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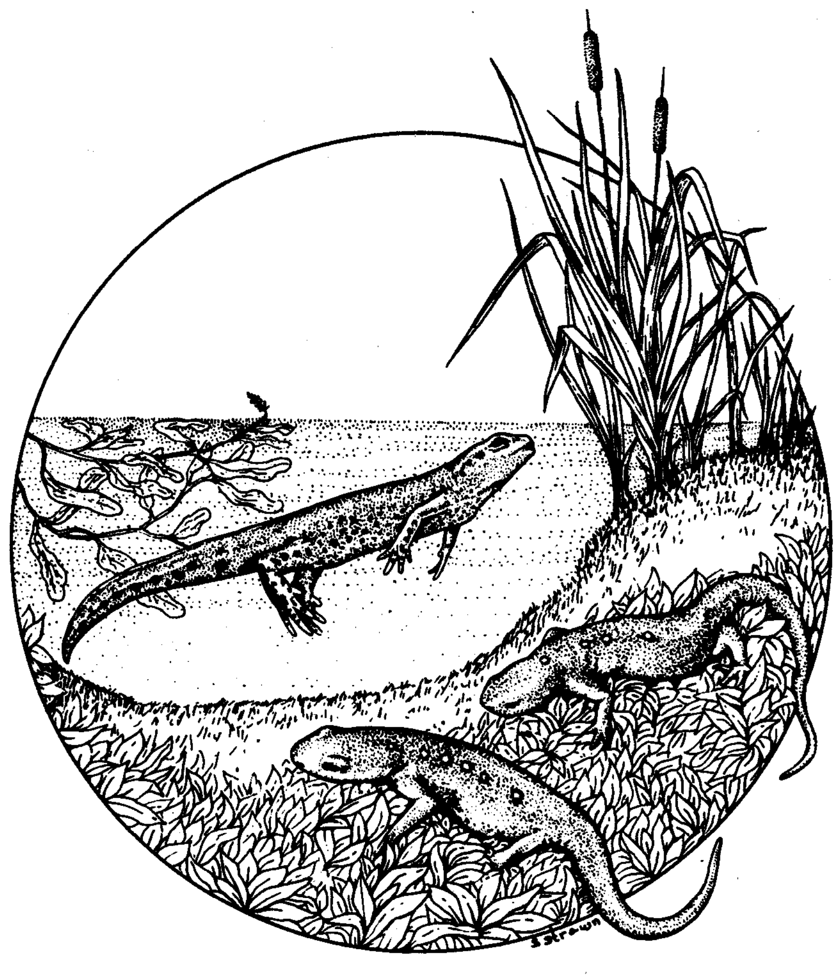
HABITAT SUITABILITY INDEX MODELS: RED-SPOTTED NEWT



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Biological Report 82 (10.111)
August 1985

HABITAT SUITABILITY INDEX MODELS: RED-SPOTTED NEWT

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is a formalized synthesis of biological and habitat information published in the scientific literature and may include unpublished information reflecting the opinions of identified experts.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

Dr. William R. Healy reviewed several earlier versions of this HSI model. Dr. Healy also conducted a field test of the model that resulted in several significant changes to the final model. Dr. Healy's efforts added significantly to the quality of this model, and his efforts are gratefully acknowledged.

Word processing for this document was provided by Carolyn Gulzow, Dora Ibarra and Elizabeth Graf. The cover was illustrated by Susan Strawn.

RED-SPOTTED NEWT (Notophthalmus viridescens viridescens)

HABITAT USE INFORMATION

General

The red-spotted newt (Notophthalmus viridescens viridescens) inhabits moist woodlands during the terrestrial portion of its life cycle (eft stage) and ponds and other lentic water bodies during its aquatic stages (larval and adult) (Mecham 1967). The red-spotted newt "... is found in southern Canada, including the Maritime Provinces and southern Quebec and southern Ontario ... and the eastern United States west to central Michigan (lower peninsula), central Indiana, Kentucky, and Tennessee east of the Mississippi Embayment, and exclusive of the southeastern coastal plain" (Mecham 1967:53.1).

Food

Newts are opportunistic predators during all life stages, including the aquatic larval and adult stages (Burton 1977) and the terrestrial eft stage (Burton 1976; MacNamara 1977). Larval newts in New Hampshire fed primarily on amphipods (Amphipoda), midges (Chironomidae), and water fleas (Cladocera) (Burton 1977). Foods of adults include cladocerans, aquatic insects, mollusks (Pelecypoda, Gastropoda), larval newts (Burton 1977), aquatic earthworms (Oligochaeta), leeches (Hirudinea) (Ries and Bellis 1966), and eggs and larvae of other amphibians (Bishop 1941; Gill 1978). Adults occasionally eat small fish (Bishop 1941) and fish eggs (George et al. 1977). Aquatic newts feed at the water surface, in all levels of the water column, and in the benthic zone (Ries and Bellis 1966). Water temperature and prey abundance appeared to be the most influential factors affecting the red-spotted newt's diet under laboratory conditions (Attar and Maly 1980). The activity level of laboratory newts increased approximately five times between 4° and 20°C with a corresponding increase in prey consumption.

Efts feed on prey from the soil surface, upper litter layer, and low vegetation (MacNamara 1977). Foraging on the forest floor occurs only when the surface is moist (Healy 1975b). Snails (Gastropoda) are the most important prey item of efts in New Hampshire, both in terms of number eaten and total prey weight (Burton 1976). Other important prey groups include flies (Diptera), springtails (Collembola), beetles (Coleoptera), aphids and leaf-hoppers (Homoptera), spiders (Araneida), and mites (Acarina).

