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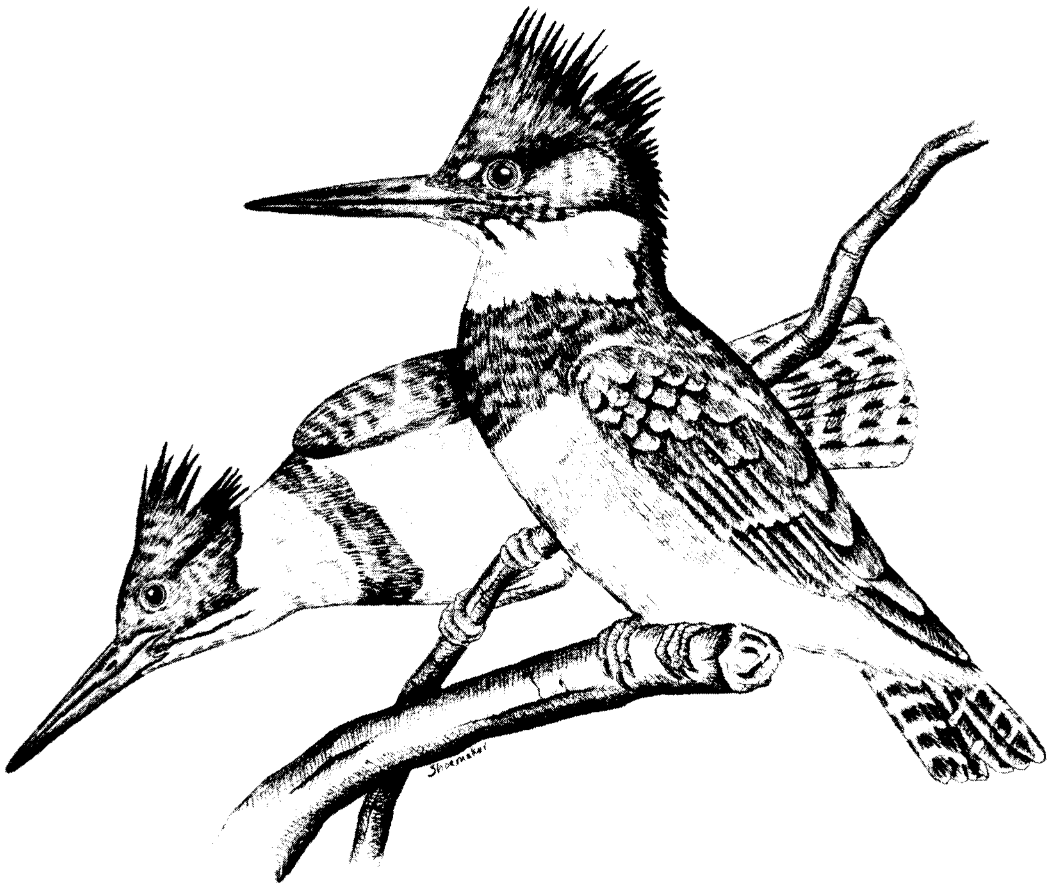
HABITAT SUITABILITY INDEX MODELS: BELTED KINGFISHER



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HABITAT SUITABILITY INDEX MODELS: BELTED KINGFISHER

by

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PREFACE

This document is part of the Habitat Suitability Index (HSI) Model Series [Biological Report 82(10)] which provides habitat information useful for impact assessment and habitat management. Several types of habitat information are provided. The Habitat Use Information Section is largely constrained to those data that can be used to derive quantitative relationships between key environmental variables and habitat suitability. This information provides the foundation for the HSI model and may be useful in the development of other models more appropriate to specific assessment or evaluation needs.

The HSI Model Section documents the habitat model and includes information pertinent to its application. The model synthesizes the habitat use information into a framework appropriate for field application and is scaled to produce an index value between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). The HSI Model Section includes information about the geographic range and seasonal application of the model, its current verification status, and a list of the model variables with recommended measurement techniques for each variable.

The model is a formalized synthesis of biological and habitat information published in the scientific literature and may include unpublished information reflecting the opinions of identified experts. Habitat information about wildlife species frequently is represented by scattered data sets collected during different seasons and years and from different sites throughout the range of a species. The model presents this broad data base in a formal, logical, and simplified manner. The assumptions necessary for organizing and synthesizing the species-habitat information into the model are discussed. The model should be regarded as a hypothesis of species-habitat relationships and not as a statement of proven cause and effect relationships. The model may have merit in planning wildlife habitat research studies about a species, as well as in providing an estimate of the relative suitability of habitat for that species. User feedback concerning model improvements and other suggestions that may increase the utility and effectiveness of this habitat-based approach to fish and wildlife planning are encouraged. Please send suggestions to:

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CONTENTS

ACKNOWLEDGMENTS

Preliminary drafts of this model were reviewed by Dr. Robert P. Brooks, Mr. Wm. James Davis, and Dr. Michael J. Hamas. Their expertise regarding habitat relationships among belted kingfishers greatly facilitated development of this model, and significantly improved the model's quality and value.

The belted kingfisher illustration on this document's cover was drawn by Jennifer Shoemaker. Word processing was provided by Elizabeth Graf, Carolyn Gulzow, and Dora Ibarra.

BELTED KINGFISHER (*Ceryle alcyon*)

HABITAT USE INFORMATION

General

The belted kingfisher (*Ceryle alcyon*) typically is a bird of stream courses and lake and pond edges (Hamas 1974) and is common on sea coasts and estuaries (Bent 1940). Kingfishers feed primarily on fish, which they catch in clear waters that are not overgrown with thick vegetation (Bent 1940). Nests usually are placed in burrows dug into high vertical cutbanks of relatively friable soil. Belted kingfishers are solitary birds except during the breeding season (Roberts 1932), when pairs establish territories for nesting and fishing (Davis 1980, 1982).

The belted kingfisher breeds from western and central Alaska, central Yukon, British Columbia, western and south-central Mackenzie, northern Saskatchewan, central and probably northern Manitoba, northern Ontario, central Quebec, east-central Labrador and Newfoundland south to southern California, southern Arizona, southern New Mexico, southern Texas, the Gulf coast and central Florida (American Ornithologists' Union 1983:372). The winter range extends from south-coastal and southeastern Alaska, central and southern British Columbia, western Montana, Wyoming, Colorado, Nebraska, southern Minnesota, the southern Great Lakes region, New York and New England south throughout the continental United States, Middle America, the West Indies, and Bermuda to northern South America and the Galapagos Islands.

Food

Fish that swim near the surface or in shallow water are the primary food of belted kingfishers (Roberts 1932; Bent 1940; Salyer and Lagler 1949; White 1953; Imhof 1962; Cornwell 1963; Sprunt and Chamberlain 1970; Davis 1980). Although the predatory potential of belted kingfishers with young to feed is more than 50 fingerlings per day at fish hatcheries (White 1936), they have relatively little effect on fish populations in natural waters, except possibly in spawning areas and nursery grounds (Salyer and Lagler 1949).

