HABITAT SUITABILITY INDEX MODELS: THE ARIZONA GUILD AND LAYERS OF HABITAT MODELS

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This document is part of the Habitat Suitability Index Model Series, which provides habitat information useful for impact assessment and habitat management. Both of the models described in this report are based on the significant association of wildlife species with vegetation structure. The models compare the structure in the study area with the vegetation structure that could potentially occur in that study area following land use changes or disturbance. These models provide a low resolution assessment of habitat structure relevant early in the land-use planning process.

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AND LAYERS OF HABITAT MODELS

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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. Both of the models described in this report are based on the significant association of wildlife species with vegetation structure. The models compare the vegetation structure in the study area with the vegetation structure that could potentially occur in that study area. These models provide a low resolution assessment of habitat structure relevant early in the land-use planning process.

Both models are based on the concept that the vertical dimension of the vegetation community is an important factor in the way that wildlife species partition the resources of habitats. Wildlife species are associated with the vertical structure of habitats in the models through the development of a species-habitat matrix. Wildlife guilds are formed according to the occurrence of species in the species-habitat matrix; the number of these guilds is strongly associated with the numbers of layers of habitat in different cover types. These models were developed for habitats in the Sonoran Desert of west-central Arizona. Model tests utilizing field data showed that habitat layers, representing a surrogate measure of habitat structure, can be used to predict, with precision, the number of guilds with birds that occur in a variety of different cover types in the Sonoran Desert (Short 1983).

Models that assess the value of the structure of the vegetation community to the wildlife community are based on: (1) the number of wildlife guilds predicted to occur in the cover types present, and the areas of those cover types, compared to the wildlife guilds and cover type areas that could potentially occur in the study area; and (2) the sum of the areas of layers of habitat that presently occur in the study area compared to the total area of the habitat layers that could potentially occur in the study area. The ability of the models to predict future conditions is dependent either on the ability of plant succession models to predict the future structure of vegetation communities or on the correctness of assumptions about the future structure of vegetation communities.

Comments, criticisms, and suggestions evaluating the basic theory behind these models or the application of the models in natural resource management are welcome. Please send suggestions to:

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THE ARIZONA GUILD AND LAYERS OF HABITAT MODELS

GENERAL INFORMATION

Introduction

This paper describes two models, a wildlife guild model and a layers of habitat model, which can be used to produce a Habitat Suitability Index (HSI) useful in initial project planning to predict potential impacts of change on terrestrial habitats. The two models are closely related; each provides a low resolution assessment of habitats that is more relevant to how the total wildlife community uses habitats than to how individual species use particular cover types. The two models were developed from a data base developed for the Hualapai-Aquarius Planning Units of the U.S. Bureau of Land Management in west-central Arizona (Short 1983). These management units comprise about 1.5 million acres within Ecoregion 3222 (Figure 1), which is a portion of the American Desert Province (Bailey 1978). Ecoregions are large land areas generally characterized by a distinctive flora, fauna, climate, landform, soil, vegetation, and ecological climax. Ecological relationships between plant species, soil, and climate are essentially similar within an ecoregion, and similar management treatments are expected to yield comparable results throughout an ecoregion. Although the two models were developed from a data base compiled specifically for the Hualapai-Aquarius Planning Units, the concepts critical to the models should be relevant and applicable throughout the United States.

The Habitat Suitability Index Models described in this paper are based on general associations between habitat use by wildlife species and vegetation structure. These associations represent an obvious simplification of natural systems. Species use is related to the structure of the vegetative community through only two of a wide variety of possible niche dimensions (where foraging and reproduction occur). Species are assumed to be a potential occupant of a cover type if the structure of that cover type meets the feeding and reproductive requirements of the species. Intraspecific and interspecific interactions, nonhabitat-related factors, and specific habitat requirements of individual species are not considered when determining potential occupancy of a cover type. The models provide an abstract value of habitat suitability, with a biological basis, that can be compared with other, similarly derived abstract values.

The intent of the models is to provide a way to measure the diversity in habitat structure in a study area. The HSI values are numerical representations of that structural diversity. The values can be used to provide a