Water

Newts require lentic water bodies for the larval and adult portions of their life cycle. Characteristics of suitable water bodies are discussed under Cover.

Cover

The life history and ecology of the newt varies throughout its range (Hurlbert 1969; Gill 1978). The eft stage can be absent in some populations (Healy 1974). In Massachusetts, individuals of populations without eft stages reached sexual maturity at 2 years of age, but individuals of populations with the eft stage did not become sexually mature until they were 4 to 8 years old. Adults may overwinter in ponds (Healy 1975b) or leave ponds for terrestrial hibernacula (Hurlbert 1969; Gill 1978). The following discussion of cover requirements may not be entirely applicable to some populations of red-spotted newts because of the large amount of variability in life history and ecology over the range of the species.

Larval and adult newts inhabit lakes, ponds, pools, ditches, and quiet sections of streams (Bishop 1941). Newts are most abundant in shallow water with dense aquatic vegetation, but also occur in areas with unvegetated rocky or sandy bottoms. Although aquatic newts generally are found in shallow water (Ries and Bellis 1966; Bellis 1968; Burton 1977), they spend much of the summer at depths down to 13 m in Lake George, New York, apparently in response to the level of the thermocline (George et al. 1977). Although a thermal preference was suggested for newts in Lake George, temperature data for the thermocline were not presented. Newt distribution in a New Hampshire lake was highly correlated with rooted aquatic vegetation in water < 2 m deep, although low prey availability may have prevented newts from inhabiting deeper water (Burton 1977). Newts in a Pennsylvania pond were concentrated in dense vegetation along the pond edge in water < 0.3 m deep (Bellis 1968). Broad-leaved floating vegetation does not provide suitable underwater cover for newts (Healy 1981). Adults were found under rotten logs and in clumps of vegetation around dried-up ponds in Virginia (Gill 1978). Breeding population size in seven Virginia ponds was significantly and positively correlated with pond age ($r_s = .85$, $.01 < P < .05$) (Gill 1978).

Efts inhabit mixed and deciduous forests (Bishop 1941). Ponds in New York surrounded by mixed or deciduous forests have higher populations of newts than ponds surrounded by evergreen forests. Efts in a Massachusetts study area spent the first year of terrestrial life migrating to suitable forested habitat (Healy 1974). Efts were abundant only in an oak-pine (Quercus spp. - Pinus spp.) forest approximately 800 m from the breeding pond; the area between the pond and the forest was used only during migration. Migrations may follow streambeds or linear depressions in the topography that provide favorable moisture conditions (Hurlbert 1969). Although efts prefer moist over dry areas, sites with excessive moisture do not provide optimum habitat (Healy 1981). Efts remain in the leaf litter, in rotten stumps, or under logs during dry periods (Healy 1975b). Adequate surface litter is critical during dry periods because efts rarely burrow (Healy 1981).

Reproduction

Female newts attach their eggs to aquatic vegetation or, less often, to the surfaces of stones in still water (Bishop 1941). Characteristics of water bodies that determine cover suitability, i.e., shallow water and fairly dense aquatic vegetation, also likely determine reproductive suitability.

Interspersion, Movements, and Composition

Populations of newts with an eft stage migrate to land following the postlarval stage, where they remain for 3 to 7 years (Healy 1974). They migrate during spring or fall back to water for breeding (Hurlbert 1969). In these populations, both suitable aquatic and terrestrial habitat are necessary. The scarcity of efts in a northern hardwood forest habitat in New Hampshire was probably due to the lack of nearby standing water (Burton 1976). Large cultivated fields or dry forests surrounding ponds can be significant barriers to movement between terrestrial and aquatic habitat (Hurlbert 1969). Suitable terrestrial habitat can be located ≤ 800 m from water (Healy 1974).

The average annual home range of efts in a Massachusetts woodland was estimated to be 270 m^2 (Healy 1975a). The total area occupied by efts during their nonmigratory terrestrial residence was estimated to be 400 to 500 m^2. Aquatic adults apparently occupied small home areas in a Pennsylvania pond (Bellis 1968). The median distance between points of capture and recapture (n = 548 recaptures between late June and late August) was only 1.12 segments (1 segment equals 3.05 m), and the mean was 2.25 segments. Movements of adult male newts within a small Virginia pond were random, indicating that neither male territoriality nor limited home ranges were characteristics of the population (Harris 1981). A population of 1,950 to 2,600 aquatic adult newts in a New Hampshire lake was restricted to about 1 ha of the 15-ha lake (Burton 1977). Eft density in Massachusetts was estimated at 0.03 efts/m^2 or 300 efts/ha (Healy 1975a).

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area. This model was developed for application throughout the range of the red-spotted newt (Fig. 1).

Season. This model was developed to evaluate the year-round habitat of the red-spotted newt.

Cover types. An earlier version of this model focused on Deciduous Forest (DF) and Deciduous Forested Wetlands (DFW) (terminology follows that of U.S. Fish and Wildlife Service 1981). Herbaceous Wetlands (HW) were considered as a feature of the forested types rather than as a separate cover type. However, a field test of the earlier model (see Verification level below) indicated that an emphasis on forested habitats was an impractical approach and possibly was misleading because relatively little suitable forested habitat

Figure 1. Geographic applicability of the red-spotted newt HSI model.

is required in relation to aquatic habitat. As a result, the approach recommended in this model is to evaluate only herbaceous wetland (HW) and lacustrine (L) cover types containing water year-round as red-spotted newt habitat. Criteria are provided to quickly evaluate the availability of suitable terrestrial habitat. It is recognized, however, that some model users may be interested in evaluating the suitability of forested habitats for the eft stage of the red-spotted newt. Criteria to evaluate deciduous forest (DF) and deciduous forested wetland (DFW) also are provided in this model.