Several feeding habitat studies have shown that belted kingfishers generally catch the prey that are most available (White 1937, 1953; Salyer and Lagler 1949; Davis 1982). Forage fish and crayfish (*Cambarus* spp.) made up 39 and 24%, respectively, of the food items caught by kingfishers in Michigan trout (Salmonidae) streams (Salyer and Lagler 1949). Forage fish apparently were caught more easily than trout and were most abundant in the open, sunlit stream areas where kingfishers frequently fed. Fishing habits in nontrout streams and lakes were similar to those in trout streams. The more abundant and vulnerable forage fish made up 43 and 53% of the food items in nontrout streams and lakes, respectively, while crayfish made up 21 and 12%, repectively. Forage fish were predominantly sculpins (Cottus spp.), brook sticklebacks (Culaea inconstans), and cyprinids. Other food items were game and pan fish, frogs (Rana spp.), crayfish, and insects.

Brook trout (Salvelinus fontinalis), slimy sculpins (Cottus cognatus), threespine sticklebacks (Gasterosteus aculeatus), alewife (Alosa pseudoharengus), banded killifish (Fundulus diaphanus), and minnows (Cyprinidae) were important food species for kingfishers foraging in streams in the Maritime Provinces of Canada (Nova Scotia, New Brunswick, and Prince Edward Island) (White 1953). Food items taken from warmer streams were white suckers (Catostomus commersoni), threespine sticklebacks, lake chubs (Cousesius plumbeus), and banded killifish. Ninespine sticklebacks (Pungitius pungitius) were the dominant food items from ponds and lakes, although white perch (Morone americana) and alewife also were eaten. Food items from the Maritime shoreline were mummichog (Fundulus heteroclitus), threespine sticklebacks, and black-spotted sticklebacks (Gasterosteus wheatlandi). Crayfish were an important food item in certain waters where mergansers (Mergus spp.) had reduced fish numbers.

Stonerollers (Campostoma anomalum) were the most common potential prey species and the most commonly caught food item in Ohio stream habitats (Davis 1982). Stonerollers made up 37.6% of the total food items; crayfish, 13.3%; nonminnows, 10.2%; and miscellaneous cyprinids, 38.8%. Crayfish may have been an important food when adverse water conditions made fishing difficult; 90% of the observations of crayfish being taken to the nest occurred during periods of high water and high turbidity. It appeared that crayfish also were eaten more during winter when ice made fish less accessible.

The diet of the belted kingfisher can be variable, with crayfish, crabs, mussels, lizards, frogs, toads, small snakes, turtles, insects, salamanders, newts, young birds, mice, and berries used as alternate foods when fish are scarce (Bent 1940). Belted kingfishers in North Carolina fed on bullfrog tadpoles (Rana catesbeiana) in an artificial pond that was devoid of fish (Terres 1968).

Belted kingfisher nestlings in Michigan apparently were fed small, delicate fish that disintegrated easily (Salyer and Lagler 1949). For the first 3 to 4 days after leaving the nest, the young kingfishers fed on flying insects, particularly mayflies (Ephemeroptera), which they captured themselves. For the next 6 days, the broods fed almost exlusively on crayfish. By the 18th day, juvenile kingfishers were catching fish. Parent kingfishers in Nova Scotia fed nestlings 85% Atlantic salmon (Salmo salar) and 15% brook trout (White 1938). Threespine sticklebacks were available but apparently were avoided.

Fish caught by belted kingfishers generally are no longer than 10.2 cm (Imhof 1962). The average length of fish eaten by belted kingfishers in Michigan was < 7.6 cm and ranged from 2.5 to 17.8 cm (Salyer and Lagler 1949); fish longer than 12.7 cm were thought to be difficult to swallow. Fish caught by kingfishers in Ohio streams ranged 4-14 cm in length (Davis 1982).

Adult belted kingfishers in Minnesota apparently selected relatively large fish (averaging 9.2 cm) to feed to nestlings (Cornwell 1963). Similarly, belted kingfisher nestlings 7 to 10 days old and weighing an average of 56.6 g were fed fish up to 10.2 cm in length in the Maritime Provinces (White 1953). Feeding relatively large fish to nestlings apparently was necessary because nestlings require their weight in food each day, nests often are long distances from water, and parents bring only one fish at a time to the nest.

Water

Belted kingfishers require clear water for an unobstructed view of their prey (Bent 1940; Davis 1980). Belted kingfishers are virtually absent on muddy waters in the Maritime Provinces (White 1953). Belted kingfishers in Michigan rarely nested on the lower reaches of large rivers where the water was usually quite turbid (Salyer and Lagler 1949); all adjacent backwaters with relatively clear water were used for nesting. Kingfishers are characteristically absent from their usual fishing areas when the water becomes temporarily muddied by runoff following heavy rains (Salyer and Lagler 1949; Davis 1980).

Masses of long trailing pondweeds (Potamogeton spp.) and water buttercup (Ranunculus spp.) may be a deterrent to kingfisher foraging in some streams in the Maritime Provinces that contain good stocks of salmon and trout (White 1953).

Fishing is confined to shallow water or near the surface in deeper water (Salyer and Lagler 1949). Fishing success is lower in deeper stream pools than in shallow waters having a slow to moderate current. White (1953) suggested that most fish are caught in water < 60 cm deep and that fish are not caught more than 60 cm below the surface in deeper water. Davis (W. J. Davis, Department of Zoology, University of Texas at Austin; pers. comm.), however, believes that fish generally are caught no more than 12 to 15 cm below the surface. A lack of shallow water may result in fewer good foraging sites for kingfishers (Brooks and Davis in prep.).

Wave action caused by wind on the water surface (especially lentic sites) is almost as important as turbidity in determining kingfisher population distribution, foraging locations, and fishing success (Salyer and Lagler 1949). Kingfisher territories along lakes in Michigan invariably included all or part of a small sheltered bay that had an unrippled fishing surface regardless of most wind directions (Salyer and Lagler 1949). Fewer kingfishers established territories along the shore of large, rough lakes than along smaller lakes. Belted kingfishers use shallow, protected bays for nesting and fishing and tend to avoid more open, wave swept areas on the Gulf of Saint Lawrence, Canada (White 1953).

Several fish species regularly congregate and feed at the ends of riffles. Thus, riffles may be an important environmental cue for kingfishers, indicating concentrations of prey (Brooks and Davis in prep.). Kingfishers in Ohio used riffles for foraging 71.3% of the time during the nonbreeding season, and apparently behaved similarly during the breeding season (Davis 1982). Although kingfisher territories in Pennsylvania were significantly larger than in Ohio, the number and total length of riffles/territory were similar for territories in both states (Brooks and Davis in prep.); indicating that shallow water and riffles are important features of territories.

