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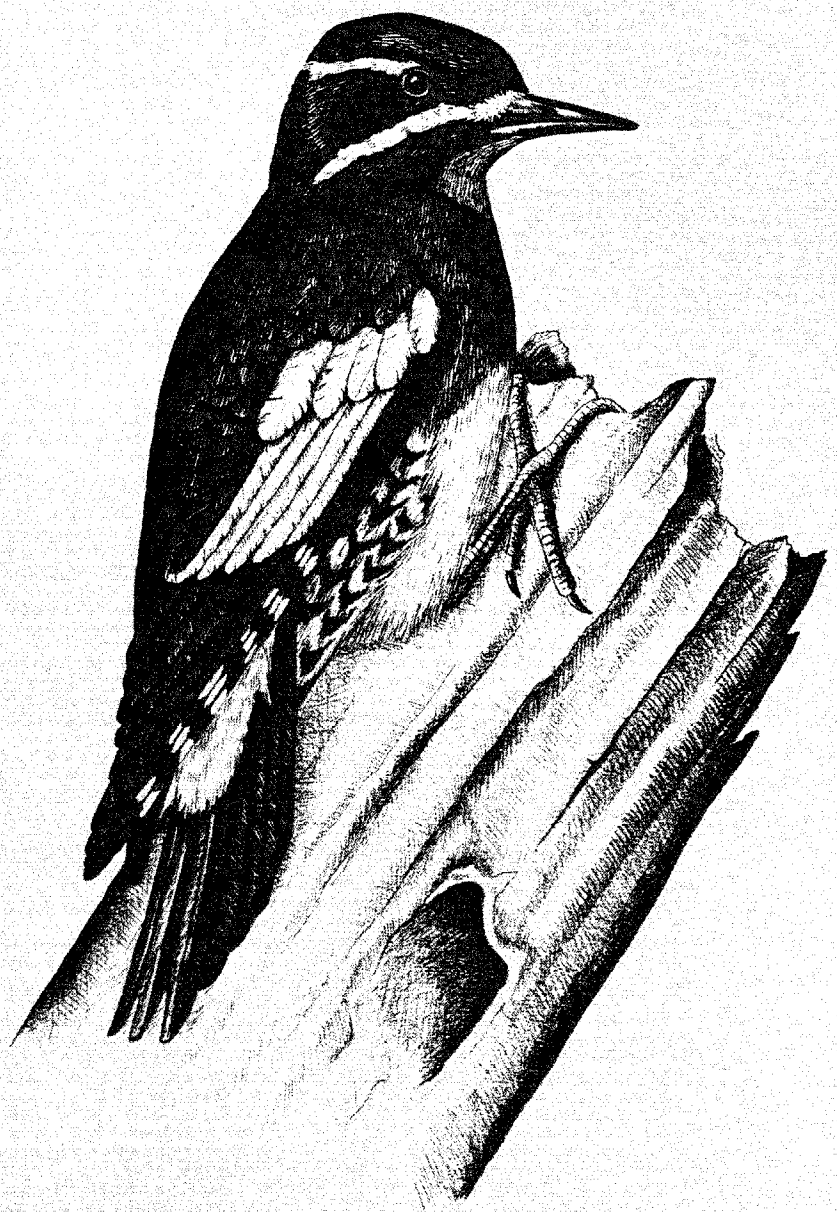
HABITAT SUITABILITY INDEX MODELS: WILLIAMSON'S SAPSUCKER



Fish and Wildlife Service

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HABITAT SUITABILITY INDEX MODELS: WILLIAMSON'S SAPSUCKER

by

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PREFACE

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

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

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

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WILLIAMSON'S SAPSUCKER (Sphyrapicus thyroideus)

HABITAT USE INFORMATION

General

The Williamson's sapsucker (Sphyrapicus thyroideus) "... inhabits middle elevation pine forests and high elevation spruce-fir forests" (Crockett 1975:111) as well as aspen stands (Hansley 1977; Hansley, pers. comm.) throughout its range in the western United States. The Rocky Mountain subspecies (S. t. nataliae) exhibits altitudinal and latitudinal migration with little overlap between summer and winter ranges, while the Pacific Coast subspecies (S. t. thyroideus) exhibits a primarily altitudinal migration (Crockett 1975).

