential food source.

It is assumed that a tree and/or shrub canopy closure between 40 and 60% is an indication of optimum food availability. Tree or shrub crown closures exceeding 60% are assumed to be less suitable due to the decreased accessibility of food. Extremely dense stands result in decreased mobility and the increased likelihood of cut trees hanging up in adjacent trees. To be assigned a maximum suitability value, the dbh of trees should range from 2.5 to 15.2 cm (1 to 6 inches), and shrubs should be at least 2 m (6.6 ft) tall.

The food value in a cover type is a function of the density, size class, and species composition of woody vegetation. Optimum conditions are a stand of preferred tree and/or shrub species, of medium density, less than 15.2 cm (6 inches) dbh. An adequate food source includes some trees, or shrubs, or both. The species composition of the vegetation present influences the value obtained for density and size class. Stands of highly preferred species enhance the habitat value of the site, while foods of low preference will lower the overall food value of the site. White or yellow water lilies in lacustrine cover types may be used to supplement the winter food supply. Lakes or ponds supporting these aquatic species have a higher value as winter habitat than lacustrine cover types lacking this additional food source.

Water component. Water provides cover for the feeding and reproductive activities of the beaver. A permanent and relatively stable source of water is mandatory for suitable beaver habitat.

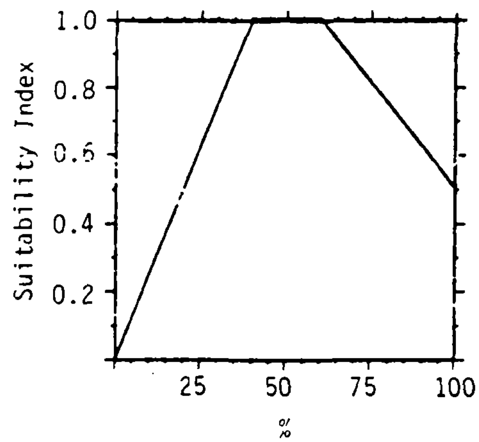
In riverine cover types, a major change in the rate of flow or a channel gradient exceeding 15% indicate poor or unsuitable habitat. Stream channel gradients of 6% or less have optimum value as beaver habitat. Stable water levels are of optimum value as beaver habitat, while major fluctuations in the water level or flow rate decrease the value of the site. Rivers or streams that are dry during some parts of the year are assumed to be unsuitable beaver habitat.

Lacustrine habitat types less than 8 ha (20 acres) in surface area are assumed to provide suitable habitat, if an adequate food source is present. Lacustrine cover types larger than 8 ha (20 acres) in surface area must provide physical diversity (e.g., bays, coves, and inlets) in the shoreline configuration in order to provide suitable beaver habitat. It is assumed that large reservoirs or lakes that are roughly circular in shape or are comprised of extensive stretches of straight shoreline provide little shelter from wind and wave action and, therefore, have little value as beaver habitat. Variation in the water level in lacustrine cover types results in less suitable habitat quality for beavers. Lakes or ponds that are dry during portions of the year are assumed to be unsuitable beaver habitat.

All wetland cover types (e.g., herbaceous wetland and deciduous forested wetland) must have a permanent source of surface water with little or no fluctuation in order to provide suitable beaver habitat.

Model Relationships

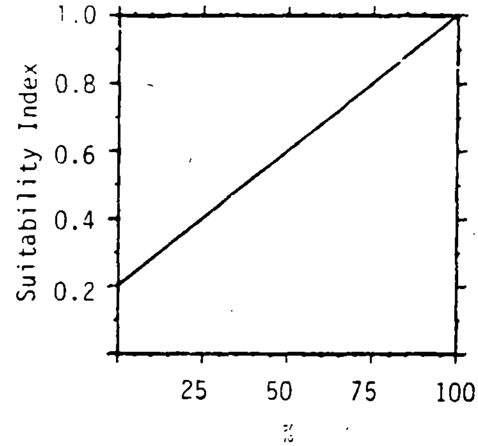
Suitability Index (SI) graphs for habitat variables. The relationships between various conditions of habitat variables and habitat suitability for the beaver are graphically represented in this section.

Cover type	Variable		
EFW, DFW, ESW, DSW, HW, R, L	V_1	Percent tree canopy closure.	

EFW,DFW,
ESW,DWS,
HW,R,L

V_2

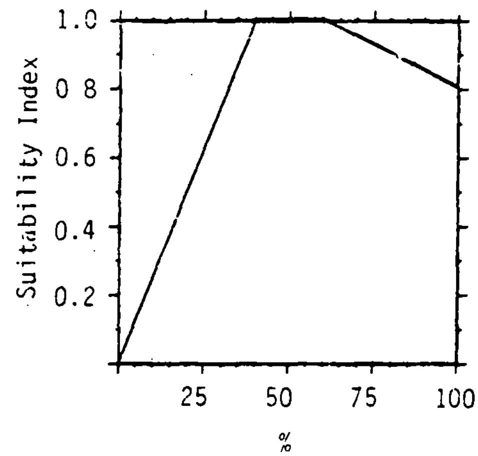
Percent of trees in 2.5 to 15.2 cm (1 to 6 inches) dbh size class.