Although most belted kingfishers migrate to southern States during late fall, some remain as far north as they can find open water for fishing (Bent 1940). Swift currents or geothermally heated water can keep fishing waters open where they otherwise would be iced over (Roberts 1932; Bent 1940).

Cover

Vegetation along the margins of feeding waters has both positive and negative implications. Belted kingfishers are seldom seen on ponds or streams that are overgrown with thick vegetation that obscures vision (Bent 1940). Narrow and heavily shaded branches of water courses were avoided by kingfishers in Alabama (Imhof 1962), and the larger and more open streams were preferred for fishing over smaller branches completely overshadowed by vegetation in the Maritime Provinces (White 1953). Belted kingfishers were absent from streams extensively overgrown with shoreline vegetation in Michigan, but increased when beaver (Castor canadensis) ponds opened large reaches of streams (Salyer and Lagler 1949). The kingfisher population increased in proportion to the increased area flooded by the beaver dams.

Kingfisher broods use shrub cover along water edges for concealment (White 1953). Young kingfishers in Michigan hid among dogwood (Cornus spp.), alder (Alnus spp.), and other shrubs along the water near their parents and flew out to catch passing insects (Salyer and Lagler 1949).

Belted kingfishers in the Maritime Provinces typically roosted among the leaves of deciduous trees and near the tips of small supple limbs, where they were safe from nocturnal predators (White 1953). Roosts were 30.5 to 61.0 m from water and 6.1 to 7.6 m above the ground. Three male kingfishers in Minnesota used night roosts located in dense northern hardwood-conifer forest stands not far from their nests (Cornwell 1963).

Belted kingfishers apparently prefer a bare tree branch at the water's edge as an observation perch for fishing (Bent 1940; Salyer and Lagler 1949). Stakes and piers are used for perches at sea coasts and estuaries (Bent 1940), and telephone wires may be used along canals (Lowery 1960).

Reproduction

Belted kingfishers establish breeding territories within which they excavate nesting burrows (Davis 1982). The nest sites preferably are near water and as close to fishing areas as possible (Bent 1940). Nests are a simple chamber located at the end of the burrow, that is generally 0.9 to 1.8 m long, although they can reach 3.0 to 4.6 m in length. Twelve nest burrows in Pennsylvania and Ohio averaged 1.2 ± 0.2 m in length and 7.8 ± 0.7 cm in diameter (R. P. Brooks, Forest Resources Laboratory, The Pennsylvania State University, University Park; pers. comm.). Burrows usually are dug into steep banks devoid of vegetation (Roberts 1932; Cornwell 1963; Hamas 1974) and may be used for several successive years (Bent 1940).

Sandy clay was the most suitable soil for nest sites in Minnesota (Cornwell 1963), and well-drained soil banks of sandy composition with vertical or slightly overhanging faces were common burrow sites in the Maritime Provinces (White 1953). Burrows in banks composed of compacted sand in Ohio were easy to excavate, kept their structural integrity, and were longer than those in banks composed of sand and gravel or clay and humus (Davis 1980). Banks of clay, gravel, and rocks apparently were unsuitable, as were banks where excavations could not exceed 80 cm in length. Sand dominated soil composition at 16 nest sites in Pennsylvania, Ohio, and Texas (Brooks pers. comm.).

Another factor that may influence nest site selection is the presence of woody roots that impede nest excavation (Brooks and Davis in prep.). Random unused sites along streams in Pennsylvania and Ohio had a larger percentage of forested edge than did occupied sites. Exposed root masses were typical of forested banks. A preference for agricultural areas with herbaceous vegetation along banks may reflect an avoidance of tree roots.

The height of the burrow entrance is an important factor in terms of protection from predators (White 1953) and flood water (Davis 1980). The elevation of nest burrows in soil banks generally depends on the height of the bank (Bent 1940; Cornwell 1963), but is at least 1.5 m from the base whenever possible (Cornwell 1963). Kingfishers in Pennsylvania and Ohio apparently selected the highest banks available (Brooks and Davis in prep.). The burrow entrance usually is 30 to 90 cm from the top of the bank (Bent 1940; White 1953; Cornwell 1963; Brooks and Davis in prep), near the bottom of the organic soil layer (Cornwell 1963). Nest chambers that are too close to the top of the bank (10 to 20 cm) can collapse or be dug out by predators (Brooks and Davis in prep.). Nests in Ohio with entrances < 2.5 m in height were susceptible to destruction by annual flooding. In Mississippi, Weber and Miller (1981) found no sign of predation at nests 2.5 m up from the base of a vertical face.

Belted kingfishers excavating nest burrows in the Maritime Provinces flew to a perch to rest between digging periods (White 1953). These perches usually overlooked the burrow. Nest sites in Minnesota had perches within 30.5 m that overlooked the nests (Cornwell 1963). Eight of nine perches were dead or dying trees, and one was a telephone wire.

Where suitable nest sites are in short supply, belted kingfishers may resort to unusual sites such as extremely low soil banks and soil caked among the roots of a fallen tree (White 1953), the top of decaying tree stumps (Beyer et al. 1908), and holes in dead trees and stumps (Sprunt 1954). Nest site shortages in the Maritime Provinces may have delayed nesting, in some cases, while parent birds searched for available sites (White 1953). Delayed nesting can result in late development of kingfisher nestlings.

Human activities can create suitable kingfisher nest sites (White 1953) that support kingfisher populations and facilitate their expansion (Hamas 1974). Suitable man-made nest sites include railroad and roadside cuts (Bent 1940), consolidated sawdust piles (Weber and Miller 1981), and sand and gravel pits (Bull 1974). A belted kingfisher nest burrow once was found in a weathered pile of iron ore tailings that had the consistency of coarse sand mixed with finely crushed cinders (Van Deusen 1947). Only 11% (Cornwell 1963) and 16% (Hamas 1974) of nests found in two Minnesota studies were located at natural sites; artificial banks formed by road cuts, gravel pits, and sanitary landfills provided the majority of nest sites. Kingfishers heavily depend on nest sites resulting from human activities in the Maritime Provinces, and would be absent from large areas with good food supplies if these artificial sites were not available (White 1953). Sand and gravel pits, railroad and highway cuts, and ditch banks were commonly used nest sites. Likewise, Hamas (1974) suspected that the kingfisher population in his Minnesota study area would be limited by a lack of natural nest sites if man-made sites were unavailable.

