FWS/OBS-82/10.46
JUNE 1984

HABITAT SUITABILITY INDEX MODELS: MUSKRAT

Fish and Wildlife Service

U.S. Department of the Interior

MODEL EVALUATION FORM

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

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

Thank you for your assistance.

Species ______________ Geographic Location ____________________________________

Habitat or Cover Type(s) ____________________________________

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

Variables Measured or Evaluated ____________________________________

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

If not, what corrections or improvements are needed? ____________________

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

If not, how were or could they be improved? ______________________________
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Were the techniques suggested for collection of field data:
Appropriate? Yes ____ No ____
Clearly defined? Yes ____ No ____
Easily applied? Yes ____ No ____

If not, what other data collection techniques are needed? _______________
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____

Were the model equations logical? Yes ____ No ____
Appropriate? Yes ____ No ____

How were or could they be improved? ______________________________________
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Other suggestions for modification or improvement (attach curves, equations, graphs, or other appropriate information) ___________________
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Additional references or information that should be included in the model:
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Model Evaluater or Reviewer ___________________________ Date _______________

Agency ____

Address ____
____
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Telephone Number Comm: _________________________ FTS _____________________

FWS/OBS-82/10.46
June 1984

HABITAT SUITABILITY INDEX MODELS: MUSKRAT

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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 studies. 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 each habitat model and the information pertinent to its application. Each 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 for each model, its current verification status, and a listing of model variables with recommended measurement techniques for each variable.

In essence, the models presented herein are hypotheses of species-habitat relationships and not statements 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 these models 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 concerning the freshwater muskrat model 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

Suggestions or questions concerning the application of the estuarine muskrat model should be forwarded to:

Coastal Habitat Evaluation Procedures Project
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

CONTENTS

ACKNOWLEDGMENTS

We gratefully acknowledge Dr. Robert Brooks, Dr. R. Chabreck, Mr. Alfred Gardner, Mr. Greg Linscombe, Dr. Thomas Michot, Mr. John Organ, Ms. Cathy Rewcastle, Mr. R. R. P. Stardom, and Mr. Thomas Thornhill for their reviews of earlier drafts of the HSI models for the muskrat. The comments and suggestions of these persons have added significantly to the quality of these HSI models. Appreciation is also extended to Dr. Jon Bart for the work he conducted in evaluating earlier drafts of the inland and estuarine muskrat HSI models. The cover of this document was illustrated by Jennifer Shoemaker. Word processing was provided by Carolyn Gulzow and Dora Ibarra.

The estuarine HSI model was developed for the National Coastal Ecosystems Team. Appreciation is extended to Rebecca Howard who served as Project Officer for the development and evaluation of the estuarine portion of this document.

Partial funding for the development of this model was provided by the Engineering and Research Center, U.S. Bureau of Reclamation, Denver, CO.

MUSKRAT (Ondatra zibethicus)

HABITAT USE INFORMATION

General

The muskrat (Ondatra zibethicus) is the most valuable semi-aquatic furbearer in North America, with a total fur trade income in the millions of dollars (Willner et al. 1980). With the exception of Florida, and coastal Georgia and South Carolina, native and introduced populations of muskrats occur throughout most of North America. Muskrats are an important component of the marsh ecosystem, serving as a food source for many predators (Wilson 1968), and can have a major impact on wetland vegetation (O'Neil 1949; Errington 1961, 1963; Weller and Spatcher 1965).

Food

Muskrats are primarily herbivorous although animal matter also is consumed (Errington 1963). Muskrats utilize the most available plant species, therefore commonly consumed foods will vary with the type of habitat (Takos 1947; Errington 1963; Neal 1968; Willner et al. 1980). Perry (1982) presented a regionalized listing of food plants used by muskrats throughout North America. The basal portions of aquatic vegetation are eaten most often followed by rhizomes and leaves (Neal 1968). Cattail (Typha spp.) has frequently been identified as a highly preferred food of the species (Hamerstrom and Blake 1939; Takos 1947; Bellrose 1950; Sather 1958; Errington 1963). Errington (1948) concluded that broad-leaved cattail (T. latifolia) was a highly preferred muskrat food and that marshes comprised of this species could support twice the density of muskrats as marshes dominated by other types of emergent vegetation. Feeding studies conducted in Manitoba have indicated that cattail can support approximately seven times as many muskrats as an equivalent amount of bulrush (Scirpus spp.) (Stardom pers. comm.). Other important food plants include sweetflag (Acorus calamus), waterlily (Nymphaea spp.), arrowhead (Sagittaria spp.), sedge (Carex spp.), and wild rice (Zizania aquatica) (Takos 1947). A wide variety of vegetation, including agricultural crops, will meet the dietary needs of stream-dwelling muskrats (Errington 1961). The foods consumed by stream and canal-dwelling muskrats tend to be more diverse than those used by muskrats inhabiting marshes (Perry 1982). Muskrats inhabiting lakes and reservoirs tend to be opportunistic feeders and may feed upon animal matter to a greater degree than do muskrats that inhabit marshes (O'Neil 1949).

In coastal marsh habitats muskrats are heavily dependent on bulrush and cattail (Willner et al. 1975). Olney bulrush (S. olneyi) made up 80% of the muskrat's diet in brackish Louisiana marshes (O'Neil 1949). Olney bulrush, common three-square bulrush (S. americanus), and cattail (T. latifolia, T. angustifolia) accounted for 80% of the muskrat's diet in coastal Maryland marshes (Smith 1938). Olney bulrush has the highest weight per square meter of any common marsh plant and grows year-round in Louisiana (O'Neil 1949). The salinity tolerance of Olney bulrush has been investigated in several studies (O'Neil 1949; Harris 1952; Schmidt 1958; Palmisano 1970; Rose and Chabreck 1972). Results of these studies indicate that the salinity most suitable for the growth of Olney bulrush ranges from 5 to 20 parts per thousand. Food is limited in winter, and appreciable quantities are not stored by muskrats (Smith 1938; Errington 1941; Schwartz and Schwartz 1959). The main advantage of cattail is that its rhizomes are of high nutritive quality and are available as a winter food source (Cook 1952).

Muskrats typically reach their greatest densities in aquatic habitats that provide dense emergent vegetation and are bordered by terrestrial herbaceous vegetation (Errington 1963). Brooks and Dodge (1981) recorded more muskrat burrows and signs of activity in riverine habitats bordered by open and agricultural land, whereas forested river banks had a significant negative effect on muskrat burrow abundance. Increasing muskrat density in Iowa was associated with the presence of dense emergent vegetation (Neal 1968). Declining population levels were associated with less densely vegetated habitat. "Food-poor" open water lakes, ponds, or dry lowlands choked with vegetation are not conducive to high muskrat densities in northern regions (Errington 1963). In addition to the amount of emergent vegetation, the amount of additional food plants and materials available for lodge construction also may regulate muskrat populations (Bishop et al. 1979). Ponds in Ohio with "good" vegetative cover produced an average of 9.6 muskrats/0.4 ha (9.6/acre) (Gilfillan 1947). Ponds with "fair" vegetative cover yielded an average of 8.7 muskrats/0.4 ha (8.7/acre), whereas ponds with no vegetative cover produced no muskrats.