Minimum habitat area. No information on the minimum size of suitable habitat required to support a self-sustaining population of red-spotted newts was found in the literature. Newts maintain small home ranges during both the aquatic and terrestrial stages. Very small permanent water bodies can supply the necessary aquatic habitat for red-spotted newts (W. R. Healy, Department of Biology, College of the Holy Cross, Worcester, MA; letter dated April 10, 1980). The model is based on the assumption that the presence of permanent water is more critical than a minimum habitat area in determining the potential suitability of a wetland for newts. Therefore, any permanent water body can be evaluated with this model, regardless of size. Similarly, any deciduous forest or deciduous forested wetland large enough to be cover typed can be evaluated with the terrestrial portion of the model. Mapping of permanent water bodies with aerial photography will likely underestimate available aquatic habitat because very small ponds that cannot be mapped with aerial photographs may be used by newts.

Verification level. Earlier versions of this model were evaluated in a field test conducted in two phases in Worcester County, Massachusetts by Dr. William R. Healy. The field tests of both the aquatic and terrestrial portions of this model resulted in a number of changes to the model. The two phases of the test are summarized in two reports by Healy (1981 and 1983, respectively).

The draft model evaluated by Healy (1981) included four variables to evaluate aquatic habitat: (1) percent of water area $\leq$ 2 m deep; (2) size of water body; (3) percent aquatic vegetative cover in the littoral zone; and (4) water regime. Only two of the 10 ponds studied contained water > 2 m deep and all 10 ponds were permanent. Five of the ponds contained newts. Comparison of model outputs to an index of newt abundance yielded a Spearman's rank correlation coefficient (r_s) of 0.778 ($P < 0.05$). Subsequently, Healy (1981) recommended elimination of size of water body as a factor affecting quality of habitat. Analysis based on the remaining three variables yielded an insignificant $r_s = 0.52$ ($P > 0.05$). The percent vegetative cover in the littoral zone was the only variable of the three to show much variation among ponds. The model was modified so that vegetative cover in ponds where vegetation was concentrated along the shoreline zone was measured as the percent of shoreline associated with submergent or emergent vegetation. The modified model yielded an $r_s = 0.65$ ($P < 0.05$).

Terrestrial habitat was evaluated with three variables in the model used for the first phase of the test. Model results were compared to numbers of efts captured in the sample areas. The three variables (percent tree canopy closure, soil texture, and percent of area covered by standing water) provided little discrimination among eight sites. A revised terrestrial component of the model that evaluated the layers of deciduous leaf litter, soil type and color, and understory vegetation resulted in a significant rank correlation with numbers of efts. Phase 2 of the model test evaluated in more detail the habitat characteristics associated with efts. The study was conducted on a 4,000 m^2 study site divided into 40 100-m^2 quadrats. Habitat variables found to be most useful as surrogate measures of substrate moisture were percent deciduous trees, percent of trees < 60 cm circumference, and percent herbaceous canopy cover. Use of these variables resulted in an r_s of

0.745 (n = 40, P < .0005) (Healy 1983). The model was applied to the eight sites from Phase 1 of the test, resulting in an r_s = 0.803 (P < 0.05). These three variables are used in the current model to evaluate terrestrial habitat suitability, in addition to the variables that evaluate tree canopy closure and distance to the nearest wetland.

The field evaluation of the earlier model resulted in a number of changes that led to the current model. The most significant of these was a change in emphasis from forested habitat with associated wetlands to the wetlands themselves. It should be noted that the structure of the current model resulted from the earlier field evaluation. The current model has not been field tested and empirical relationships between model outputs and red-spotted newt abundance is unknown.

Model Description

Overview. Optimal habitat for the red-spotted newt consists of permanent, small, lentic bodies of water with shallow areas and moderately dense herbaceous vegetation located within moist mixed or deciduous forests. This model provides a method to evaluate both terrestrial and aquatic habitats. If the newt population being studied does not have a terrestrial life stage, only the aquatic portion of the model should be used. In cases where both terrestrial and aquatic stages occur, it is recommended that only the aquatic portion of the model be used (the rationale for this recommendation is discussed below). Newts feed on a wide variety of invertebrate prey, and it is assumed that food in both terrestrial and aquatic habitats is directly related to cover suitability.

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

Aquatic cover/reproduction component. The aquatic cover/reproduction value corresponds to fairly dense aquatic vegetation in permanent shallow water. Although aquatic newts can survive periods of drought, the model is intended only for permanent water bodies, which will support the greatest proportion of newts in a given area.