EFW,DFW,
ESW,DSW,
HW,R,L

V_3

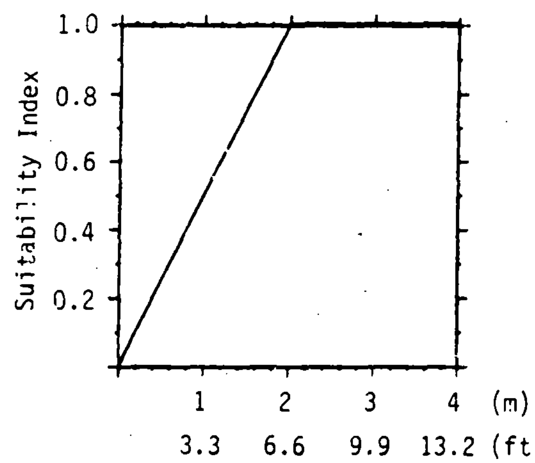
Percent shrub crown cover.



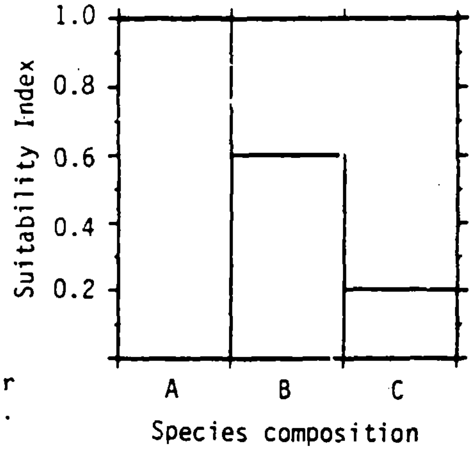
EFW,DFW,
ESW,DSW,
HW,R,L

V_4

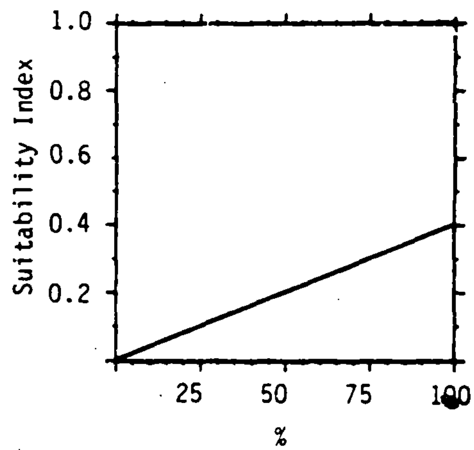
Average height of shrub canopy.



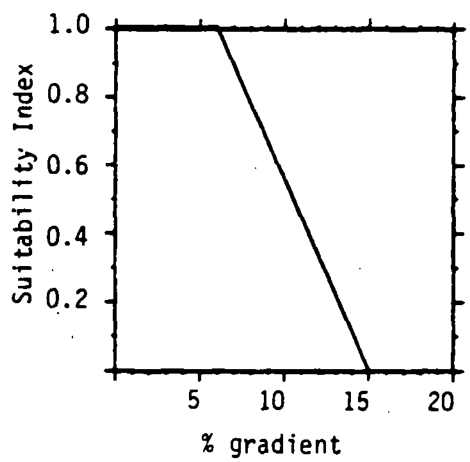
EFW, DFW, ESW, DSW, HW, R, L	V_5	Species composition of woody vegetation (trees and/or shrubs) A) Woody vegetation dominated (≥ 50%) by one or more of the following species: aspen; willow; cottonwood; or alder. B) Woody vegetation dominated by other deciduous species. C) Woody vegetation dominated by coniferous species (e.g., fir and pine).