The importance of vegetation in providing cover is difficult to separate from its role as a food source. In high quality habitat, 50% or more of the area is covered with dense, emergent vegetation. Dozier (1953) believed that an 80:20 ratio of emergent vegetation to water would provide ideal muskrat habitat. Errington (1963) rated marsh conditions as excellent when two-thirds of the marsh was covered, but gave a poor rating to a marsh with only 17% coverage. Bishop et al. (1979) recorded an 18-fold increase in muskrats after a lake in Iowa revegetated to a 75:25 ratio of vegetation to open water.

Muskrat feeding and house construction activities may have detrimental effects upon aquatic vegetation (Willner et al. 1980). Danell (1978) reported that stands of horsetail (Equisetum fluviatile) decreased as muskrat population density increased. High muskrat population density may result in the elimination of preferred food plants in an area and an eventual decline in the muskrat population (Errington 1963). "Eat-outs" by muskrats, discussed in detail by Errington (1951), Harris (1952), Sipple (1979), and Willner et al. (1980), may severely affect the humus layer and thus retard vegetative regeneration for several years.

Water

Suitable muskrat habitat requires a permanent supply of still or low velocity water (Errington 1963). Stream gradient and discharge were believed to be key factors in determining the potential quality of streams as muskrat habitat in a Massachusetts study (Brooks and Dodge 1981). Muskrats were present where the stream gradient was low [< 6.1 m/km (32.2 ft/mi)] and discharge exceeded 0.1 m^3/s (4 ft^3/s) but were absent on streams with a gradient in excess of 9.0 m/km (47.5 ft/mi) and discharge flows of less than 0.1 m^3/s. Riverine habitats with mean annual discharge in excess of 30 m^3/sec (approximately 1,000 ft^3/s) are probably poor muskrat habitat because of water level fluctuation, scouring, and erosion of the banks. Water stability has a more direct effect on habitat quality than does water depth (Hamerstrom and Blake 1939). Bellrose and Brown (1941) reported that muskrats were more abundant in lakes having stable water levels than in lakes with fluctuating water levels. Muskrat population density was more affected by changes in water level than by the types of emergent vegetation present. Low water levels result in reduced food and cover availability (Errington 1939). Low water level during winter has a greater affect on muskrats than low water conditions during summer (Perry 1982). Low water during winter may permit the entire water column to freeze resulting in reduced availability of food resources in the normally unfrozen water and substrate. Seabloom and Beer (1964) associated the absence of snow cover in North Dakota to heavy ice formation resulting in freezeout and subsequent high muskrat mortality.

High water also results in habitat deprivation by altering vegetative composition and forcing muskrats out of refuge (lodge and burrow) sites (Sather 1958; Olsen 1959). Lakes in Ohio that were subjected to severe flooding [> 0.6 m (2 ft) rise in water level], produced 0.17 muskrats/0.4 ha (0.17/acre) (Gilfillan 1947). Lakes that did not experience such severe flooding produced 1.45 muskrats/0.4 ha (1.45/acre). Muskrat production in severely flooded marshes was 4.24 animals/0.4 ha (4.24/acre) as compared to 8.59 animals/0.4 ha (8.59/acre) in marshes with stable water levels. The best muskrat marshes in Manitoba experience cyclic water level fluctuations of approximately 0.6 m (2 ft) (Rewcastle pers. comm.). It is believed that water fluctuation is required with some regularity (approximately every 5 years) to provide a suitable seedbed for vegetative regeneration.

Water depth between 0.46 m (18 inches) and 1.2 m (4 ft) is most suitable for muskrats (Errington 1963). Danell (1978) reported that 96% of all muskrat lodges located in his study area were constructed in water or within 1 m (3.3 ft) of water. The average water depth at lodge sites was 0.2 m (0.6 ft), whereas the average water depth within 2 m (6.6 ft) of the lodge was 0.33 m (1.0 ft). All lodges located during a California study were in water 0.3 m (1.0 ft) deep or less (Earhart 1969). Optimum water depth for lodge construction in Illinois was 0.3 to 0.40 m (1 to 1.5 ft) (Bellrose and Brown 1941). Muskrats inhabiting streams prefer deep holes and backwater areas; however, a lack of such conditions is not critical if adequate food is present (Errington 1937). Brooks and Dodge (1981) found that the number of coves and islands was strongly associated with muskrat abundance in an evaluation of riverine habitats in Massachusetts. Coves, islands, and other deviations in the main channel provided increased shoreline length, areas of lower water velocity, and often provided a source of emergent vegetation.

Lay and O'Neil (1942) and Lay (1945) believed that water depth in Gulf of Mexico coastal marshes should be maintained at depths of 2.0 to 30.0 cm (0.8 to 11.8 inches) year-round to provide the best muskrat habitat. Palmisano (1967) recommended that the water level should be maintained near the marsh surface and should not fall more than 8.0 cm (3.1 inches) below the substrate surface for optimum propagation of Olney bulrush. Bellrose (1950) reported that muskrats frequently moved to marginal vegetation when water depth dropped to unfavorable levels. Fluctuating water depths were found to be the critical factor limiting muskrat populations in North Carolina coastal marshes (Wilson 1949). Water level fluctuations also prevented establishment of desirable muskrat food plants in Louisiana (Moody 1950). Perry (1982), citing a study by Wilson (1968), concluded that in general, Atlantic coastal marshes managed with control structures can yield 3 to 5 times as many muskrats as undiked marshes.

Cover

Muskrats may construct conical lodges or dig burrows in the banks adjacent to aquatic habitats (Willner et al. 1980). The ability to build either type of shelter enables the species to inhabit most types of wetland habitats. Water depth, soil texture, and the amount of vegetation all influence site selection for lodge construction (Danell 1978). Muskrats often build two types of lodges, a main dwelling lodge and smaller feeding lodges or platforms (Dozier 1947; Sather 1958). Lodge construction typically begins on a firm substrate and is made up of the dominant emergent plants available in the immediate vicinity of the lodge site (Willner et al. 1980). Submergent vegetation seldom provides suitable material for lodge construction (Errington 1963).

MacArthur and Aleksiuk (1979) distinguished between dwelling and feeding lodges primarily on the basis of external size. Feeding lodges are smaller than dwelling lodges and vary considerably in construction. In summer, and throughout the year in the South, feeding lodges are usually thin-walled and may be simple platforms. They are thick-walled in winter to provide insulation in the northern region of the muskrat's range. Structures called push-ups are made when muskrats chew through ice or snow and push a 30.0 to 45.0 cm (11.8 to 17.7 inches) pile of vegetation onto the surface. Push-ups are typically used as temporary feeding sites (Perry 1982). Other temporary shelters include hollow logs, the dens of other animals, and overhanging banks (MacArthur and Aleksiuk 1979).