Shallow water with dense submerged vegetation provides aquatic cover and reproductive habitat. Most red-spotted newt activity occurs in shallow water with rooted aquatic vegetation. Aquatic habitat is evaluated by considering the percentage of a water body in the littoral zone (defined here as areas ≤ 2 m deep) and the amount of vegetative cover in the littoral zone. An estimate of the proportion of water area in the littoral zone will estimate the proportion of the habitat available to the red-spotted newt. An estimate of vegetative cover within the littoral zone will estimate the quality of the habitat within the area most frequently used by the red-spotted newt. Conditions are assumed to be optimum when 100% of the water body is ≤ 2 m deep (i.e., totally available) and unsuitable when the entire body of water is > 2 m deep (Fig. 2a). Vegetative cover is assumed to be optimum when ≥ 75% of the littoral zone contains submergent or emergent herbaceous vegetation (Fig. 2b). If the littoral zone contains no vegetation, then the habitat is

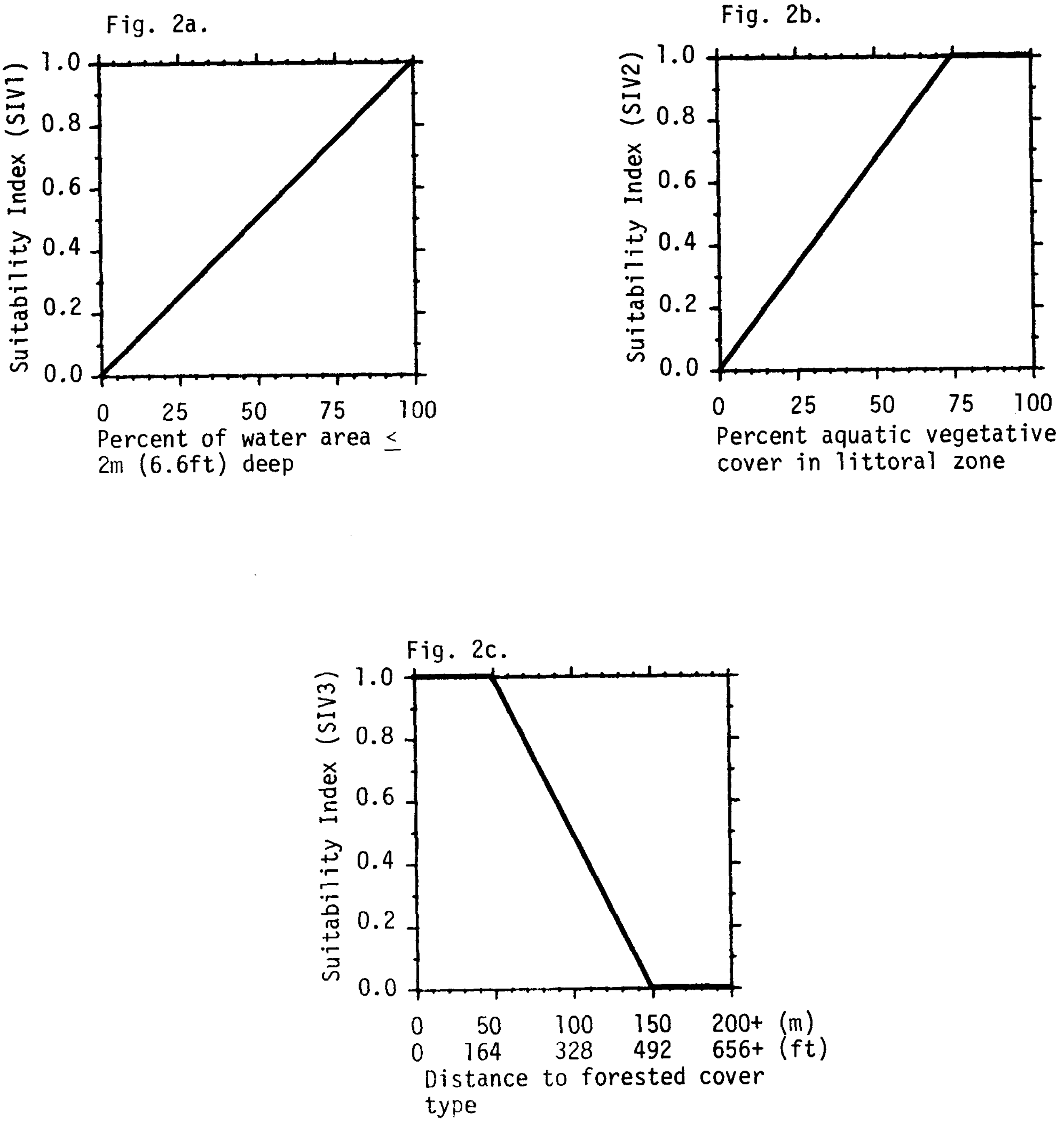

Figure 2. Relationships between variables used to evaluate suitability of water bodies as red-spotted newt habitat and suitability indices for the variables.

assumed to be unsuitable. The quality of the aquatic habitat as measured by percent vegetative cover in the littoral zone applies only to this zone. In order to obtain a habitat value representative of the entire water body (SIAH), the habitat suitability for the littoral zone must be multiplied by the proportion of the habitat in the littoral zone. This relationship is depicted in Equation 1 which yields an estimate of suitability applicable to the entire body of water being evaluated, including the littoral and nonlittoral zones.

$$SIAH = SIV1 \times SIV2 \qquad (1)$$

The relationship described by Equation 1 is based on the assumption that the entire area of a body of water will be used to determine Habitat Units for use in the Habitat Evaluation Procedures (U.S. Fish and Wildlife Service 1980). Therefore, Equation 1 is used to yield a suitability index applicable to an entire body of water. SIV1 can be eliminated from Equation 1 if Habitat Units are calculated based on the area of the littoral zone rather than the entire area of the body of water being evaluated.