Food

The Williamson's sapsucker is a timber-drilling omnivore (Diem and Zeveloff 1980), although seasonal food habits are highly specialized (Crockett 1975). The Williamson's sapsucker is adapted to feeding on sap and exposed insects and it is poorly adapted for feeding on subcortical insects (Spring 1965). The migratory habitat of the Williamson's sapsucker results from the need to be in "... areas where sap, active insects, and fruits are available throughout the winter" (Crockett 1975:20). Sap and phloem fibers are the major dietary items during much of the nonbreeding season (Crockett 1975). During the period between arrival on the breeding grounds and hatching of the young, Williamson's sapsuckers in Colorado fed exclusively on sap and phloem of live conifers (Stallcup 1968; Crockett 1975). Sap is high in sucrose and represents a high energy source, which is especially important in spring and early summer prior to the emergence of surface insects (Crockett 1975). Following the hatching of young, the diet shifted dramatically to almost exclusively ants, especially carpenter ants (Camponotus spp.) and wood ants (Formica spp.). The stomach contents of 17 sapsuckers collected during the breeding season consisted of 86% ants, 1% other insects, and 13% vegetable matter (Beal 1911, cited by Crockett 1975). Crockett (1975) collected prey items from the mouths of 20 Williamson's sapsuckers during the process of banding; 280 of 283 total insects were ants. Bachelor males continued feeding on sap throughout the nestling period of pairs, suggesting that the shift from sap to insects by nesting pairs was related to the needs of the nestlings.

Each pair of nesting Williamson's sapsuckers on a Colorado study area used four or five conifers as sap trees during the breeding season (Crockett 1975). Sap trees were significantly smaller in height and diameter when

compared to the average size of available trees, a preference that may be related to the thinner bark and easier drilling of small trees. Douglas-fir (Pseudotsuga menziesii) sap trees averaged 15.8 cm (6.2 inches) dbh and 6.3 m (20.7 ft) tall, compared to an average dbh of 25.0 cm (9.8 inches) and an average height of 10.5 m (34.4 ft) of available Douglas-fir trees. Ponderosa pine (Pinus ponderosa) sap trees averaged 26.9 cm (10.6 inches) dbh and 6.9 m (22.6 ft) tall compared to an average of 40.0 cm (15.8 inches) dbh and 9.0 m (29.5 ft) tall for all available ponderosa pine trees.

Nestlings are fed partially digested food during the first week following hatching (Crockett and Hansley 1977). After the first week, nestlings are fed whole insects by both adults. Ants are obtained by gleaning on the trunks and limbs of conifers (Stallcup 1968; Crockett 1975), as well as on the ground (Crockett 1975). Young are capable of foraging on their own by gleaning within a few hours after leaving the nest (Crockett 1975; Crockett and Hansley 1977).

Water

There is little information in the available literature regarding the water requirements of the Williamson's sapsucker. However, they have been reported to use small puddles of water for bathing and drinking during the summer (Crockett 1975).

Cover

The Williamson's sapsucker apparently inhabits a relatively wide variety of forested types throughout its range. It is considered to be most common in middle elevation forests of ponderosa pine, lodgepole pine (P. contorta), and Douglas-fir, although the species also inhabits subalpine forests of spruce-fir (Picea spp.-Abies spp.) (Crockett 1975; Smith 1982a, b). However, lodgepole pine stands are considered to provide marginal habitat for the Williamson's sapsucker (Hansley, pers. comm.). Williamson's sapsuckers inhabit open stands of ponderosa pine (Stallcup 1968; Crockett 1975; Crockett and Hadow 1975), as well as mature and old-growth mixed conifer forests in the northwestern United States (Thomas et al. 1979a; Sanderson et al. 1980). This species inhabits early successional conifer stands following fires (Jewett et al. 1953), although it has not been reported associated with burns in the Rocky Mountain area (Crockett 1975). Williamson's sapsuckers in California nested in snags on a burned area, but foraged on live timber in an adjacent unburned stand (Bock and Lynch 1970). Breeding densities of Williamson's sapsuckers in an Arizona mixed conifer forest were similar on an unlogged area and a logged area, even though tree [≥ 7.6 cm (3 inches) dbh] density was 626/0.4 ha (1.0 acre) on the unlogged area and 168/0.4 ha (1.0 acre) on the logged area (Franzreb 1977).