Interspersion and Movements

Territorial behavior in belted kingfishers serves to obtain food and nesting sites (Davis 1980). Breeding territories averaged more than twice as long as nonbreeding territories (1,030 ± 219 m versus 389.29 ± 92.63 m) along stream habitat in Ohio (Davis 1982). Nonbreeding territory size was inversely related to food abundance, but breeding territory size was not. However, breeding territory size appeared to be related to the distribution of food sources; i.e., the smallest territories contained the richest food sources near the nests. Breeding habitat quality may therefore be better represented by food density near the nest than by total food quantity. A larger territory was thought to be advantageous in situations where food is not concentrated near the nest, because larger territories may contain greater amounts of food and provide alternative food sources during fluctuations in water levels.

In Michigan, territory sizes on lakes were much smaller than those on rivers (Salyer and Lagler 1949). Lakeside territories averaged approximately 0.8 km of shoreline, with a maximum of 2.4 km. Territory size along rivers usually was 2.4 to 4.8 km or more. The relatively large river territories may be related to excessive vegetative cover, deep unfishable pools, and fast currents that reduced visibility and limited fishing areas. Another territory that included two small ponds was approximately 14.2 ha in size.

Belted kingfishers prefer to nest in close proximity to suitable fishing areas (Bent 1940). Close proximity of nest sites to fishing habitat was indicated in reports by Mousely (1938), Salyer and Lagler (1949), White (1953), and Davis (1982). Occasionally, kingfishers nest some distance from water. Nearby water apparently was not critical in nest site selection in Minnesota (Cornwell 1963); two of nine nests were directly over water, three were within 152.4 m of water, and four were within 0.5 to 1.6 km. Kingfishers did not necessarily restrict their fishing to the water nearest the nest. Fishing sites usually were within 1.6 km of nest sites, although a daily flight of 3.2 km was not uncommon. The daily range of nesting adults was between 0.8 and 8.0 km. Hamas (M. J. Hamas, Department of Biology, Central Michigan University, Mount Pleasant; pers. comm.) located a belted kingfisher nest in northern Minnesota nearly 3.2 km from the nearest lake, but the site was at a higher elevation and within view of the lake.

Special Considerations

Belted kingfishers have a low tolerance of human disturbance near nest sites. Potential nest sites in Ohio were unsuitable because of nearby human activity. Nest desertion due to human disturbance has been reported by White (1953) and Cornwell (1963).

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area. This model was developed for application within the entire range of the belted kingfisher.

Season. This model was developed to evaluate breeding season habitat of the belted kingfisher. Winter habitat is not considered in this model because winter habitat requirements for the belted kingfisher are not well documented (Hamas pers. comm.).

Cover types. This model can be applied in Riverine (R) and Lacustrine (L) cover types (terminology follows that of U.S. Fish and Wildlife Service 1981).

Minimum habitat area. Minimum habitat area is defined in this model as the minimum amount of contiguous habitat that is required before a breeding pair of kingfishers will occupy an area. Specific information on the minimum habitat area that is required by the belted kingfisher was not found in the literature, but is estimated from territory size data to be 1.0 km of lake shore or stream.

Verification level. This model is a hypothesis of species-habitat relationships and not a statement of proven cause and effect relationships. Preliminary drafts were reviewed by:

Robert P. Brooks, Forest Resource Laboratory, The Pennsylvania State University, University Park;

Wm. James Davis, Department of Zoology, University of Texas at Austin; and

Michael J. Hamas, Department of Biology, Central Michigan University, Mount Pleasant.

Their review comments and suggestions have been incorporated into the model.

Dr. Brooks provided unpublished measurements from stream habitats having high and low belted kingfisher populations, and from randomly selected stream areas unused by kingfishers. This data was helpful in hypothesizing species-habitat relationships, and finalizing equations for HSI determination.

Model Description

Overview. This model is divided into components, each representing a life requisite of the belted kingfisher. The components for belted kingfisher breeding habitat are water, cover, and reproduction. Food requirements are assumed to be represented by the habitat variables used to evaluate the water life requisite. Interspersion requirements are considered by the reproduction life requisite. Measurement of water variables should be taken in the spring during typical water conditions; e.g., not after heavy rains which may cause unusually high water turbidity. The Habitat Suitability Index (HSI) is determined from suitability indices for the life requisites. These life requisite suitability indices are, in turn, derived from suitability indices for habitat variables, which represent the condition of habitat characteristics.

Water component. Wave action can be an important deterrent to kingfisher foraging activities in large lake habitats. Small, sheltered bays apparently are preferred territory locations in such habitats. Lacustrine habitats that are frequently or constantly subject to wave action severe enough to deter kingfisher foraging are assumed to be less suitable than undisturbed waters. Water suitability, in respect to wave action, is assumed to decrease as the percentage of shoreline subject to severe wave action increases. It is assumed that shorelines 100% subject to severe wave action are unsuitable. The variable representing adverse effects of wave action on water suitability is "percent of shoreline subject to severe wave action" (V1). This variable applies only to lacustrine habitats that are frequently or constantly subject to wave action severe enough to deter kingfisher foraging. The relationship between V1 and its associated suitability indices (SIV1) is shown in Figure 1a.

Belted kingfishers generally fish along the edges when water bodies are large. Fishing away from the edges generally requires hovering. However, hovering over water is energetically expensive, and Hamas (pers. comm.) does not believe kingfishers would resort to this behavior on a regular basis unless food was abundant. No information was found in the literature regarding the width of the zone along the water's edge used for fishing; Hamas (pers. comm.) believes that 15 m is a reasonable estimate. When using this model, only this 15-m zone should be considered when measuring the remaining variables identified in the water component (where water bodies > 15 m in width are concerned). Variables should be measured in the spring during a time when water conditions are most typical for the breeding season.

Belted kingfishers require clear water for foraging; turbid water reduces their ability to see prey. Water clarity is influenced by the light absorption characteristics of the water and the presence of dissolved and particulate matter (Wetzel 1975). Because most fish are caught in water < 60 cm deep, it