In the absence of sufficient emergent vegetation muskrats may establish shelter in bank burrows (Dozier 1953). Three types of burrows were identified in a California study: (1) breeding burrows composed of numerous entrance tunnels and chambers; (2) winter burrows composed of one tunnel and chamber; and (3) shallow, simple feeding burrows (Earhart 1969). Clay soils provide the most suitable substrate for burrow construction (Errington 1937, 1963; Beshears and Haugen 1953; Earhart 1969). Beshears and Haugen (1953) reported that the amount of sand in the soil was inversely related to burrow longevity. Embankments with soils containing more than 70% sand supported only temporary burrows in California (Earhart 1969). Soils with a high sand content may provide suitable burrowing sites if dense vegetation is present (Errington

1937). Earhart (1969) believed that burrow construction required a bank slope of 10° or more regardless of soil sand content. Gilfillan (1947) reported that optimum conditions for bank burrows exist when the slope of the bank is 30° or more and a minimum height of 0.5 m (1.6 ft). Muskrat burrows were absent in riverine habitats in a Massachusetts and Pennsylvania study where the bank height was less than 0.2 m (0.6 ft), bank slopes were less than 10%, or the bank composition was in excess of 90% sand and gravel (Brooks 1982).

High quality muskrat habitat along streams generally has an abundance of retreats (e.g., downfall, lodged debris, deep pools, backwaters, undercut banks) and is bordered by dense herbaceous vegetation (Errington 1937). Muskrat burrows in Massachusetts and Pennsylvania riverine habitats were established where dense herbaceous vegetation or littoral zone emergent vegetation was present (Brooks 1982). Ohio muskrat harvest data indicated that streams bordered by agricultural crops produced an average of 89 muskrats/ 1.6 km (89/mi), whereas, those bordered by dense and sparse native vegetation produced 45 muskrats/1.6 km (45/mi) and 22 muskrats/1.6 km (22/mi), respectively (Gilfillan 1947). Although the main channel may serve as a travel avenue, large streams and rivers are generally unsuitable habitat if they are subject to fluctuating water levels, or are highly turbid (Errington 1963). In such conditions, muskrats may be common in oxbows, tributary streams or wetlands adjacent to the main channel. The availability of cover and backwater areas is strongly correlated with muskrat abundance in riverine habitats (Brooks 1980). Evaluation of riverine muskrat habitat in Massachusetts and Pennsylvania indicated that pools and backwater coves were inhabited by muskrats 35% more often than their relative availability (Brooks 1982). Shallow, steep gradient streams with high water velocity and rocky substrate are poor muskrat habitat (Errington 1937). Stream gradient and discharge were believed to be the most influential characteristics in determination of muskrat habitat quality in small streams in Massachusetts and Pennsylvania (Brooks and Dodge in prep.). High gradient streams were characterized as having rocky, coarse to fine substrates as compared to low gradient streams that had substrates comprised of fine to organic materials.

Intensive grazing of livestock has detrimental effects on muskrat density due to decreased vegetative cover, increased bank erosion, and trampling of burrow systems (Errington 1937). Muskrat harvest data from Iowa indicated that more than twice as many animals were captured along streams with ungrazed banks than were along streams with grazed banks (Gilfillan 1947).

Brackish marshes in coastal habitats appear to have the greatest potential as muskrat habitat. Aerial surveys of Louisiana coastal marshes indicated that approximately 72% of the muskrat lodges counted were in brackish waters although this habitat type occupied only 37% of the area surveyed (Palmisano 1972). Brackish marshes characterized as being comprised of cordgrass (Spartina spp.), saltgrass (Distichlis spicata), needle rush (Juncus roemerianus) and Olney bulrush were attributed to be the most productive muskrat habitat in coastal Texas (Lay and O'Neil 1942). Slightly brackish marshes, dominated by Olney bulrush and cattail, adjacent to wooded areas supported the greatest muskrat production in Maryland coastal habitats (Dozier et al. 1948).

Reproduction

The reproductive habitat requirements of the muskrat are assumed to be identical with its water, food, and cover requirements as described above.

Interspersion

The area occupied by muskrats may be influenced by a variety of factors that include environmental conditions, the size, configuration and diversity of the aquatic habitat, social pressures, and season (Perry 1982). Neal (1968) believed that habitat quality was more important in determining muskrat density than were intraspecific interactions. Muskrat home ranges in Iowa were consistently larger in aquatic habitats with less dense vegetation than they were in habitats with dense emergent vegetation. Danell (1978) reported that the mean distance between muskrat lodges was 110 m (360.8 ft) and no houses were closer together than approximately 40 m (131.2 ft). Most summer and fall home ranges of muskrats in Iowa were 45.7 to 60.9 m (150 to 200 ft) in diameter (Neal 1968). More than 50% of muskrat observations in Manitoba were recorded within 15 m (49.2 ft) of the primary dwelling lodge (MacArthur 1978). Few movements of muskrats exceeded 150 m (492 ft) whereas almost all foraging took place within 5 to 10 m (16.4 to 32.8 ft) of the lodge. Most muskrats recorded in a New Brunswick study remained in the same habitat type, within a relatively confined area, throughout the summer and fall seasons (Parker and Maxwell 1980). Movement between habitat types occurred most frequently between the fall and spring seasons probably due to muskrats being forced from winter lodges and burrows because of early spring increases in the water level. Several authors have reported that the home range size for bank-dwelling muskrats in riverine habitats ranges from 200 to 300 m (656 to 984 ft) along the stream or river channel (Errington 1963; Stewart and Bider 1974). Brooks (1982) estimated the home range for muskrats inhabiting riverine habitats to range between 250 to 400 m (273 to 437 yds) in length. Muskrats inhabiting edge or linear habitats may have oblong home ranges, whereas inhabitants of interior portions of marshes may have home ranges that are more circular in shape (Perry 1982).

O'Neil (1949) reported that high-quality coastal Olney bulrush marshes in Louisiana could support about 13 muskrats/0.4 ha (13/acre), although densities were occasionally much higher for short periods of time because of immigration. Marshes managed for muskrat production also may have much higher densities (Perry 1982). Considerable variation occurs, however, in muskrat density between years. These "cycles" in northern inland marshes have been extensively discussed by Errington (1951, 1954, 1963); however, their causes are not well understood. Lowery (1974) summarized the stages in a cycle as low muskrat numbers, development of an abundant food supply, followed by a rapid build-up of muskrat density with eventual severe overpopulation, habitat destruction, and, finally, starvation. The length of the cycle varies geographically, and cycles may be out of phase within a region.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. The inland muskrat model has been developed for application in freshwater habitats throughout the range of the species.

The estuarine model is applicable to Atlantic and Gulf of Mexico coastal marshes (Fig. 1).

Figure 1. Geographic applicability of the estuarine muskrat HSI model. The freshwater muskrat model is applicable to wetland and riverine cover types throughout the range of the species.

Season. These models have been developed to evaluate the potential quality of year-round habitat in both freshwater and estuarine habitats. Since vegetation type and density must be determined, application of the models may be most effective during the growing season.

Cover types. The freshwater muskrat model was developed to evaluate habitat quality in the following cover types (terminology follows that of U.S. Fish and Wildlife Service 1981): Herbaceous Wetland (HW); and Riverine (R).