The quality of terrestrial habitat is assumed not to affect habitat potential of wetlands as long as some terrestrial habitat is available. This assumption is based on the fact that only a small area of terrestrial habitat may be used during the eft stage (Healy 1981). Although efts will travel up to 800 m to suitable terrestrial habitat, large expanses of nonwooded habitat can present a barrier to movement. This model evaluates the availability of potential terrestrial habitat simply by measuring distance to the nearest forested or shrub-dominated habitat. Even if the nearest potential habitat is of low quality for sustained use, it can serve as a travel lane to more suitable habitat. This model defines optimal terrestrial habitat as wooded habitat within 50 m of the water's edge (Fig. 2c). If the nearest potential terrestrial habitat is $\geq$ 150 m from water, it is assumed that the habitat is unavailable. If the model user determines that the population in the habitat being evaluated includes a terrestrial stage, then the suitability of wetland habitat (SIAH) may be modified by considering the availability of potential terrestrial habitat, using Equation 2.

$$SIAH = SIV1 \times SIV2 \times SIV3 \qquad (2)$$

Equation 2 reduces the inherent quality of a wetland (estimated using SIV1 and SIV2) by the likelihood that newts are able to reach terrestrial habitat (estimated by SIV3). If newts need to travel $\geq$ 150 m, Equation 2 will indicate that the wetland is not available to newt populations with a terrestrial stage, regardless of the inherent quality of water depth and vegetation in the wetland.

Terrestrial cover component. The red-spotted newt inhabits moist deciduous or mixed deciduous-coniferous forests during its eft stage. However, efts may concentrate in a relatively small portion of the available habitat and do not require an extensive area of high quality forest habitat. The eft stage may not occur where terrestrial habitat is unsuitable (Healy 1983), suggesting that terrestrial habitat may not be necessary. Habitat sampling over large areas would likely result in an estimate of low terrestrial habitat suitability even though the suitability of microhabitats may be optimum. It is possible that intensive sampling over large areas can be used to identify suitable microhabitats although intensive sampling will be impractical in most applications of this model. Habitat variables that were useful in estimating differences in the suitability of terrestrial microhabitats (Healy 1983) are discussed below.

The key factor determining presence of efts is adequate substrate moisture (Healy 1983). However, newts can survive dry periods by using leaf litter or other debris that provides the necessary moist microclimate. It is more appropriate to measure characteristics that reflect the long-term soil moisture conditions of a forested cover type than to estimate soil moisture, which is difficult to measure and variable from day to day. Healy (1983) suggested that the following variables be used to indirectly evaluate the suitability of substrate moisture for efts: (1) percent deciduous trees; (2) percent of trees with a circumference < 60 cm; and (3) percent herbaceous canopy cover. This model includes variables to evaluate tree canopy closure and distance to permanent water. Tree canopy closure was not found to be a useful discriminating variable when this model was field tested (Healy 1983), but is included for use in areas with a more open tree canopy than encountered in the field test. The variable for distance to permanent water evaluates the likelihood that a specific forested area is close enough to larval/adult habitat to be used by the eft stage.

The amount of tree canopy closure determines the amount of ground shading and, therefore, influences the temperature and moisture of a site. It is assumed that a canopy closure ≥ 75% provides optimal conditions and that canopy closures ≤ 25% result in surface temperatures and xeric conditions that are unsuitable for efts (Fig. 3a).

The percent of deciduous trees in a forest stand can be useful in determining substrate moisture because soils usually are drier under coniferous trees than under deciduous trees (Healy 1983). It is assumed that the likelihood of suitable substrate conditions existing in a forest stand increases with an increasing percentage of deciduous trees in the stand (Fig. 3b). Stands with only coniferous trees are assumed to be unsuitable for efts.

Concentrations of small trees in a forest stand provide a large amount of ground shading, resulting in a favorable microclimate for efts. Healy (1983) found that an estimate of the percent of trees with a dbh ≤ 19.1 cm was correlated with eft abundance ($r_s = 0.53$; $P < 0.01$) and was a useful variable for estimating terrestrial habitat suitability. A stand that has ≥ 80% of the trees with a dbh ≤ 19.1 cm is considered to represent optimal conditions for efts (Fig. 3c).

Fig. 3a.

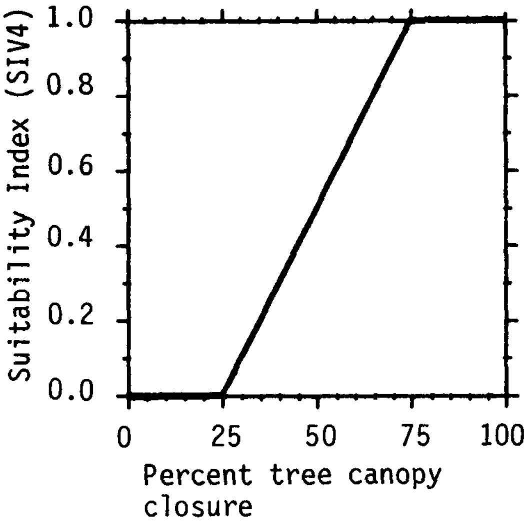

Fig. 3b.

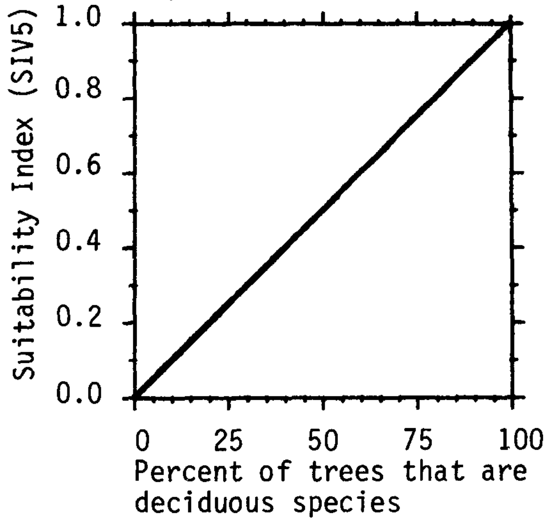

Fig. 3c.