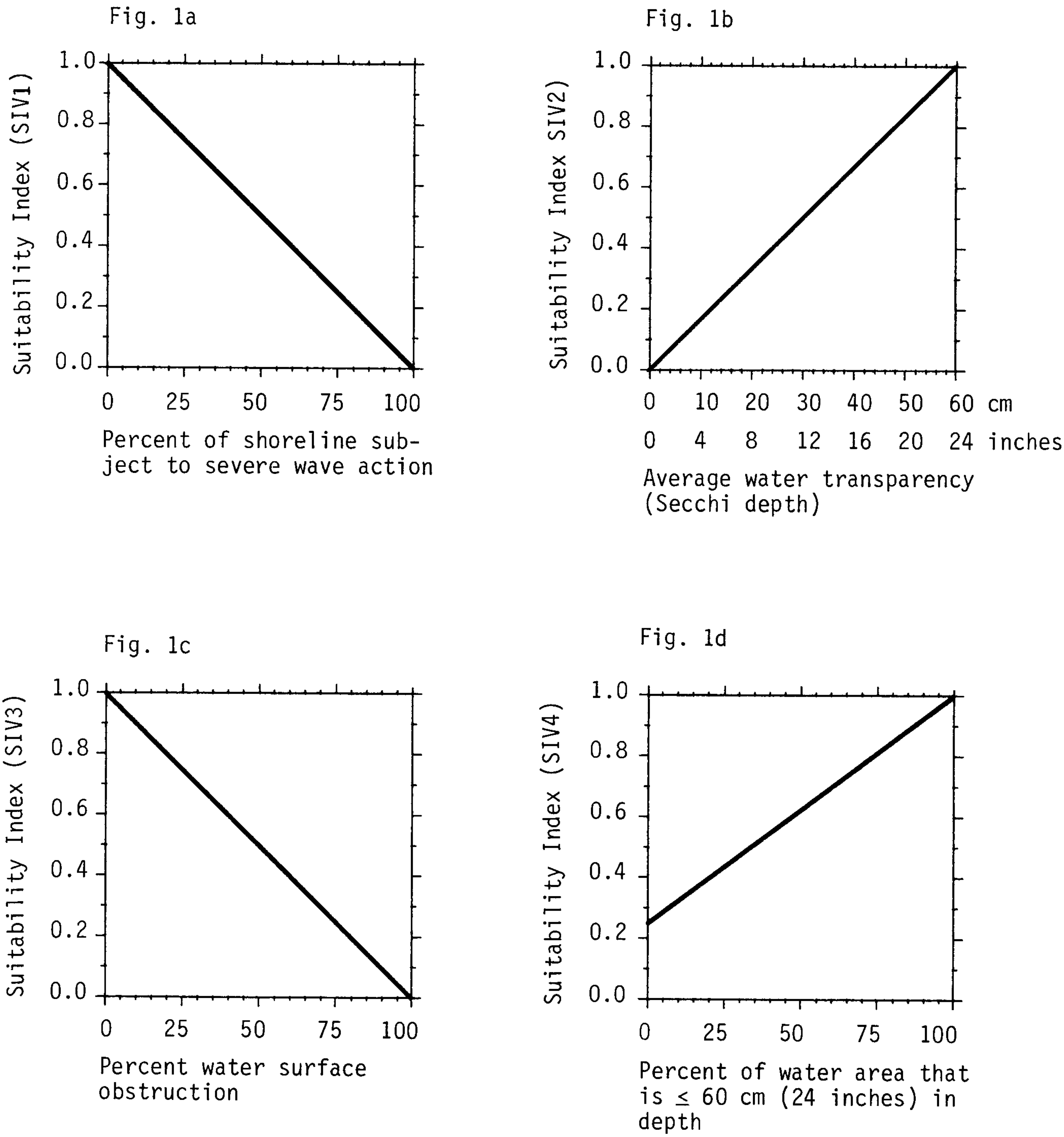


Figure 1. The relationships between habitat variables for the water life requisite and their respective suitability indices.

is assumed in this model that optimum conditions for water clarity exist when fish can be seen at a depth of 60 cm or more. Suitability decreases as the depth at which fish can be seen decreases. In waters < 60 cm deep, suitability is assumed to be maximum if the substrate is visible. The habitat variable that represents water clarity is "average water transparency" (V2), which is measured with a Secchi disk. Although water yielding a Secchi depth reading of 60 cm may appear relatively cloudy, this measurement only represents the depth to which prey are visible. The top 15 cm of water, where prey are actually caught, should be substantially clearer. The relationship between V2 and its associated suitability indices (SIV2) is shown in Figure 1b.

Dense overhanging vegetation along water margins can obstruct foraging waters for belted kingfishers, and kingfishers usually are absent from these areas. Emergent and floating vegetation, rocks, logs, and similar items on the water surface also can interfere with foraging activities. It is assumed that water suitability in respect to surface obstruction is greatest when 100% of the surface area is unobstructed; 100% surface obstruction is assumed to be unsuitable. Obstacles on the water surface and overhanging vegetation ≤ 1.0 m above the water are assumed to be obstructive. The habitat variable representing obstruction of the water surface is "percent surface obstruction" (V3). The relationship between V3 and its associated suitability indices (SIV3) is shown in Figure 1c.

The fishing success of belted kingfishers is greater in shallow water than in deeper water. Most fish are caught in water < 60 cm deep, and no more than 15 cm below the surface. It is assumed in this model that foraging areas with the highest proportion of water ≤ 60 cm in depth are the most suitable in terms of water depth. As the proportion of shallow water decreases, water suitability is assumed to decrease. However, even if no shallow water is available, some suitability is assumed to exist because kingfishers can fish in deeper water, although success may be lower. A suitability index of 0.25 is assumed for this condition. Users of this model should realize that not all shallow waters in northern habitats may be suitable. When lentic waters are frozen over, snow and ice cover reduces light penetration, thereby reducing photosynthesis and oxygen production (Bennett 1971). Shallow lakes in northern habitats often are subject to winter kill due to oxygen depletion (Hamas pers. comm.). Some shallow lakes in these northern areas freeze completely. Low oxygen levels or completely frozen water, however, do not necessarily indicate that fish will be absent in spring after the ice has thawed. Fish often migrate to other water bodies during the winter and return to the shallow waters when conditions are more favorable. The habitat variable representing the availability of shallow water for feeding is "percent of the water area that is ≤ 60 cm in depth" (V4). The relationship between V4 and its associated suitability indices (SIV4) is shown in Figure 1d.

The presence of riffles in stream habitats enhances kingfisher habitat quality by providing rich food sources. Kingfishers in these habitats tend to forage in riffles where prey are most abundant (Davis 1982). This can be partly explained by the density of invertebrates in riffles. Invertebrates are the most widespread and important food of a great range of running water fish species, and are considerably more abundant in riffles than in pools (Hynes 1972). Brooks and Davis (in prep.) compared riffle and pool proportions between breeding territories within a relatively high density kingfisher population in Ohio, and breeding territories within a relatively low density population in Pennsylvania. The percentages of riffles and pools within the Ohio territories were 31 and 30%, respectively, of the territory lengths. Riffles and pools within Pennsylvania territories were 12 and 50%, respectively, of the territory lengths. It is therefore assumed in this model that stream habitat must contain riffles for at least 30% of its length for optimum water suitability. When riffles are completely absent, kingfishers can still catch fish in pools and runs, although fishing success may be relatively low. It is therefore assumed that a suitability index of 0.2 is appropriate for 0% riffles. Because fish often use pools for resting and hiding, 100% riffles may be suboptimal fish habitat, and consequently, suboptimal kingfisher habitat. This model, therefore, assumes that water suitability decreases as the percentage of the stream length containing riffles exceeds 70%, until a suitability level of 0.5 is reached at 100%. The habitat variable representing the presence of riffles in stream habitat is "percent riffles" (V5). The relationship between V5 and its associated suitability indices (SIV5) is shown in Figure 2.