The estuarine model is applicable in the following classes of the estuarine intertidal (EI) habitats as described by Cowardin et al. (1979): Emergent (EM); Aquatic Bed (AB); and Unconsolidated Shore (US).

Minimum habitat area. Minimum habitat area is the minimum area of contiguous habitat necessary before an area will be occupied by a species. Information on the minimum habitat area for the muskrat was not found in the literature. It is assumed that potential muskrat habitat will exist in any freshwater or estuarine cover type large enough to be classified as such, if adequate food, water stability, and cover are provided.

Verification level. The freshwater and estuarine muskrat HSI models provide habitat information useful for impact assessment and habitat management. The models are hypotheses of species-habitat relationships and do not reflect proven cause and effect relationships.

The freshwater muskrat models were reviewed by: Dr. Robert Brooks, Pennsylvania State Univeristy, University Park; Mr. Alfred Gardner, U.S. Fish and Wildlife Service, National Museum of Natural History, Washington, DC; Mr. John Organ, U.S. Fish and Wildlife Service, Newton Corner, Massachusetts; Mr. Richard Stardom, Manitoba Department of Natural Resources, Winnipeg; and Ms. Cathy Rewcastle, Manitoba Department of Natural Resources, Winnipeg. Suggestions and comments for improvement were incorporated into the model.

An earlier version of the herbaceous wetlands muskrat model was evaluated by Dr. Jonathan Bart, Ohio Cooperative Wildlife Research Unit, Ohio State University (Bart et al. 1984). HSI values were compared to 1 year's estimates of muskrat house density on 25 sites in northwest Ohio. The minimum amount of persistent emergent vegetation present on any site was 30.6% and all but three sites had greater than 40% emergent vegetation canopy cover. Measuring the degree of linear relationship between muskrat lodge density and HSI's yielded a correlation coefficient of 0.441.

The estuarine model has been reviewed by: Mr. Greg Linscombe, Louisiana Department of Wildlife and Fisheries, New Iberia, LA; Dr. R. Chabreck, Louisiana State University, School of Forestry and Wildlife, Baton Rouge; Mr. Thomas Thornhill, U.S. Fish and Wildlife Service, Daphne, AL; and Dr. Thomas Michot, U.S. Fish and Wildlife Service, Lafayette, LA. The comments and suggestions of these individuals have been incorporated into this model.

An earlier version of the model was evaluated in coastal Louisiana marshes using the 3-year average pelt take as an indication of habitat suitability. Subsequent revisions in the model were based on the results of this field evaluation.

Model Description

Freshwater. Year-round habitat requirements of the muskrat can be fulfilled within wetland habitats that provide herbaceous vegetation and permanent surface water with minor fluctuations in water levels. Wetlands characterized by seasonal drying, an absence of emergent vegetation, or both, have less potential as year-round muskrat habitat than wetlands with permanent water and an abundance of emergent vegetation. It is assumed that food and cover are interdependent characteristics of the muskrat's habitat and that measures of vegetative abundance and water permanence within a wetland can be aggregated to reflect habitat conditions favoring maintenance of the muskrat's food and cover requirements. The reproductive habitat requirements of the species are assumed to be met when adequate water, food, and cover conditions are present.

Estuarine. The estuarine muskrat model describes and defines the variables affecting habitat suitability in coastal (brackish and salt water) wetlands. The model consists of a single component that reflects the potential quality of food and cover. In order to provide potentially suitable year-round habitat for muskrats, coastal marshes must support relatively stable water levels and the water must be of sufficient chemical composition to support an adequate food source. Prior to applying the following estuarine muskrat model, the following factors must be considered to determine if the model is applicable to the habitat being evaluated.

If marsh water level fluctuates more than 90.0 cm (35.4 inches) per year or below the marsh substrate during summer or winter, or water salinity exceeds 30 ppt for more than one week - - - - - - - - - - - - Do not continue with model; HSI for muskrats is assumed to be 0.0.

If marsh water level is relatively stable, does not fluctuate > 90.0 cm (35.4 inches) per year or below marsh surface in summer or winter, and water salinity does not exceed 30 ppt for more than one week - Continue with model application to determine a HSI value.

The following sections provide documentation of the logic and assumptions used to translate habitat information for the muskrat into the variables and equations used in the HSI models. Specifically, these sections cover: (1) identification of variables; (2) definition and justification of the suitability levels of each variable; and (3) description of the assumed relationships between variables. Figure 2 is an illustration of the relationships of habitat variables, life requisites, and cover types to a habitat suitability value for the muskrat in freshwater habitats. Figure 3 is an illustration of the relationships of habitat variables, life requisites, and cover types to a habitat value for the muskrat in estuarine habitats.