Reproduction

Although the western subspecies of the Williamson's sapsucker (S. t. thyroideus) prefers coniferous forests for nesting, quaking aspen (Populus tremuloides) may be the preferred nest tree, at least throughout the Rocky

Mountain region (Crockett 1975). A literature review by Crockett (1975) revealed that virtually all aspen nest site records were for S. t. nataliae in the Rocky Mountain region, while nearly all records of lodgepole pine nest sites were for S. t. thyroideus in California. Ponderosa pine nest site records were reported for both subspecies. Williamson's sapsuckers in the Bear River Mountains of Utah and Idaho bred in the subalpine fir (Abies lasiocarpa) and Engelmann spruce (Picea engelmannii) seral stages, but not in the earlier aspen seral stage (Smith 1982a, b). However, the fir and spruce seral stages contained aspen, and habitat for the Williamson's sapsucker was described as having "... aspens for nest sites, but mostly conifers and dead trees for foraging" (Smith 1982a:466). Eighty-six percent (49 of 57) of the nests on three study areas in Colorado and Wyoming were located in aspen (Crockett and Hadow 1975). The remaining eight nests were located in pines where suitable aspen trees were unavailable. Thomas et al. (1979b) summarized 50 nest records of the Williamson's sapsucker (presumably all S. t. thyroideus) in the Pacific Northwest; 46 sites (92%) were in conifers and 4 (8%) were in aspen. Conifer snags may be of secondary preference to Williamson's sapsuckers and may be most often used during years of high breeding densities (Crockett, pers. comm.). On an Arizona study area dominated by ponderosa pine, Williamson's sapsuckers nested only in dead aspen or dead portions of live aspens, even though most of the available snags were ponderosa pine (Scott et al. 1980). The sapsuckers nested in dead conifers on a subalpine area where aspens were not available. In Colorado, nests were "... most commonly in live aspen but also in stumps or dead conifers" (Crockett and Hansley 1977:18). Aspens located near openings are apparently of greater value as nest sites than are aspen within dense conifer stands (Crockett, pers. comm.). Nest cavities may be reused from year-to-year (Michael 1935; Crockett 1975; Crockett and Hansley 1977), although pairs may also switch cavities within the same territory used previously or switch territories (Crockett 1975).

Thomas et al. (1979b) considered a dbh of 30.5 cm (12.0 inches) to be the minimum size of snag capable of supporting a nest cavity for the Williamson's sapsucker in the Pacific Northwest. Scott (pers. comm.) believes that the minimum size snag may differ by tree species. Ponderosa pine snags less than 45.7 cm (18 inches) are infrequently used by Williamson's sapsuckers, since these smaller snags usually fall before becoming suitable for excavation. The minimum snag size for Williamson's sapsuckers in spruce snags is 30.5 to 38.1 cm (12 to 15 inches), while 30.5 cm (12 inches) is probably adequate for snags of other species. Forty aspen trees used for nesting in Colorado averaged 23.5 cm (9.3 inches) dbh and ranged from 18 to 32.4 cm (7.1 to 12.8 inches) dbh, with 32.4 cm approaching the largest diameter tree available (Crockett and Hadow 1975). Eight pines used for nesting on the same Colorado study area averaged 50.9 cm (20.0 inches) dbh and ranged from 34.2 to 54.8 cm (13.5 to 21.6 inches) dbh. Cavity height in aspens averaged 2.4 m (7.9 ft) and ranged from 0.9 to 5.1 m (3.0 to 16.7 ft) above ground, while cavities in pines averaged 5.1 m (16.7 ft) above ground, ranging from 0.8 to 7.9 m (2.6 to 25.9 ft). The larger diameters of pines apparently allowed nest cavities to be located higher above ground than in aspens. However, the location of nest cavities may be primarily determined by the location of decayed wood in the tree (Miller et al. 1979). Sixty-nine percent (18 of 26) of nests in an Arizona study area were in dead aspen (Scott et al. 1980). Nest heights averaged 7.6 m (25 ft), and ranged from 3.0 to 18.3 m (10 to 60 ft) above

ground, while heights of nest trees averaged 16.8 m (55 ft) and ranged from 7.3 to 30.5 m (24 to 100 ft). Diameters of nest trees averaged 35.6 cm (14 inches) dbh, ranging from 17.8 to 83.8 cm (7 to 33 inches) dbh.