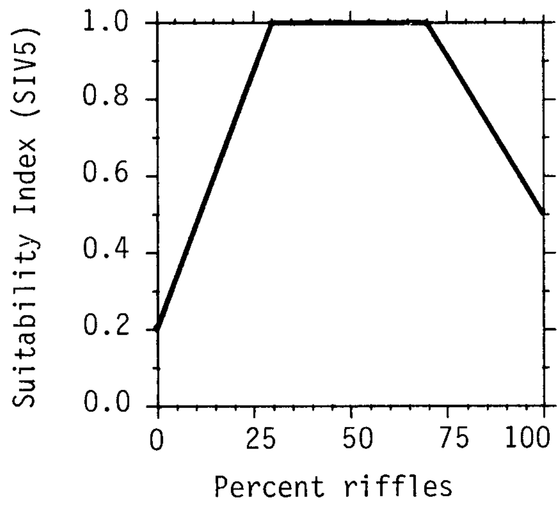


Figure 2. The relationship between percent riffles and water suitability.

Water suitability is a function of clarity, depth, available foraging area, presence of riffles (lotic habitats), and the extent of severe wave action (lentic habitats). Equation 1 is used to determine the suitability index for the water life requisite (SIW) in lentic habitats that are not constantly subject to severe wave action. Equation 2 is used to determine SIW in lentic habitats that are constantly subject to severe wave action. Equation 3 is used to determine SIW in all lotic habitats.

$$SIW = (SIV2 \times SIV4)^{1/2} \times SIV3 \quad (1)$$

$$SIW = (SIV1 \times SIV2 \times SIV4)^{1/2} \times SIV3 \quad (2)$$

$$SIW = (SIV2 \times SIV4 \times SIV5)^{1/3} \times SIV3 \quad (3)$$

Equation 1 consists of a geometric mean of SIV2 (for average water transparency) and SIV4 (for percent of the water area that is ≤ 60 cm in depth), multiplied by SIV3 (for percent water surface obstruction). The geometric mean represents an assumed compensatory relationship between V2 and V4; e.g., a large proportion of shallow water can moderate the negative influence of cloudy water by providing a relatively large fishing area. V3 has a direct negative influence on water suitability because it decreases the water area available for foraging. The geometric mean of SIV2 and SIV4 is, therefore, directly multiplied by SIV3 so that the overall water life requisite value is lowered in proportion to the water area obstructed. If SIV2 is zero, the geometric mean will equal zero, resulting in an overall value of zero for the water life requisite. Equation 2 is similar to equation 1, except that SIV1 (for percent of shoreline subject to severe wave action) is included to represent the effect of severe wave action on kingfisher foraging activities. Equation 3 is also similar to Equation 1 except that SIV5 (for percent riffles) is included to represent the effect of riffles on prey abundance. The product of SIV2, SIV4, and SIV5 taken to the one-third power is a geometric mean, and represents a compensating relationship between V2, V4, and V5.

Cover component. Foraging belted kingfishers prefer an open perch over the water from which they can locate prey before diving. Bare, woody limbs are commonly used, but electrical wires, metal or wooden posts, and other perches are used. No data were found in the literature regarding the number of perches required for belted kingfishers, but Davis (pers. comm.) estimates that ≥ 40 perches/km of lake shoreline or stream are optimal in terms of perch availability. It is therefore assumed in this model that 40 or more evenly spaced perches per kilometer of lake shoreline or stream are optimal and that fewer perches result in decreased suitability. Forty evenly spaced perches per kilometer of lentic shoreline or stream would provide surveillance of potential fishing areas of 12.5 m on either side of each perch. The number and spacing of perches along a 1-km section of lentic shoreline or stream can be measured by dividing it into 40 subsections of 25 m each, and determining the number of subsections containing one or more perches. Optimal conditions are assumed to exist if all 40 subsections contain a perch; fewer than 40 indicates suboptimal perch availability. Some suitability is assumed to exist even if no perches are available, because belted kingfishers can hover over water to spot prey (White 1953). The habitat variable representing the availability of fishing perches is "average number of lentic shoreline or stream subsections that contain one or more perches" (V6). The relationship between V6 and its associated suitability indices (SIV6) is shown in Figure 3.

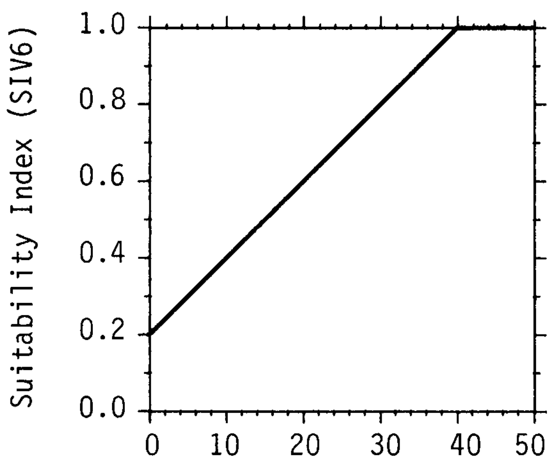


Figure 3. The relationship between perch availability and cover suitability.

Because V6 is the only habitat variable used in evaluating the cover life requisite, the SI for the cover life requisite (SIC) is equal to SIV6 as shown in Equation 4:

$$SIC = SIV6 \quad (4)$$

Reproduction component. Nest site quality and availability are important aspects of belted kingfisher reproduction cover. Important characteristics affecting the quality of soil banks used for nesting are steepness, vegetative cover, height, and soil texture. Belted kingfishers usually excavate nesting burrows in vertical to overhanging soil banks that are devoid of excessive vegetation, root masses, rocks, etc., on the faces. Soil bank heights of 1.5 m or more apparently are preferred; lower banks may be used but are more vulnerable to predation. Sandy soils (sand mixed with small amounts of clay and/or silt) apparently are the most suitable for kingfisher nest sites. Sandy soils are relatively easy to excavate and are structurally sound; i.e., burrows dug into sandy banks do not easily collapse. Sandy soils also are porous and provide drainage for the semi-liquid wastes of nestlings, and water that may enter nests during heavy rains (Brooks and Davis in prep.). Soils with a high percentage of clay and little sand or silt may be hard or sticky and difficult to excavate, while rocky soils and pure sand may be impossible to excavate. It is assumed in this model that suitable soil banks for potential nest sites must be vertical or overhanging, devoid of excessive vegetation, root masses, rocks, etc., on the faces , and ≥ 1.3 m in height [the minimum height observed by Brooks (pers. comm.) for successful nesting]. Soils must contain 70 to 96% sand and ≤ 15% clay (Brooks pers. comm.). These soils fall into the sand, loamy sand, and sandy loam soil types as classified by the U.S. Department of Agriculture (1975), and are based on soil particle size (see Fig. 4).