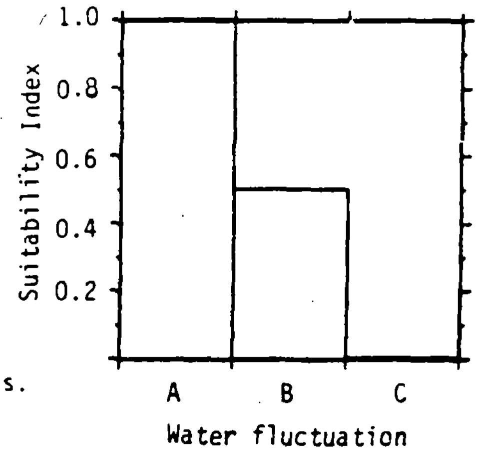
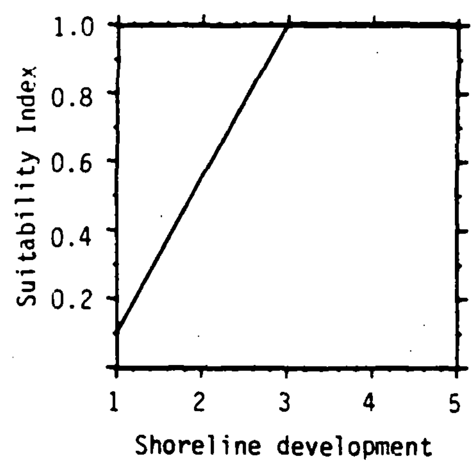


L	V_6	Percent of lacustrine surface dominated by yellow and/or white water lily.



R	V_7	Percent stream gradient.



EFW, DFW, ESW, DSW, HW, R, L	V_8	Average water fluctuation on annual basis. A) Small fluctuations that have no effect on burrow or lodge entrances. B) Moderate fluctuations that affect burrow or lodge entrances. C) Extreme fluctuations or water absent during part of year.	
L	V_9	Shoreline development factor (see variable definition in Figure 4).	

Equations. In order to obtain life requisite values for the beaver, the suitability index values for appropriate variables must be combined with the use of equations. A discussion and explanation of the assumed relationships between variables was included under Model Description. The suggested equations for obtaining food and water values for the beaver are presented by cover type in Figure 3.

Life requisite	Cover type	Equation
Winter food	DFW, EFW, DSW, ESW, HW	$\frac{a+b+c}{2.5}$
Winter food	R	$\frac{b+c}{1.5}$
Winter food	L	$\frac{b+c}{1.5} + V_6$

where: a = woody vegetation value within actual wetland boundary. The suggested equation is:

$$[(V_1 \times V_2)^{1/2} \times V_5]^{1/2} + [(V_3 \times V_4)^{1/2} \times V_5]^{1/2}$$

b = woody vegetation value within 100 m (328 ft) from the water's edge. The suggested equation is:

$$[(V_1 \times V_2)^{1/2} \times V_5]^{1/2} + [(V_3 \times V_4)^{1/2} \times V_5]^{1/2}$$

c = woody vegetation value within 100 m (328 ft) to 200 m (656 ft) from the water's edge. The suggested equation is:

$$0.5\left([(V_1 \times V_2)^{1/2} \times V_5]^{1/2} + [(V_3 \times V_4)^{1/2} \times V_5]^{1/2}\right)$$

Life requisite	Cover type	Equation
Water	R	V_7 or V_8, whichever is lowest.
Water	L	V_9 or V_8, whichever is lowest, if lacustrine area ≥ 8 ha (20 acres) in surface area. V_8, if lacustrine area is < 8 ha (20 acres) in surface area.
Water	DFW, EFW, DSW, ESW, HW	V_8

Figure 3. Equations for determining life requisite values by cover type for the beaver. If equation products exceed 1.0, they should be considered equal to 1.0.

HSI determination. Based on the limiting factor concept, the HSI is equal to the lowest life requisite value obtained for either food or water.

Application of the Model

Definitions of variables and suggested field measurment techniques (Hays et al. 1981) are provided in Figure 4.

SOURCES OF OTHER MODELS

Slough and Sadleir (1977) developed a land capability classification system for beaver that related habitat variables to beaver colony site density through multiple regression analysis. The model can be used for beaver population inventory because it predicts beaver colony site density.

Howard (1982) developed a land capability classification system for the identification and ranking of potential beaver habitat. Discriminant and principle components regression analysis models are used to relate habitat variables that quantify food availability and water reliability to beaver colony site selection and longevity. The models are applicable to stream habitats in typical mixed coniferous-deciduous forests of the Northeast.

Variable (definition)		Cover types	Suggested technique
V_1	Percent tree canopy closure [the percent of the ground surface shaded by a vertical projection of the canopies of woody vegetation ≥ 5.0 m (16.5 ft) in height].	R,L,DFW EFW,DSW, ESW,HW	Transect, line intercept, remote sensing
V_2	Percent of trees in 2.5 to 15.2 cm (1 to 6 inches) dbh size class [the percent of trees with a dbh of 2.5 to 15.2 cm (1 to 6 inches)].	R,L,DFW, EFW,DSW, ESW,HW	Transect, quadrat, diameter tape
V_3	Percent shrub crown cover [the percent of the ground surface shaded by a vertical projection of the canopies of woody vegetation < 5 m (16.5 ft) in height].	R,L,DFW, EFW,DSW, ESW,HW	Line intercept, quadrat, remote sensing
V_4	Average height of shrub canopy (the average height from the ground surface to the top of those shrubs that comprise the uppermost shrub canopy).	R,L,DFW, EFW,DSW, ESW,HW	Line intercept, quadrat, graduated rod
V_5	Species composition of woody vegetation (trees and/or shrubs) (refer to model page 12).	R,L,DFW, EFW,DSW, ESW,HW	Transect, line intercept
V_6	Percent of lacustrine surface dominated by yellow and/or white water lily [the percent of the surface dominated by yellow water lily (*Nymphaea variegatum*) and/or white water lily (*N. odorata*)].	L	Line intercept, remote sensing

Figure 4. Definitions and suggested measurement techniques of habitat variables.