Thomas et al. (1979b) calculated that 371 snags (dead or partially dead trees) ≥ 30.5 cm (12.0 inches) dbh per 100 ha (150/100 acres) are required to support maximum populations of Williamson's sapsuckers in the Blue Mountains of Oregon and Washington. Potential sapsucker density was considered to be directly correlated with snag density (e.g., 50% of the recommended snags would support 50% of the maximum population). However, Scott (pers. comm.) indicated that this density should refer to suitable snags; i.e., those snags that are soft enough for excavation. For example, lodgepole pine snags typically lose their bark quickly and harden, becoming unuseable for excavating birds.

The preference for aspen as nest sites, at least in the Rocky Mountain region, may be related to the soft core of aspen, even in live trees (Crockett and Hadow 1975). Examination of 12 trees used as nest sites by Williamson's sapsuckers in Oregon indicated that areas of decayed wood were selected for cavity excavation (Miller et al. 1979). Sixty-five percent (13 of 20) of the aspens containing nests in a Colorado study showed external signs of infection by a shelf fungus (Fomes igniarius var. populinus) which may provide a visual cue that a tree is in a weakened condition and easier to excavate (Crockett 1975; Crockett and Hadow 1975). Most nests in this study area were located in small stands of aspen [range = 0.024 to 1.171 ha (0.06 to 2.89 acres); mean = 0.34 ha (0.84 acres)] with an average stem density of 772.4 trees/ha (312.6 trees/acre) [range = 182 to 1,312 trees/ha (73.6 to 531 trees/acre)] (Crockett 1975). The nest sites were apparently "... chosen for their proximity to suitable foraging habitat [i.e., open ponderosa pine stands] rather than on the characteristics of the aspen nest stand itself" (Crockett and Hadow 1975:368). The small aspen stands used for nesting were located in ephemeral or permanent drainages within stands of conifers (Crockett 1975). Aspen groves surrounding high mountain meadows are also typically inhabited by Williamson's sapsuckers in Rocky Mountain National Park (Hansley, pers. comm.). Extensive stands of aspen are not usually occupied unless conifers are available nearby for foraging (Crockett, pers. comm.). Williamson's sapsuckers in Arizona nested in aspen within ponderosa pine stands, but did not nest in a stand dominated by quaking aspen (Scott et al. 1980).

Interspersion

Williamson's sapsuckers establish territories around the nest site that are defended against other males of the same species, as well as against other species of woodpeckers early in the breeding season (Crockett 1975). Defense is restricted to the nest tree later in the nesting cycle. Most nesting pairs in a Colorado study maintained home ranges of 4 to 9 ha (9.9 to 22.2 acres), with an average size of 6.75 ha (16.7 acres) (Crockett 1975). The shape of the home range was strongly influenced by vegetation and topography. Thomas et al. (1979a) reported a territory size of 4 ha (10 acres) per pair of Williamson's sapsuckers in ponderosa pine forests.

Williamson's sapsuckers in an open ponderosa pine stand in Colorado had a spring density of 3.7 birds/40.5 ha (100 acres) in April and May (Stallcup 1968). Hansley (1977) found a breeding density of 10 pairs per 40.5 ha in an open aspen stand with abundant aspen snags and scattered conifers in Colorado.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area. This HSI model is intended for use throughout the breeding range of the inland subspecies of the Williamson's sapsucker, S. t. nataliae. The breeding range of S. t. nataliae is "... from southeastern British Columbia (Kootenay) south in the mountains of Idaho, western Montana, Wyoming, Nevada (except the Sierra Nevada), Utah, and Colorado to central Arizona and northern New Mexico" (American Ornithologists' Union 1957:322). It is unclear whether the habitat needs of S. t. nataliae differ significantly from the habitat needs of the Pacific Coast subspecies, S. t. thyroideus.