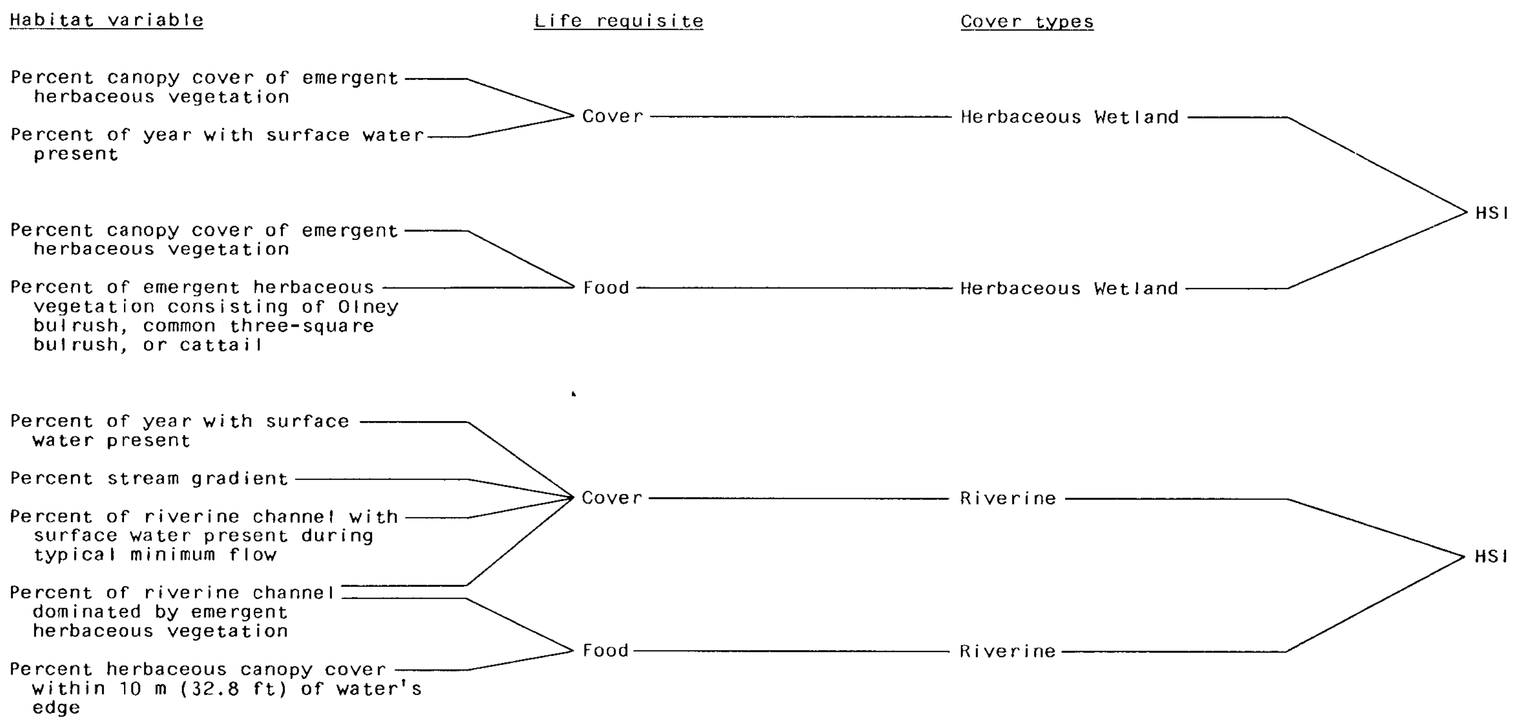


Figure 2. Relationships of habitat variables, cover types, and life requisites in the freshwater muskrat model.

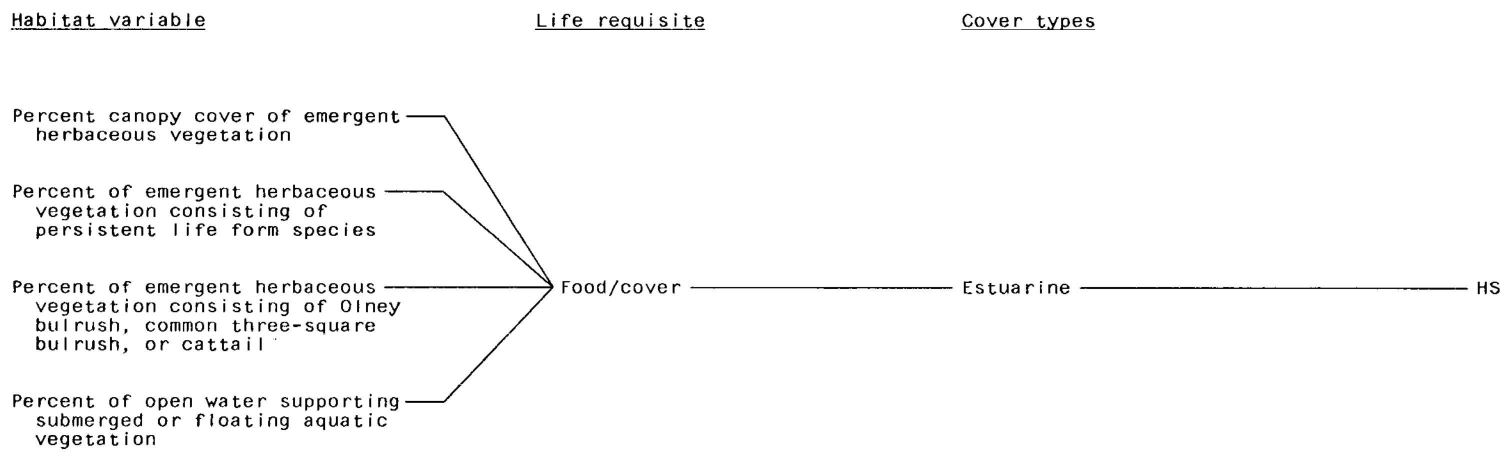


Figure 3. Relationships of habitat variables, cover types, and life requisites in the estuarine muskrat model.

Cover component: freshwater. Suitable cover for muskrats in wetland cover types is a function of the presence and abundance of emergent vegetation suitable for lodge construction and the permanence of water within the wetland basin. Persistent emergent vegetation, such as cattail, normally remains standing throughout the winter months as compared to nonpersistent emergent vegetation whose leaves and stems break down at the end of the growing season (Cowardin et al. 1979). Although both types of emergent vegetation may provide food and cover for muskrats during the growing season, nonpersistent vegetation will not provide optimum lodge construction materials. Woody vegetation in shrub or forested wetlands may provide some cover and physical support for lodge construction. However, it is assumed that emergent vegetation also must be present in these cover types to provide suitable cover and material for lodge construction. If emergent vegetation is absent in these cover types, the cover is assumed to be minimal regardless of the amount of woody vegetation present. It is assumed that optimum cover conditions are present when 50 to 80% of a wetland basin is dominated by emergent vegetation. Canopy cover of emergent vegetation below 50% is assumed to reflect less suitable cover for muskrats. Muskrats may establish bank burrows and are not totally dependent upon the availability of vegetation for lodge construction, therefore, wetlands devoid of emergent vegetation are assumed to have minimal value as muskrat habitat. As the density of emergent vegetation increases above 80%, it is assumed that habitat quality will decrease slightly due to a reduction in escape cover that is provided by open water. Muskrats inhabiting riverine areas establish burrows within river and stream banks and are less dependent upon emergent vegetation for providing adequate cover.

Water permanence is an important characteristic that defines muskrat habitat potential and is assumed to be equally as important as the presence and abundance of emergent vegetation in defining the quality of muskrat habitat. Wetlands that provide permanent year-round surface water are assumed to provide potentially optimum habitat conditions for muskrats. Conversely, wetlands that contain water on a seasonal basis are assumed to have little, if any, potential for meeting the year-round cover requirements of the species. Major changes in water level, either drawdown or flooding, will result in habitat deprivation for the species. Wetlands with water present for 75% of the year (9 months) or less are assumed to be less suitable muskrat habitat, regardless of the amount of persistent emergent vegetation present. Wetlands with water present for 50% of the year (6 months) or less are assumed to be unsuitable year-round muskrat habitat.

Within riverine cover types muskrats require permanent water of low velocity for optimum cover conditions. The cover potential of muskrat habitat in riverine cover types is assumed to be a function of the permanence of surface water and stream gradient. A measure of actual water velocity may yield a more precise indication of riverine habitat quality. However, due to the potential variability in water velocity a measure of velocity at one point in time may yield a relatively inaccurate estimate of habitat conditions when considered on an annual basis. For the purposes of this model, water velocity is assumed to be a function of stream gradient. Low gradient streams are assumed to have greater potential as muskrat habitat than high gradient streams. High water velocity, rocky substrate, low pool/riffle ratio, and less cover immediately adjacent to the water's edge are typically associated with high gradient streams (Reid 1961). In contrast, low gradient streams are characterized as having low water velocity, substrates consisting of finer sediments, high pool/riffle ratio, and more cover in the form of undercut banks, debris and vegetation in and immediately adjacent to the water's edge. It is assumed in this model that riverine reaches with a gradient of 1% [10 m/km (53 ft/mi)] or less will be indicative of potentially optimum cover conditions for the muskrat by providing water of low velocity and banks suitable for the establishment of burrow systems. A gradient of 4% [40 m/km (211 ft/mi)] or greater is assumed to be indicative of marginal muskrat habitat. Brooks (pers. comm.) cautioned that stream gradient may give an inaccurate indication of muskrat habitat quality when applied over long distances [> 1.0 km (0.6 mi)]. The presence of a dam or rapids may yield an incorrect estimate of habitat quality when long stream reaches are evaluated. For example, evaluation of a stream reach containing a large rapid may result in a relatively high gradient value, indicating low muskrat habitat potential, even though the stream channel both above and below the rapid may be of low gradient and represent potentially high quality muskrat habitat. Brooks (pers. comm.) suggested that the evaluation of riverine habitat conditions by Stream Order (Horton 1945) may be a more accurate method when used on an individual watershed.