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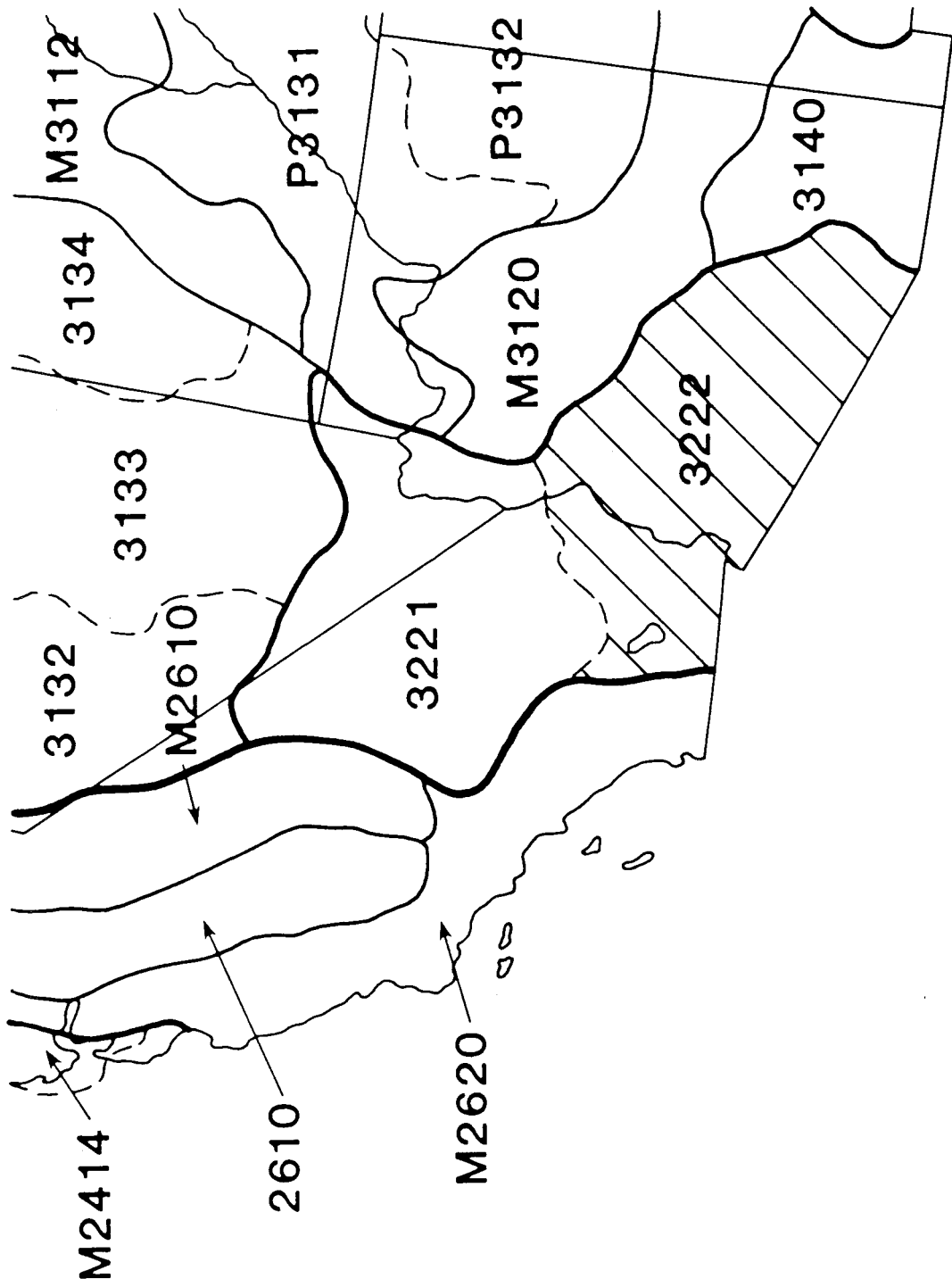
Figure 1. These Habitat Suitability Index Models were developed for the Sonoran Desert of west-central and southwestern Arizona in Ecoregion 3222.

statistical evaluation of habitat values of assessment areas, to measure the effects of land use change on wildlife habitat, to design inventories and assessments of available wildlife habitat, and as a basis for evaluating mitigation plans. Greater HSI values determined with these models may represent greater habitat diversity which may be accompanied by increased animal diversity. The models, however, are not intended to provide value judgements of the merits of wildlife species diversity. The models also say nothing about the utility of habitat for individual species; that information is dependent on species specific models.

These HSI models are based on several assumptions. (1) The volume of space comprising a terrestrial habitat can be considered in terms of discrete and definable habitat layers. (2) Wildlife species can be associated with the structure of terrestrial habitats by positioning their niche spaces within one or more layers of habitat. (3) Wildlife guilds can be formed as groups of vertebrate species whose niche space occurs in the same layer or group of habitat layers (Short and Burnham 1982; Short 1983). (4) Some habitats are structurally more complex than others because of the presence of additional habitat layers. Structurally complex habitats tend to provide more niche spaces and to accommodate more wildlife guilds and wildlife species. (5) Habitats can be compared and evaluated by calculating a summed product of the area of each cover type and the number of guilds that can occur within each cover type, or by calculating a summed product of the number of habitat layers present and the area of each of those habitat layers. The summed products can be respectively compared to a maximum wildlife guild-area measure or layers of habitat-area measure to provide HSI estimates.

BASIS FOR THE DEVELOPMENT OF THE HSI MODELS

This section describes the association between wildlife species and the structure of habitats and the processes used to develop wildlife guilds. The development of a wildlife guild-area product and a layer of habitat-area product into HSI models is accomplished in the following HSI model section.