Season. This model is intended as a means of evaluating the suitability of reproductive habitat (i.e., spring and summer) for the Williamson's sapsucker.

Cover types. This model can be used to evaluate habitat in the following cover types (terminology follows that of U.S. Fish and Wildlife Service 1981): Evergreen Forest (EF); Evergreen Tree Savanna (ETS); Deciduous Forest (DF); and Deciduous Tree Savanna (DTS). Within the range of the Williamson's sapsucker, deciduous habitats will be those dominated by quaking aspen. Aspen stands ≤ 4 ha (10 acres) should be considered a component of the surrounding forested type, while those > 4 ha should be typed as DF or DTS (see Application of the Model for rationale).

Minimum habitat area. Minimum habitat area is defined as the minimum amount of contiguous habitat that is required before an area will be occupied by a species. Information on minimum habitat area was not reported in the literature. However, the minimum reported home range size is about 4 ha (10 acres) (Crockett 1975; Thomas et al. 1979a). If available habitat is less than 4 ha (10 acres), the HSI for the Williamson's sapsuckers is assumed to be 0.0.

Verification level. An earlier draft of an HSI model for the Williamson's sapsucker was reviewed by Allen B. Crockett, Paula Hansley, and Virgil E. Scott. Their review comments and suggestions have been incorporated into this model.

Model Description

Overview. This HSI model for the Williamson's sapsucker considers habitat needs for cover and reproduction to be identical during the breeding season. Food is assumed not to be limiting if adequate cover and reproductive habitat is present. Water is assumed not to be limiting to the Williamson's sapsucker.

The following section identifies important habitat variables, describes suitability levels of the variables, and describes the relationships between variables. The relationship between habitat variables, life requisites, and cover types used in this model and an HSI value for the Williamson's sapsucker is shown in Figure 1.

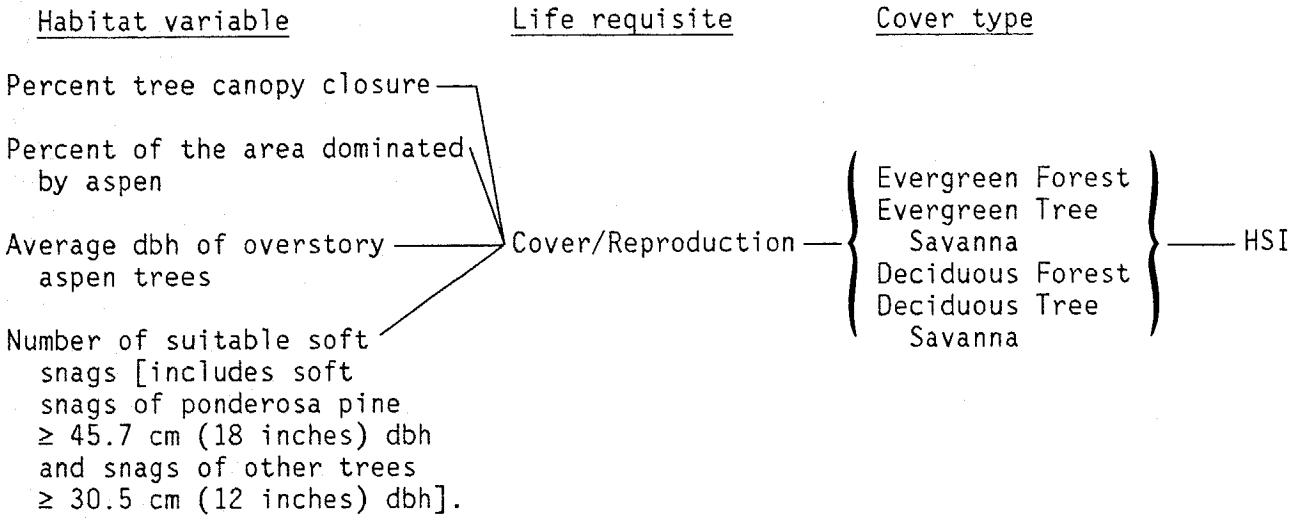


Figure 1. The relationship of habitat variables, life requisites, and cover types to an HSI value for the Williamson's sapsucker.