Riverine cover types must provide permanent surface water for ideal muskrat habitat. However, the amount of surface water present also has an influence on habitat potential for the species. The amount of suitable muskrat habitat in riverine cover types is probably no greater than the amount of surface water present during minimum flow periods. Riverine cover types with relatively stable discharge have greater habitat potential than do those that have widely fluctuating flows. Intermittent streams probably have little, if any, year-round habitat potential for muskrats due to a seasonal absence of water in the channel. Riverine habitats that maintain minimum flows and/or isolated pools during low flow periods are of minimum value as muskrat habitat. Depending upon their size and depth, isolated pools may provide adequate habitat during low flow periods from which muskrats may disperse during higher flow periods. Therefore, in riverine habitats, the cover potential for muskrats is assumed to be a function of the percent of the riverine channel with surface water during minimum discharge periods.

Food component: freshwater. The major component of the muskrat's diet is herbaceous vegetation. High-density muskrat populations are typically associated with wetland habitats that support dense stands of emergent vegetation. Cattail has often been identified as a preferred food in fresh water wetlands, and is believed to be capable of supporting higher numbers of muskrats than other types of emergent vegetation. Nonpersistent vegetation, submerged aquatic vegetation, and terrestrial herbaceous vegetation also are consumed by muskrats. However, it is assumed that the stems, leaves, and rhizomes of emergent vegetation are the primary components of the muskrat's annual diet. Within wetland cover types food quality is assumed to be related to the total amount of emergent vegetation present and the proportion of that vegetation that consists of cattail.

Emergent vegetation, persistent or nonpersistent, is assumed to be most suitable as a potential food source when present at a density of 50 to 80% canopy closure. Canopy coverage less than 50% or greater than 80% is assumed to be indicative of less suitable food quality. Food quality is assumed to be positively correlated to the amount of cattail making up the total amount of emergent vegetation present. Stands of emergent vegetation consisting wholly of cattail will be of maximum value as a muskrat food source. Stands of emergent vegetation other than cattail are assumed to be of lower value as a potential food source even though total density may be within the optimum range. Wetlands with a density of emergent vegetation in excess of 80% are assumed to have a lower potential as a diverse year-round food source for muskrats due to a decreased availability of submergent vegetation resulting from a reduction in open water. Inasmuch as muskrats will forage on submerged aquatic and terrestrial herbaceous vegetation, wetlands devoid of emergent herbaceous vegetation are assumed to have minimum potential for providing muskrat food. However, not all wetlands are suitable muskrat habitat. For example, alkaline wetlands (pH $\geq$ 7.4) probably have no potential as muskrat habitat.

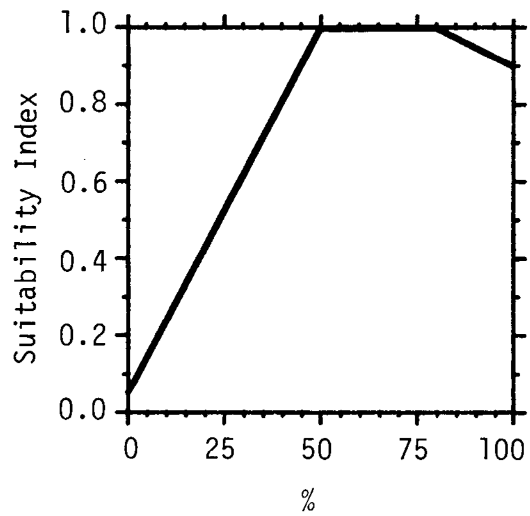
Muskrats inhabiting riverine habitats obtain most of their food from terrestrial vegetation adjacent to the stream channel. Emergent vegetation may be an adequate food source if present; however, the absence of such vegetation will not limit the potential food value if terrestrial herbaceous vegetation is present in an adequate amount. Due to the muskrat's relatively small home range size, it is assumed that density of herbaceous vegetation within 10 m (32.8 ft) of the water's edge will indicate potential food availability. The value of terrestrial herbaceous vegetation as a potential muskrat food source is assumed to be positively related to density. Stream channels bordered by trees and/or shrubs will probably have less dense herbaceous ground cover than would channels bordered by open ground or cropland. Emergent vegetation is an additional food source in riverine habitats that probably contributes to a more stable food supply when considered on an annual basis. The abundance of emergent vegetation is assumed to be twice as important as the presence and abundance of terrestrial herbaceous vegetation in determining potential year-round values of food resources for muskrats in riverine habitats.

Food/cover component: estuarine. Emergent vegetation provides food and cover for muskrats. The estuarine model does not attempt to separate these functions. Fifty to 80% canopy coverage of emergent herbaceous vegetation is assumed to be characteristic of optimum muskrat habitat in estuarine habitats. Although muskrats will create small amounts of open water in dense stands of emergent vegetation as a result of their feeding and lodge construction activities, estuarine habitats with a density of emergent vegetation in excess of 80% are assumed to be of slightly lower habitat potential due to a decreased availability of escape cover provided by open water. Estuarine habitats with no emergent vegetation are assumed to have almost no potential as muskrat habitat. However, because dikes or shoreline habitats may provide sites for bank burrows and submerged and floating aquatic vegetation may provide a limited food source, the complete absence of emergent herbaceous vegetation is assumed to represent estuarine habitats with minimum muskrat habitat potential.

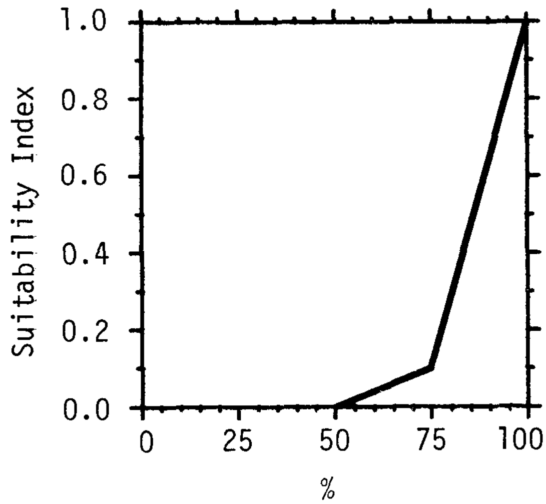
Persistent emergent herbaceous vegetation is believed to be of greater value for providing food and cover for the muskrat than is nonpersistent emergent vegetation. Therefore, the suitability of muskrat habitat is assumed to increase as the proportion of emergent vegetation consisting of persistent life form species increases. However, the estuarine muskrat model is based on the assumption that a marsh with no persistent emergent vegetation does have a low value as muskrat habitat. Although there is no evidence that muskrats exhibit a preference among emergent vegetation used as lodge construction materials, coastal muskrats do prefer bulrush (Olney and common three-square) and cattails as food items. It is assumed that an 80 to 100% occurrence of these preferred species represents optimum food and cover conditions in estuarine wetlands. However, these species are not required by muskrats and wetlands with a 0 to 10% occurrence of bulrush and cattails are assumed to retain a low value as muskrat habitat. Muskrats also feed on submerged and floating-leafed aquatic vegetation and use these forms of vegetation in lodge construction to a limited degree. It is assumed that the value of open water habitat increases as the percentage of the habitat that supports submerged and floating vegetation increases. The absence of submerged or floating aquatic vegetation in a mixed open water/emergent marsh is assumed not to preclude muskrat use of the area.