Variable (definition)		Cover types	Suggested technique
V_7	Percent stream gradient (the vertical drop in meters or feet per kilometer or mile of stream or river channel). % stream gradient = $(\frac{A}{B})$ 100 where A = difference in elevation between sample points. B = distance between sample points.	R	Topographic map
V_8	Average water fluctuation on an annual basis (refer to model page 13).	R,L,HW, DFW,EFW, DSW,ESW	Local data
V_9	Shoreline development factor (a ratio relating the relative edge of a water body to its area. To obtain a value for shoreline development factor (SDF), divide the length of the shoreline by the length of the circumference of a circle with the same area as the water body. The following formula may be used: $SDF = \frac{\ell}{2\sqrt{A\pi}}$ where SDF = shoreline development factor ℓ = length of shoreline A = area of water body A circle would have a SDF equal to 1.0. The greater the deviation from a circular shape, the greater the SDF value will be. Values of 3 or more are assumed to be optimum for beavers).	L [≥ 8 ha (20 acres)]	Remote sensing, topographic map, dot grid, map wheel

Figure 4. (concluded).

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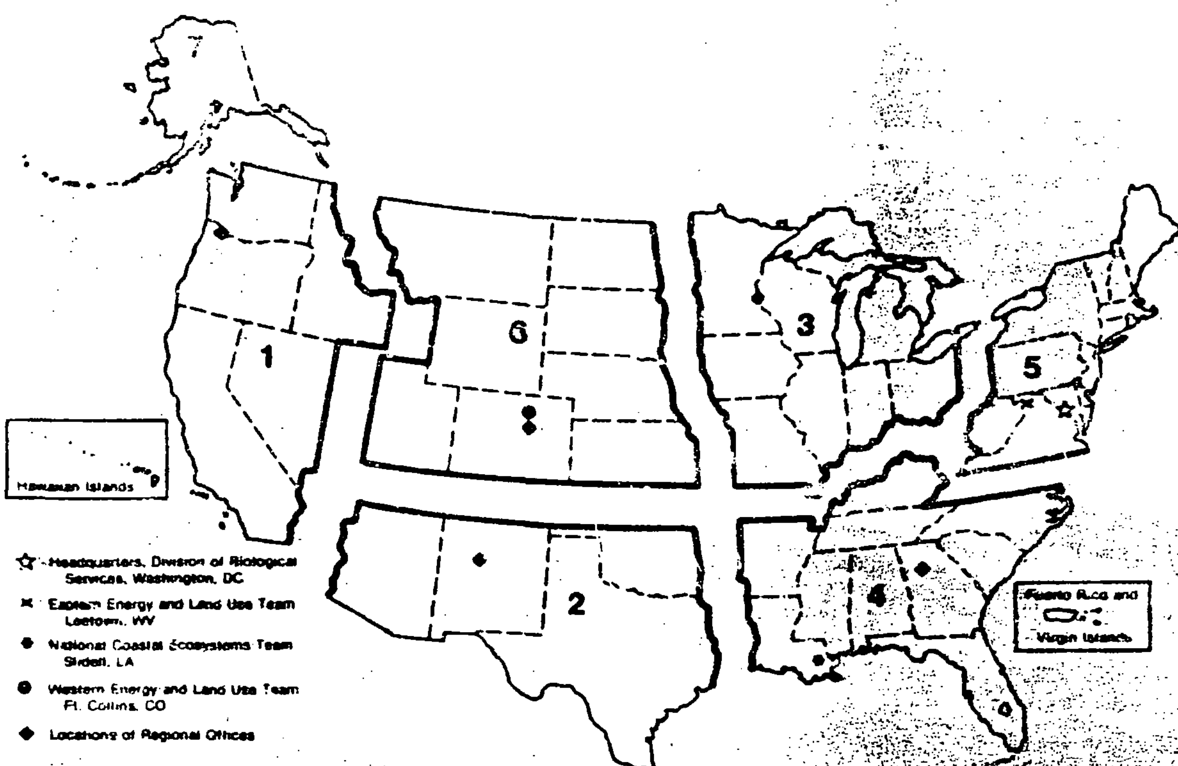

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