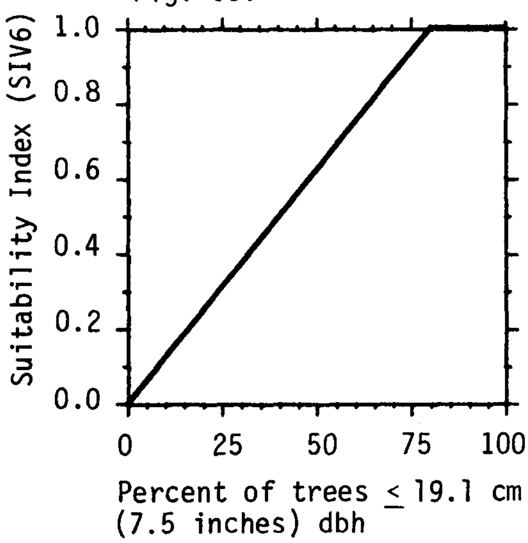

Fig. 3d.

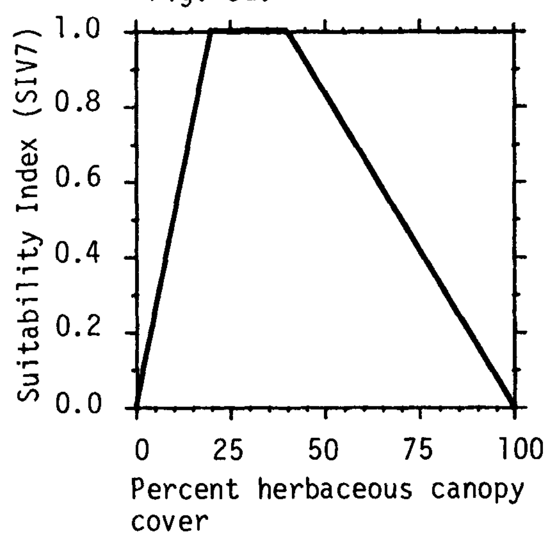

Figure 3. Relationships between habitat variables used to evaluate terrestrial habitat suitability for the red-spotted newt and suitability indices for the variables.

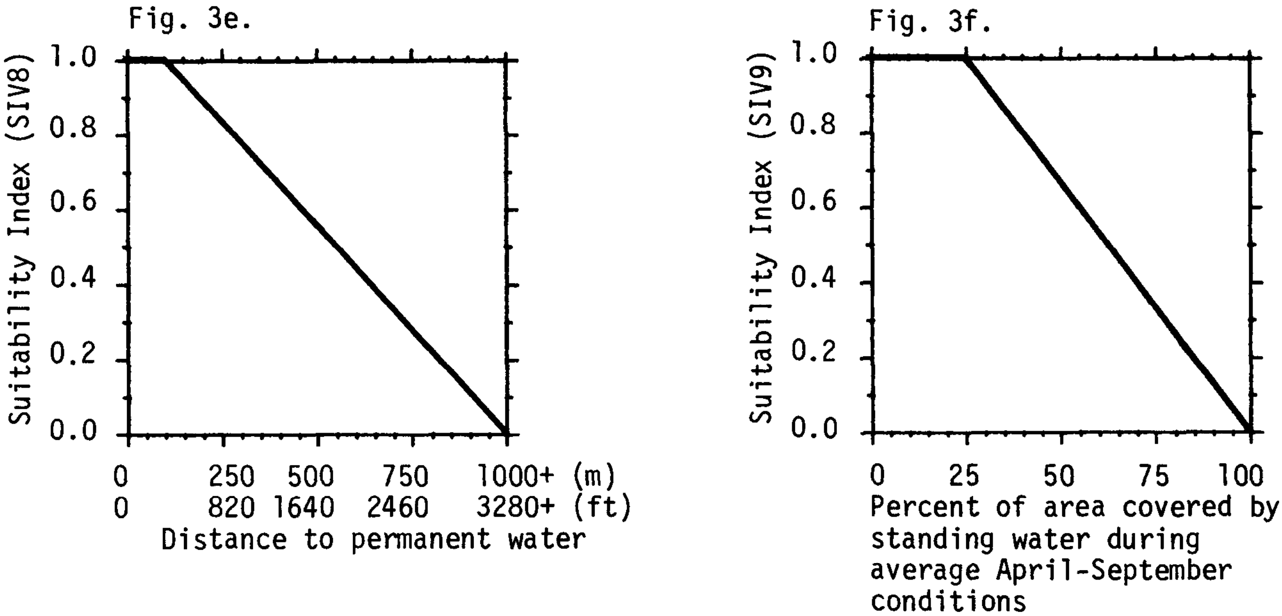

Figure 3. (concluded).

Herbaceous canopy cover also may reflect substrate moisture conditions and was found to be a useful variable for predicting eft abundance (Healy 1983). Areas covered with low growing herbaceous vegetation or dense stands of ferns reflected dry conditions and low habitat suitability for efts. Ideal conditions for efts were considered to be patches of herbaceous vegetation interspersed with unvegetated runoff channels for rain. Herbaceous canopy cover of 20 to 40% is assumed to be the optimal vegetation condition for efts (Fig. 3d).

Regardless of substrate moisture, a forest stand will only be used by efts if some larval/adult habitat is available within the movement range of the species. Efts have been recorded up to 800 m from larval habitat, although survival is presumably higher when movements between aquatic and terrestrial habitat are minimized. It is assumed in this model that forested habitat is most likely to be used by efts if it is within 100 m of potential larval/adult habitat (i.e., permanent water with aquatic vegetation) (Fig. 3e). Forested habitat located ≥ 1000 m from permanent water is assumed to be unavailable to efts, regardless of the substrate moisture conditions.