Model Relationships

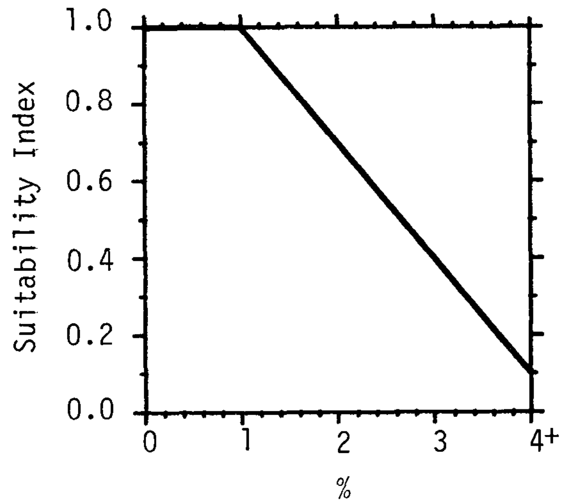
Suitability Index (SI) graphs for habitat variables. The relationships between various values of habitat variables and habitat suitability for the muskrat are graphically presented in this section.

Cover type	Variable		
HW, EI	V_1	Percent canopy cover of emergent herbaceous vegetation.	

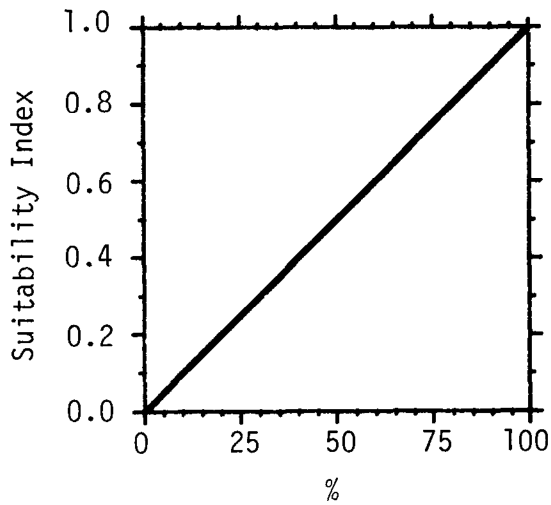
HW V_2 Percent of year with surface water present.



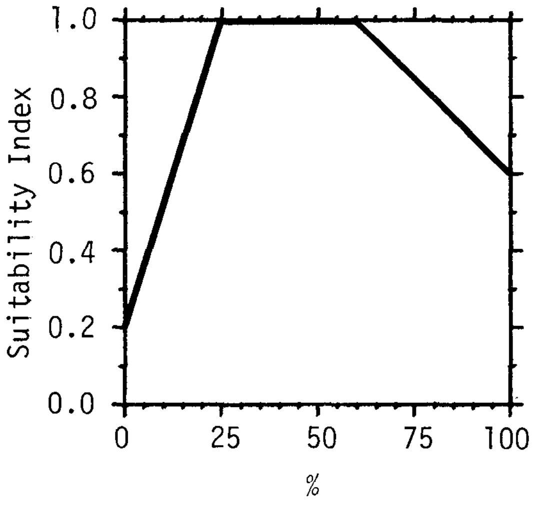
R V_3 Percent stream gradient.



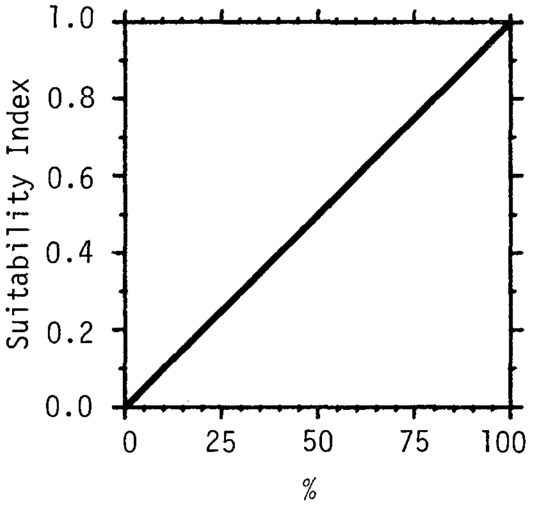
R V_4 Percent of riverine channel with surface water present during typical minimum flow.



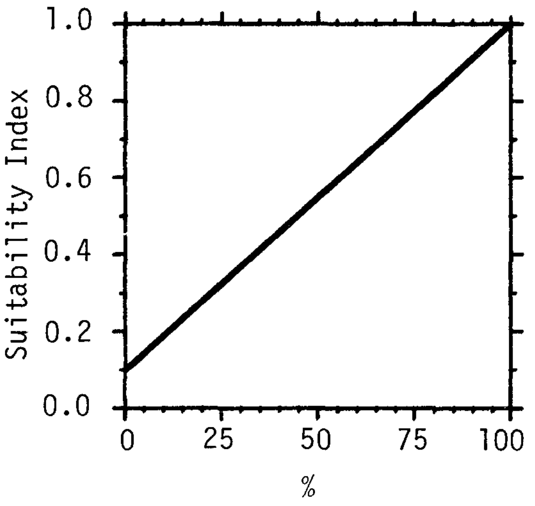
R V_5 Percent riverine channel dominated by emergent herbaceous vegetation.



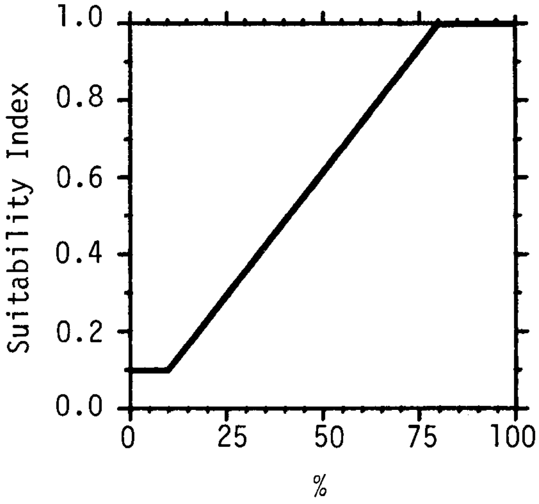
R V_6 Percent herbaceous canopy cover within 10 m (32.8 ft) of water's edge.