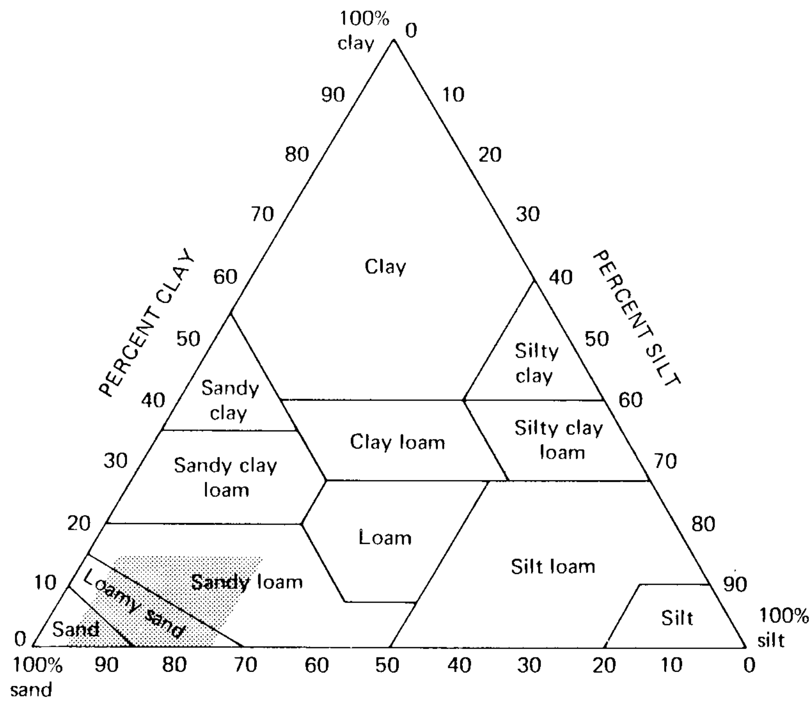


Figure 4. Soil texture classification used by the U.S. Department of Agriculture (1975). Suitable soil textures for potential nesting banks are shaded (Brooks pers. comm.).

Soil texture classes can be determined in the field using the "feel" method (see Hays et al. 1981), which consists of rubbing a moistened soil sample between the thumb and fingers. The grittiness and plasticity of this sample are diagnostic of soil particle size.

The abundance of nest sites and their distance from fishing waters affect nest site availability. Belted kingfisher territories along lentic shorelines and streams during the breeding season commonly are about 1 km in length. If it is assumed that each 1-km section of lake shoreline or stream represents a potential territory, then the presence of a suitable soil bank within a given distance of each 1-km section represents optimal soil bank availability. If soil banks are not immediately adjacent to water, they must be near enough to allow many daily foraging flights from the nest if they are to be suitable nest sites. It is assumed in this model that suitable soil banks immediately adjacent to water are the most suitable nest sites and that nest site suitability decreases as the distance to suitable soil banks increases. Because kingfisher nests usually are well within 3.0 km of water, it is assumed that a distance of 3.0 km between water and a soil bank is a reasonable upper limit for nest site suitability. The habitat variable representing soil bank availability is "distance to nearest suitable soil bank from 1-km sections of lentic shoreline or stream" (V7). The relationship between V7 and its associated suitability indices (SIV7) is shown in Figure 5.

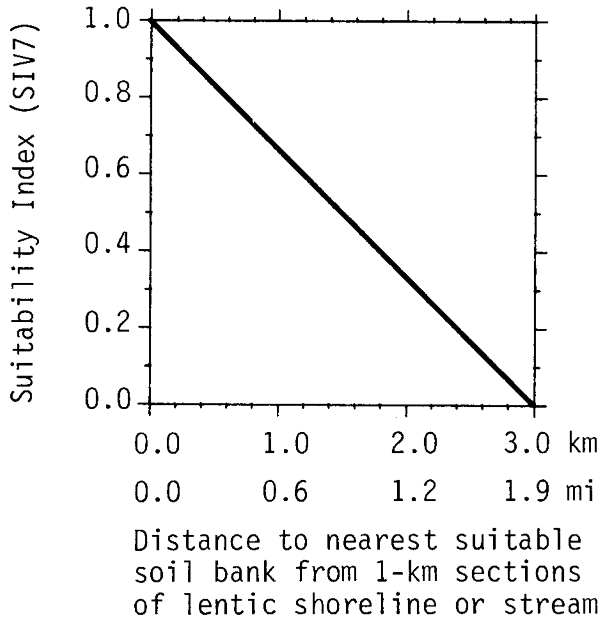


Figure 5. Relationship between distance to a suitable soil bank from the water's edge and habitat suitability for reproduction.

The soil bank distance for each 1-km section should be entered into the V7 graph and SI's obtained. One-kilometer sections without a suitable soil bank within 3.0 km should receive an SIV7 of zero. The resulting values for SIV7 should then be averaged to obtain an overall value for the reproduction life requisite. Each soil bank should be counted only once; i.e., each bank should correspond to only one section of lentic shoreline or stream. When streams are very wide (30 m may be a good estimate), it may be practical to consider each side separately when measuring V7, because territories may be established on both sides of the water.

Because V7 is the only habitat variable used to evaluate the reproduction life requisite, the SI for the reproduction life requisite (SIR) is equal to SIV7 as shown in Equation 5:

$$SIR = SIV7 \tag{5}$$

A study-wide SIV7 should be obtained by calculating the mean of the individual suitability indices, rather than using a single SIV7 obtained from averaged distance measurements, because all soil banks $\geq$ 3.0 km from water are assumed to be equally unsuitable. That is, distances > 3.0 km should not influence suitability more than distances equal to 3.0 km, as would be the case if the distances were averaged.

HSI determination. Based on the limiting factor concept, the HSI for belted kingfisher breeding habitat is equal to the lowest life requisite suitability index for either water (SIW), cover (SIC), or reproductive cover (SIR).