The extent to which a forested wetland is flooded during the season when efts are active (roughly April to September) is included in this model because efts require some terrestrial surface area. It is assumed that conditions are optimal for efts if ≤ 25% of the forested area floods during this period (Fig 3f). Habitat suitability is assumed to decrease as the amount of flooded area (i.e., the area unavailable to efts) increases above 25%. If the whole area floods (e.g., in a hardwood swamp), the entire area is assumed to be unsuitable for efts.

The terrestrial cover value for efts in forested habitats is assumed to be a function of: (1) percent tree canopy closure; (2) percent deciduous trees; (3) percent trees with a dbh ≤ 19.1 cm; (4) herbaceous canopy cover; (5) distance to permanent water; and (6) percent of area covered by standing water. Healy (1983) found that the geometric mean of the suitability indices determined for variables 2-4 above was significantly correlated with eft abundance on 40 quadrats ($r_s = 0.74$; $P < 0.0005$). Application of this approach to another study area ($n = 8$) also resulted in a significant correlation ($r_s = 0.80$; $P < 0.05$) (Healy 1983). However, the studies were conducted in an unflooded area within 400 m of permanent water and with little variation in tree canopy closure. The variables in this model that evaluate tree canopy closure, distance to water, and flooding are considered direct modifiers of the habitat value determined by the geometric mean of the suitability indices for the remaining three variables in this model. An estimate of habitat suitability of forested habitats (SITH) can be determined using Equation 3.

$$\text{SITH} = \text{SIV4} \times (\text{SIV5} \times \text{SIV6} \times \text{SIV7})^{1/3} \times \text{SIV8} \times \text{SIV9} \quad (3)$$

<u>HSI determination</u>. It is recommended that only aquatic cover types be evaluated for habitat suitability for the red-spotted newt, although an approach for evaluating terrestrial habitat suitability also is included. Equation 1 or 2 is used to determine the suitability of aquatic habitats (SIAH) and the HSI for a given aquatic cover type equals the SIAH determined for the cover type. Similarly, the HSI of a forested habitat equals the suitability index (SITH) determined for the cover type using Equation 3.

A field evaluation of an earlier version of this model was conducted by Dr. W. R. Healy. Results of the field evaluation indicated that the aquatic and terrestrial components of the model ranked study sites in a statistically significant manner when compared with site rankings based on sampled newt and eft populations. However, an overall HSI, which was determined as the lower of the aquatic or terrestrial components, failed to correlate significantly with overall site ratings. Healy (1983) suggested that the terrestrial component of the model should be given less emphasis than the aquatic portion. This recommendation was based on the fact that efts may concentrate in a relatively small portion of the available terrestrial habitat. When applying this model, sampling over a large area would likely underestimate the quality of terrestrial habitat. As a result of the field test of the model, it is recommended that the model be applied to aquatic habitats only, although a process for evaluating terrestrial habitat also is included.

Application of the Model

Summary of model variables. A summary of the variables used in this model is presented in Figure 4. Definitions of the variables and suggested measurement techniques (Hays et al. 1981) are included in Figure 5.

The variable "percent of trees ≤ 19.1 cm dbh" (Fig. 3c) is used to evaluate the likelihood that a substrate will provide cool, moist conditions because of shading from small trees. In forested wetlands, the substrate may be suitably moist even in the absence of small trees. The suitability index for this variable will be low in this situation, perhaps even 0.0, and have a major impact on the suitability of terrestrial habitat (SITH) determined with Equation 3. Users of this model may decide to eliminate this variable as a surrogate measure of substrate moisture suitability in forested wetlands and determine the suitability of terrestrial habitat with the remaining variables, using Equation 4.

$$SITH = SIV4 \times (SIV5 \times SIV7)^{1/2} \times SIV8 \times SIV9 \qquad (4)$$

Model assumptions. A number of assumptions were made in this HSI model. The primary assumptions involved in assessing aquatic habitat quality are: (1) newts will use only those portions of herbaceous wetland or lacustrine habitats that are ≤ 2 m deep, despite some evidence that deeper water also is occasionally used (George et al. 1977); and (2) a measure of submergent and emergent vegetation is an adequate measure of the suitability of food, cover, and reproductive habitat. The first of these assumptions provides the basis for determining the potentially available habitat and the second provides the basis for evaluating the quality of the available habitat. An additional assumption in the recommended approach to evaluating aquatic habitat is that it is unnecessary to estimate the quality of terrestrial habitat as long as some potential (i.e., forested) terrestrial habitat is available. This latter assumption appears valid based on input from Healy (unpubl.). However, users should be aware that aquatic habitat that is suitable for newts may not be used due to the poor quality of surrounding terrestrial habitat. In most cases, however, it is assumed that the quality of aquatic habitat will be more limiting to red-spotted newt populations than will the quality of terrestrial habitat.