Cover/Reproduction component. The inland subspecies of the Williamson's sapsucker apparently prefers open conifer stands or open mixed conifer-hardwood stands. It is assumed in this model that optimum canopy conditions occur when average tree canopy cover ranges from 30% to 60%. Small areas of dense canopy may be heavily used if interspersed with areas of sparser tree canopy (Crockett, pers. comm.). Habitat is assumed to be unsuitable for Williamson's sapsuckers if the average tree canopy closure is less than 10% or greater than 80%.

The Williamson's sapsucker may nest in either dead trees or live trees with internal decay (e.g., trees infected by Fomes ignarius var. populinus). Hard snags are not often used (Scott, pers. comm.). Aspen appears to be the preferred live tree for nesting. Home range size of Williamson's sapsuckers in Colorado averaged 6.75 ha (16.7 acres), while the aspen stands used for nesting averaged 0.34 ha (0.84 acres) (Crockett 1975). The proportion of the home range dominated by aspen, therefore, was approximately 5% [i.e., (0.34/6.75) x 100]. The minimum home range reported was approximately 4 ha (10 acres). If it is assumed that the aspen stand used for nesting was 0.34 ha, then the proportion of this home range dominated by aspen is 8.5% [i.e., (0.34/4) x 100]. Based on this information, it is assumed in this model that the potential for optimal suitability for nesting in aspen exists if 5 to 15% of the area under consideration is dominated by aspen. An implicit assumption is that the aspen resources are distributed evenly across the

potential sapsucker territories in a specific study area. Overall habitat quality is assumed to decrease as the proportion of the area dominated by aspen increases above 15%, due to a presumed imbalance between potential nest sites and preferred foraging sites (i.e., conifers), with a low suitability when the aspen component exceeds 50%. Study areas with greater than half of the total area dominated by aspen are considered unlikely to support Williamson's sapsuckers (Scott et al. 1980; Crockett, pers. comm.). Aspen trees must also be of sufficient size in order to be potential nest sites. It is assumed in this model that aspen provides the only suitable live tree nesting sites, and that nesting in conifers is restricted to dead or partially dead trees. The minimum dbh of trees reported to be used as nest sites is 18 cm (7.0 inches). It is assumed that the potential for optimal tree size exists if the average diameter at breast height (dbh) of the overstory aspens in a stand equals or exceeds 25 cm (10.0 inches), and that the stand is unsuitable if the average dbh of overstory aspens is ≤ 12.7 cm (5.0 inches). The suitability of live aspens for nesting is a function of aspen size and the proportion of the area dominated by aspen. Habitat suitability based on size of aspens is modified by the availability of aspen in order to obtain an overall value for nesting in live trees. Inherent in this assumption is that a zero suitability for either of these two variables will result in a zero suitability for potential nesting in live trees, regardless of the species and size of other live trees in the stand.

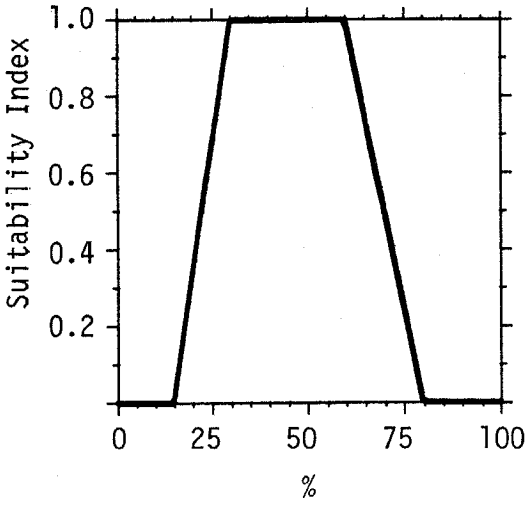
Nesting potential in snags (defined as any dead or partly dead tree) was assumed by Thomas et al. (1979b) to be optimal when the following conditions are met: 1.5 snags per 0.4 ha (1.0 acre) with a minimum dbh of 30.5 cm (12.0 inches) and at least 4.6 m (15.0 ft) tall. The minimum reported home range of a breeding pair is 4 ha (10 acres). The recommendations of Thomas et al. (1979b) equate, therefore, to about 15 snags within a breeding territory. However, Scott (pers. comm.) believes that the minimum size snag may differ by tree species, and is related to the length of time that a tree of a certain dbh and species can be expected to remain standing. The minimum size snag for most tree species is assumed to be 30.5 cm (12 inches) dbh; however, ponderosa pine snags less than 45.7 cm (18 inches) dbh are likely to fall before decay has advanced enough to be used by Williamson's sapsuckers (Scott, pers. comm.). Furthermore, a snag must be a soft snag before being available for use (Scott, pers. comm.). A soft snag has been defined as one composed primarily of wood "... in advanced stages of decay and deterioration ... [they] usually have broken tops and few limbs (Gale et al. 1973)" (Thomas et al. 1979b:60-61).