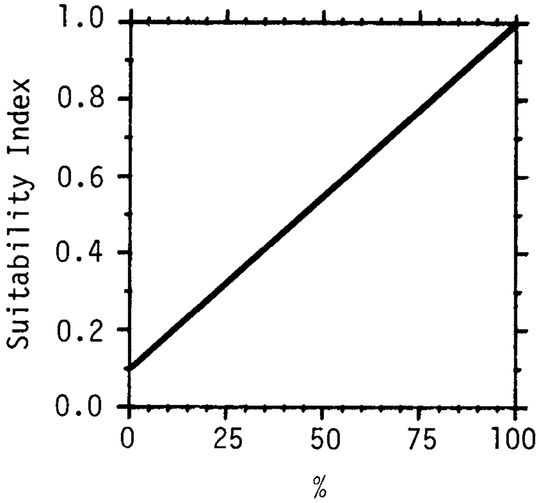
EI V_7 Percent of emergent herbaceous vegetation consisting of persistent life form species.



HW,EI V_8 Percent of emergent herbaceous vegetation consisting of Olney bulrush, common three-square bulrush, or cattail.



EI V_9 Percent of open water supporting submerged or floating aquatic vegetation.



Equations. In order to obtain life requisite values for the muskrat, the SI values for appropriate variables must be combined through the use of equations. A discussion and explanation of the assumed relationships between variables for freshwater and estuarine habitats was included under Model Description. The suggested equations for obtaining life requisite and HSI values are presented in Figure 4.

Life requisite	Cover type	Equation
Cover	HW	$(V_1 \times V_2)^{1/2}$
Food	HW	$(V_1 \times V_8)^{1/2}$
Cover	R	$\frac{(V_2 \times V_3 \times V_4)^{1/3} + V_5}{2}$
Food	R	$\frac{V_6 + 2(V_5)^*}{2}$ *In instances where a value greater than 1.0 is obtained, the value should be considered to equal 1.0.
Cover/Food	EI	$[(V_1 \times V_7 \times V_8{}^2)^{1/4} \times (a)] + [V_9 \times (b)]^{**}$ where: a = the percent of the total estuarine habitat being evaluated that supports > 10% emergent vegetation canopy cover b = the percent of the total estuarine habitat being evaluated that supports ≤ 10% emergent vegetation canopy cover **See Application of the Model section for specific instructions for the calculation of this value.

Figure 4. Equations for determining life requisite values by cover type for the muskrat.

HSI determination. The HSI value in freshwater herbaceous wetlands and riverine cover types is computed by assuming a limiting factor mechanism. The HSI will equal the lowest life requisite value received for either cover or food in either cover type. The HSI value in estuarine cover types is equal to the cover/food life requisite value.

Application of the Model

Calculation of the food/cover life requisite for estuarine muskrat habitat is a function of: (1) the quality of emergent vegetation (V_1, V_7, V_8); (2) the area dominated by emergent vegetation (> 10% canopy closure); (3) the percentage of the evaluation area in open water (≤ 10% canopy closure of emergent vegetation); and (4) the amount of floating or submerged aquatic vegetation in open water areas (V_9). A weighted (weighted by area) food/cover value is calculated by performing the following steps:

1. Stratify the estuarine habitat into areas dominated by emergent vegetation and open water.

2. Determine the area dominated by emergent vegetation, area dominated by open water, and total estuarine area.

3. Determine an SI value for the area dominated by emergent vegetation $[(V_1 \times V_7 \times V_8{}^2)^{1/4}]$ and an SI value for the area dominated by open water (V_9).

4. Multiply the area dominated by emergent vegetation and the area dominated by open water by their respective SI values (Step 3).

5. Add the products calculated in step 4 and divide the sum by the total area of the estuarine habitat to obtain the weighted food/cover life requisite value.

Definitions of variables and suggested field measurement techniques (Hays et al. 1981) are provided in Figure 5.

Variable (definition)		Cover types	Suggested technique
V_1	Percent canopy cover of emergent herbaceous vegetation (the percent of the water surface shaded by a vertical projection of the canopies of all emergent herbaceous vegetation, both persistent and non-persistent).	HW,EI	Remote sensing, line intercept
V_2	Percent of year with surface water present (the proportion of the year in which the cover type has surface water present).	HW	Remote sensing, local data
V_3	Percent stream gradient (specific expression of decrease in elevation of a stream or river bed; determined by dividing the change in elevation between two points of the riverine reach by the horizontal distance between those two points, then multiplying the product by 100).	R	Topographic map
V_4	Percent of riverine channel with surface water present during typical minimum flow (the proportion of the riverine channel covered by surface water during the lowest discharge in the driest period of the year).	R	Remote sensing, line intercept

Figure 5. Definitions of variables and suggested measurement techniques for the freshwater and estuarine muskrat model.

Variable (definition)		Cover types	Suggested technique
V_5	Percent of riverine channel dominated by persistent emergent vegetation [the percent of the stream or river channel's bed that supports emergent vegetation that normally remains standing after the growing season e.g., cattail (*Typha* spp.) or bulrush (*Scirpus* spp.)].	R	Remote sensing, line intercept
V_6	Percent herbaceous canopy cover within 10 m (32.8 ft) of water's edge (the percent of the ground surface within 10 m of the edge of the riverine cover type which is shaded by a vertical projection of all nonwoody vegetation).	R	Line intercept, quadrat
V_7	Percent of emergent herbaceous vegetation consisting of persistent life form species [the proportion of the emergent herbaceous vegetation that normally remains standing after the growing season (e.g., cattail or bulrush)].	EI	Remote sensing, line intercept
V_8	Percent of emergent herbaceous vegetation (both persistent and nonpersistent) consisting of Olney bulrush, common three-square bulrush, or cattail.	HW,EI	Remote sensing, line intercept, quadrat
V_9	Percent of open water supporting submerged or floating aquatic vegetation.	EI	Remote sensing, line intercept, quadrat

Figure 5. (concluded).

SOURCES OF OTHER MODELS

Brooks (1980) and Brooks and Dodge (in prep.) have developed a model using principle component regression for estimating muskrat density in riverine habitats. The model can be used to identify favorable riverine muskrat habitat and rank watersheds with respect to potential muskrat abundance. Habitat information gathered from remote sensing data are used to identify gross physiognomic features of potential muskrat habitat. Microhabitat characteristics and local population attributes are investigated by on-site reconnaissance. The model is not recommended for application in northern coniferous forests, riparian habitats in arid regions, or tropical climates.

No other habitat model designed for the evaluation of coastal muskrat habitat was located in the literature.

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16. Abstract (Limit: 200 words)

Habitat preferences of the muskrat (Ondatra zibethicus) are described in this report, which is one of a series of Habitat Suitability Index (HSI) models. A review and synthesis of the literature is followed by development of estuarine and freshwater habitat models incorporating life requisites of the muskrat. HSI models are designed for use with Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service.

17. Document Analysis a. Descriptors
Mathematical models
Wildlife
Habitability

b. Identifiers/Open-Ended Terms
Habitat Suitability
Muskrat
Ondatra zibethicus

c. COSATI Field/Group

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