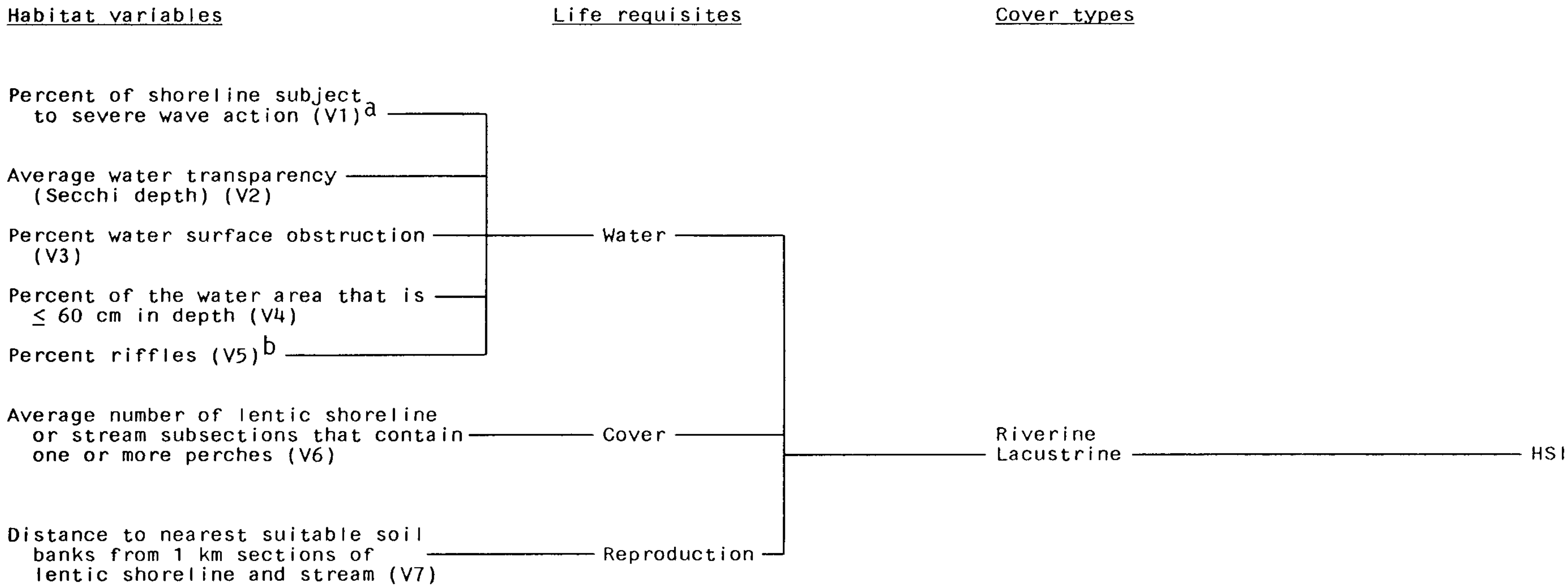
Application of the Model

Summary of model variables. This model uses five habitat variables to evaluate the water life requisite and one habitat variable to evaluate each of the cover and reproduction life requisites. The relationships among habitat variables, life requisites, cover types, and the HSI for the belted kingfisher are shown in Figure 6.

Model assumptions. Several major assumptions should be considered when applying this model.

1. Food requirements are assumed to be represented by the habitat variables used to evaluate the water life requisite. However, many dead fish may indicate that disease or pollutants have reduced fish populations below levels suitable for belted kingfishers. Fish may also be scarce or absent in waters subject to winterkill, or in temporarily flooded waters that are isolated from permanent waters.

2. Kingfishers are assumed to forage no more than 15 m from the shoreline when water bodies are large. This is based on the supposition that perches will be available only along the shore. Therefore, this model specifies that sampling be limited to a 15-m zone in water bodies that are wider than 15 m. However, situations may exist where the assumed foraging zone would exceed 15 m in width; e.g., when perches are provided by trees, shrubs or other objects standing in the water.



[a]Applies only to lacustrine habitats that are frequently or constantly subject to wave action severe enough to deter kingfisher foraging.

[b]Applies only to the riverine cover type.

Figure 6. The relationship of habitat variables, life requisites, cover types, and the HSI for belted kingfisher breeding habitat.

3. Optimal reproduction conditions are assumed to exist if there is a soil bank suitable for nesting within 3.0 km of each 1-km section of lentic shoreline or stream. This is based on the fact that breeding territory sizes in dense kingfisher populations are often about 1 km in length, and on the supposition that soil banks meeting the suitability criteria are actually suitable for nesting, while all others are not. Due to the subjectivity of some of the suitability criteria for soil banks, suitability determination for soil banks is partly dependent on the discretion of the individuals responsible for evaluation.

Definitions of variables and suggested field measurement techniques are provided in Figure 7.

	Variable (definition)	Cover types	Suggested technique
V1	Percent of shoreline subject to severe wave action (the percent of the shoreline that is frequently or constantly subject to wave action that is severe enough to deter foraging).	L	On-site inspection
V2	Average water transparency [the average depth at which a weighted white disk, 20 cm (8 inches) in diameter, disappears from view when measured in a 15-m (49.2 ft) zone from shore during the spring].	R,L	Secchi disk (Orth 1983)
V3	Percent water surface obstruction [the percent of the water surface in a 15-m zone from shore that is shaded or covered by emergent and floating vegetation, logs, leaves, or overhanging shore vegetation $\leq$ 1.0 m (3.3 ft) above the water during the spring].	R,L	Line intercept (Hays et al. 1981)

Figure 7. Definitions and suggested measurement techniques of habitat variables.

Variable (definition)		Cover types	Suggested technique
V4	Percent of the water area that is ≤ 60 cm (24 inches) in depth [the percentage of the water area that is ≤ 60 cm in depth in a 15-m zone from shore during the spring].	R,L	On-site inspection
V5	Percent riffles [the percent of stream length containing riffles (shallow rapids in an open stream, where the water surface is broken into waves by obstructions wholly or partly submerged)].		Optical rangefinder (Hays et al.1981), measuring tape
V6	Average number of lentic shoreline or stream subsections that contain one or more perches [the average number of 25-m (82.5 ft) lentic shoreline or stream subsections within 1-km sections that contain one or more perches (tree or shrub limbs, electrical wires, metal or wooden posts, or similar perches, immediately adjacent to or overhanging the water, that provide kingfishers with unobstructed views of the water)].	R,L	On-site inspection

Figure 7. (continued).

Variable (definition)	Cover types	Suggested technique
V7 Distance to nearest suitable soil bank from 1-km sections of lentic shoreline or stream [the average distance to the nearest suitable soil bank (vertical to overhanging soil banks that are devoid of excessive vegetation, root masses, rocks, etc., $\geq$ 1.3 m (4.3 ft) in height, composed of 70-96% sand and $\leq$ 15% clay (see Fig. 4), and within 3.0 km (1.9 mi) of the water].	R,L	On-site inspection and mapping

Figure 7. (concluded).

SOURCES OF OTHER MODELS

No other habitat models for the belted kingfisher were located in the literature.

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16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop a Habitat Suitability Index (HSI) model for the belted kingfisher (Ceryle alcyon). The model consolidates habitat use information into a framework appropriate for field application, and is scaled to produce an index between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). HSI models are designed to be used with Habitat Evaulation Procedures previously developed by the U.S. Fish and Wildlife Service.

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