Overall nesting suitability is a function of the suitability of live and/or dead trees as nest sites. It is assumed in this model that optimal conditions can be satisfied by either live aspens alone, snags alone, or a combination of live aspens and snags. [However, snags may be less-preferred nest sites (Crockett, pers. comm.).] The overall cover/reproduction value of a cover type is a function of both canopy conditions and potential nest sites. If either of these factors has a suitability of 0.0, then the overall cover/reproduction value also equals 0.0. However, if both factors have a suitability value greater than 0.0, then potential nest sites are considered to be more important than canopy conditions in determining overall cover/reproduction value.

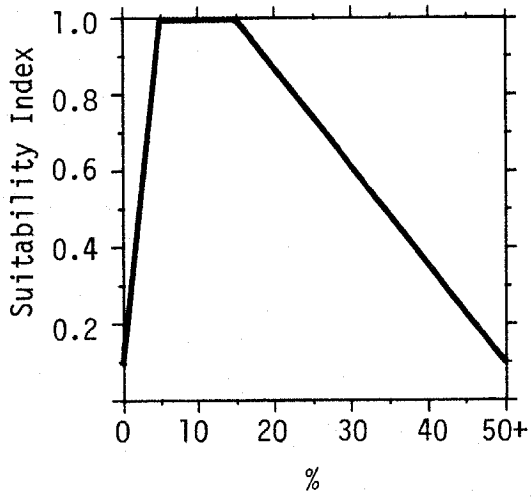
Model Relationships

Suitability Index (SI) graphs for habitat variables. This section contains suitability index graphs that illustrate the habitat relationships described in the previous section.

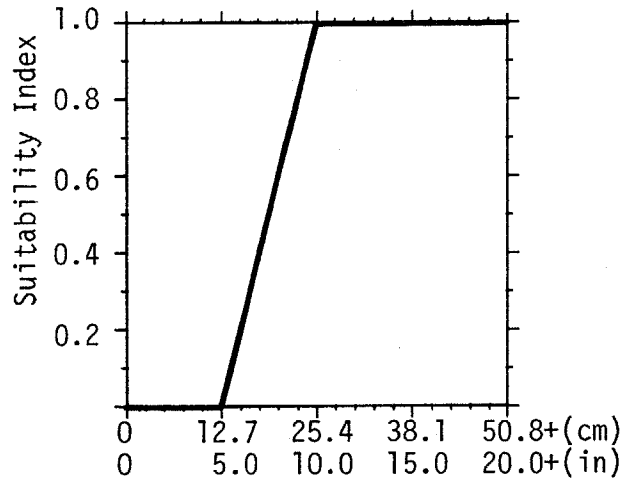
Cover type	Variable	
EF,ETS, DF,DTS	V_1	Percent tree canopy closure.



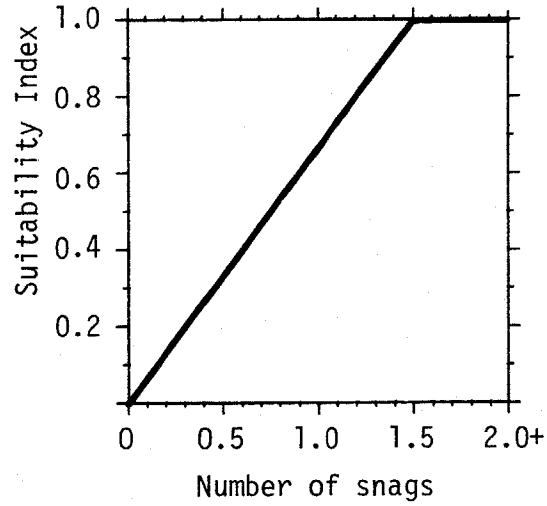
EF,ETS, DF,DTS	V_2	Percent of the area dominated by aspen.