The three major assumptions in the terrestrial portion of this model are: (1) habitat variables found to be useful in differentiating between eft use of microhabitats also will be useful to evaluate larger habitat areas; (2) the selected variables are accurate reflections of substrate moisture; and (3) any permanent water body will provide potential aquatic habitat for the newt. An alternative to measuring surrogate measures of substrate moisture is to make a direct estimate of this variable. However, substrate moisture may vary over a short period of time, and also may differ at various points within a cover type at the same point in time. The surrogate measures included in this model are assumed to more accurately reflect the long-term potential of a cover type

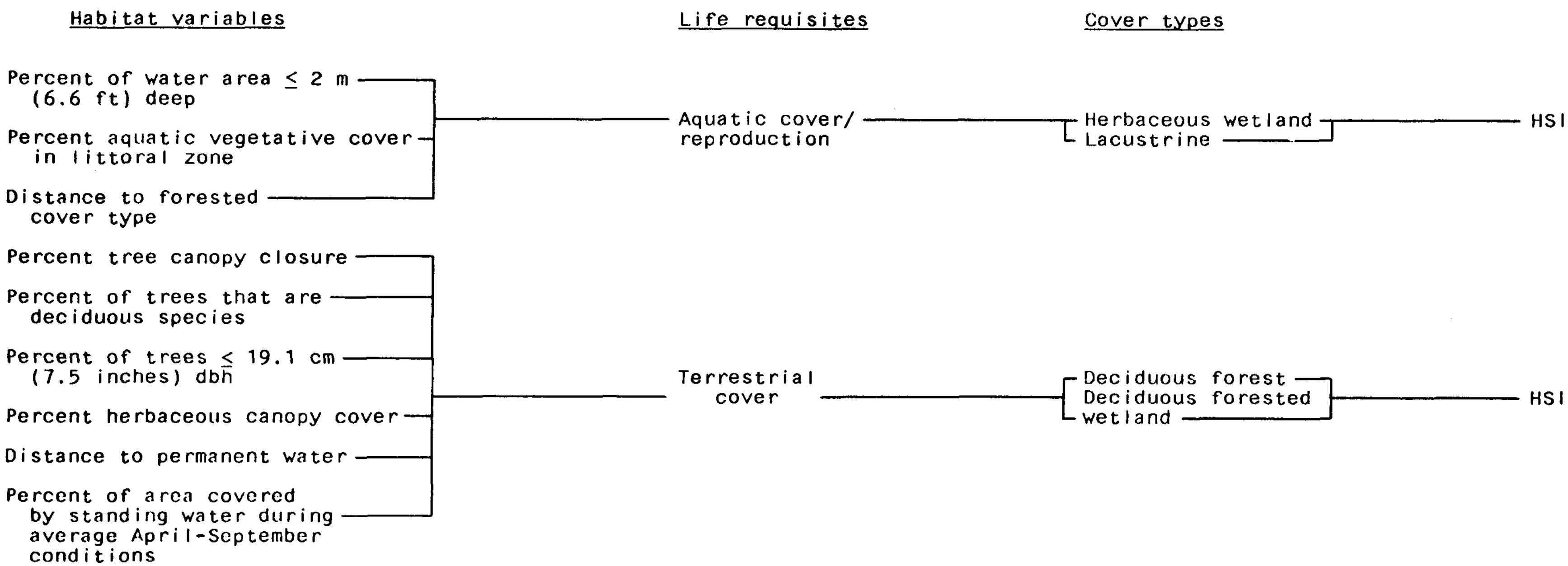

Figure 4. The relationships between habitat variables, life requisites, and cover types in the HSI model for the red-spotted newt.

Variable (definition)	Cover types	Suggested techniques
Percent of water area ≤ 2 m (6.6 ft) deep (average summer conditions) (the area of a wetland that is ≤ 2 m during average summer conditions divided by the total area of the wetland containing water during average summer conditions, multiplied by 100).	HW, L	Transect, graduated rod, local data
Percent aquatic vegetative cover in littoral zone (average summer conditions) (the % of the aquatic substrate that is shaded by a vertical projection of submergent or emergent vegetation in the littoral zone).	HW, L	Ocular estimate, quadrat, line intercept
Distance to forested cover type (the average straight line distance from sample points to the edge of a cover type dominated by trees).	HW, L	Tape measure, pacing, map and ruler
Percent tree canopy closure [the % of the ground surface that is shaded by a vertical projection of all woody vegetation > 5.0 m (16.5 ft) in height].	DF,DFW	Line intercept, remote sensing
Percent of trees that are deciduous species (the number of deciduous trees divided by the total number of trees, multiplied by 100).	DF,DFW	Line intercept, quadrat, remote sensing

Figure 5. Definitions of variables and suggested measurement techniques.

Variable (definition)	Cover types	Suggested techniques
Percent of trees ≤ 19.1 cm (7.5 inches) dbh (the number of trees ≤ 19.1 cm dbh, divided by the total number of trees, multiplied by 100).	DF,DFW	Quadrat, diameter tape
Percent herbaceous canopy cover (the % of the ground that is shaded by a vertical projection of all nonwoody vegetation).	DF,DFW	Line intercept
Distance to permanent water (the average straight line distance from sample points to the edge of the nearest herbaceous wetland or lacustrine cover type with water present throughout the year).	DF, DFW	Tape measure, pacing, map and ruler
Percent of area covered by standing water during average April-September conditions (self-explanatory).	DF, DFW	Transect, local data

Figure 5. (concluded).

to provide suitable substrate moisture conditions that are suitable for supporting terrestrial efts. The approach of assessing only the proximity and not the quality of the nearest aquatic habitat is based on the assumption that any permanent body of water will provide some aquatic habitat that will produce an adequate number of newts to occupy the available terrestrial habitat.

SOURCES OF OTHER MODELS

No other habitat models were found during literature searches on the habitat needs of the red-spotted newt.

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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 red-spotted newt (Notophthalmus viridescens viridescens). The model consolidates habitat use information into a framework appropriate for field application, and is scaled to produce an index between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). HSI models are designed to be used with Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service.

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