EF,ETS, DF,DTS	V_3	Average dbh of overstory aspen trees.



EF,ETS, DF,DTS	V_4	Number of suitable soft snags [includes soft snags of ponderosa pine ≥ 45.7 cm (18 inches) dbh and soft snags of other trees ≥ 30.5 cm (12 inches) dbh that are in advanced stages of decay and deterioration].



Equations. In order to obtain a cover/reproduction value for the Williamson's sapsucker, the SI values for the appropriate variables must be combined by an equation based on the functional relationships of the variables. A discussion and explanation of the assumed relationships between variables was included under Model Description, and the specific equation in this model was chosen to mimic these perceived biological relationships as closely as possible. The suggested equation for obtaining a cover/reproduction value for the Williamson's sapsucker in the cover types considered in this model is as follows:

$$([(V_2 \times V_3) + V_4]^2 \times V_1)^{1/3}$$

Note that $[(V_2 \times V_3) + V_4]$ can exceed 1.0. If this occurs, its value should be set to equal 1.0 before continuing with the solution to the data set.

HSI determination. Because cover/reproduction was the only life requisite considered in this model, the HSI equals the cover/reproduction value.

Application of the Model

Aspen stands that occur as narrow stands (e.g., in drainages) or scattered clumps within extensive coniferous forests should be considered as a component of the coniferous forest. Sampling to determine estimates for habitat variables within coniferous forests will ideally reflect the aspen component. Extensive aspen stands should be cover-typed as deciduous forest (DF) or deciduous tree savanna (DTS). As a general guideline, aspen stands less than 4 ha (10 acres) in size should be considered as part of a larger, surrounding stand, while those greater than 4 ha should be treated as DF or DTS. This guidance is based on the minimum reported home range size of 4 ha. Aspen stands less than 4 ha will potentially contain only a portion of a pair's home range, while those greater than 4 ha may potentially be used as a pair's entire home range.

Definitions of variables and suggested field measurement techniques (Hays et al. 1981) are provided in Figure 2.

SOURCES OF OTHER MODELS

No other habitat models for the Williamson's sapsucker were located.

Variable (definition)		Cover types	Suggested technique
V_1	Percent tree canopy closure [the percent of the ground surface that is shaded by a vertical projection of the canopies of woody vegetation greater than 5 m (16.5 ft) tall].	EF,ETS, DF,DTS	Line intercept, remote sensing
V_2	Percent of the area dominated by aspen [the proportion of the total area being evaluated where aspen (Populus tremuloides) comprises > 50% of the overstory tree canopy].	EF,ETS, DF,DTS	Line intercept, remote sensing
V_3	Average dbh of overstory aspen trees [the average diameter at breast height (1.4 m; 4.5 ft) of those aspens that are ≥ 80% of the height of the tallest tree in the stand].	EF,ETS, DF,DTS	Cruise for tallest tree in stand. Sample with optical range finder and Biltmore stick on strip quadrat.
V_4	Number of suitable soft snags per 0.4 ha (1.0 acre) [the number of standing dead or partly dead ponderosa pines ≥ 45.7 cm (18 inches) dbh or other dead or partly dead trees ≥ 30.5 cm (12 inches) dbh per 0.4 ha (1.0 acre). Only soft snags should be included in this estimate. Soft snags are those with signs of advanced stages of decay and deterioration, including soft wood, broken tops, and few limbs].	EF,ETS, DF,DTS	Quadrat

Figure 2. Definitions of variables and suggested measurement techniques.

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16. Abstract (Limit: 200 words)

A review and synthesis of existing information was used to develop a habitat suitability model for Williamson's sapsucker (Sphyrapicus thyroideus). The model is scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat) for the Williamson's sapsucker breeding range in North America. Habitat suitability indices (HSI's) are designed for use with Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service.

17. Document Analysis a. Descriptors

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