The tendency of vertebrate species to utilize specific layers of habitat may represent a basic strategy for partitioning habitat resources. For example, fish species often can be characterized as occurring in vertical zones within the water column (see, e.g., Pflieger 1975). Heatwole (1982) indicated that the spatial separation of sea snakes along coral reefs included a vertical zonation. The use of vertical layers was illustrated by Heatwole (1982) for several lizard species in terrestrial habitats in the West Indies. The dependency of some rodent species on the tree canopy was described by Maser et al. (1981). Numerous authors (e.g., Martin 1960; Karr 1971; Rabenold 1978; Geibert 1979) have published data on the use of vertical habitat zones by avian species.

Ornithologists frequently emphasize the importance of layers of habitat as a determinant of the diversity of an avian community. Birds, in temperate climates at least, seem to partition habitat resources according to understory, midstory, and overstory layers. Studies in tropical climates, however,

indicate that avian species in Puerto Rico may not separate the midstory and overstory layers, whereas, in Panama, they may subdivide the mid- and overstory into three layers of habitat (MacArthur et al. 1966).

The development of these models was based on the assumptions that nonfish vertebrate wildlife species partition habitat resources along a vertical dimension and that this vertical dimension can be represented as habitat layers. Habitat layers used in these models are defined in Table 1. These definitions are assumed and not proven either for the Sonoran Desert of west-central Arizona or for other regional habitats.

The quantity of vegetation that the different habitat layers must contain in order to provide the necessary structure for wildlife use is unknown. Presumably, animal species react to the presence of a particular habitat layer when the structure is developed beyond some threshold value.

A process has been developed that associates wildlife species with the different vertical layers of habitats (Short and Burnham 1982; Short 1983). This was accomplished by positioning wildlife species within a species-habitat matrix formed by selecting, as axes, two very important niche parameters for which species-habitat information was likely to be available. The x-axis of the matrix was subdivided into layers of habitat where breeding (nesting, hatching, or birthing) occurs, and the y-axis of the matrix was subdivided into layers of habitat where foraging occurs (Fig. 2). The y-axis of the matrix was split so that guilds of primary consumers (plant eaters) and secondary consumers (animal eaters) could be developed separately. The wildlife species that occur in the different cover types within the Hualapai-Aquarius Planning Units were identified. Each species was positioned within the species-habitat matrix developed for that cover type by determining the layer(s) of habitat required for feeding and the layer(s) of habitat required for reproduction. This information about species use of cover types and habitat layers was the data base used in the development of wildlife guilds. These species-habitat data were coded, computerized, and analyzed with a merge-sort routine that separated into wildlife guilds groups of species whose niche spaces were located in the same layer or layers of habitat. Details about the guild formation process are located in the Appendix. The number of wildlife guilds varied with the number of layers of habitat in a cover type; e.g., few guilds occurred in structurally simple habitats like grasslands, whereas many guilds occurred in riparian treeland habitats, which were the most structurally complex associations present in the Planning Units.

The number of guilds of primary consumers and secondary consumers and the total number of wildlife guilds in the Planning Units were significantly related to the number of habitat layers (water surface, terrestrial subsurface, terrestrial surface, shrub or midstory, tree bole, and overstory) present in the 13 terrestrial cover types identified in the west-central Arizona study area (Fig. 3) (Short 1983). This positive relationship occurs because addi-tional habitat layers provide more guild blocks (the cells located in the matrix of Fig. 2), which, in turn, provide more ways in which wildlife species can use the resources of a habitat. The relationship between habitat layers and the number of wildlife guilds is so significant that the presence of layers of habitat seems to be a variable that can be used to compare the usefulness of different habitats for wildlife.

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Table 1. A suggested list of criteria for determining the presence of different layers of habitat.

Layer	Criteria
Tree canopy or overstory	Vegetation or structure extends upwards from 8 m (25 ft) (suggested by MacArthur and MacArthur 1961.) Provides at least 5% cover when projected to the surface (500 m²/ha or 2,200 ft²/acre).
Tree bole	Dbh ≥ 20 cm (8 inches). Density of boles ≥ 12/ha or 5/acre.
Shrub midstory	Vegetation or structure extends from 0.5 m (20 inches) up to, but not including, 8 m (25 ft) in height. Provides at least 5% cover when projected to the surface (500 m²/ha or 2,200 ft²/acre).
Understory	Layer extends from 10 cm (4 inches) below the apparent surface up to, but not including, 0.5 m (20 inches) above the apparent surface. Provides at least 5% cover when projected to the surface (500 m²/ha or 2,200 ft²/acre).
Terrestrial subsurface	Extends down from more than 10 cm (4 inches) below the apparent surface.
Surface water layer	Land surface-water interface and shallow water up to 25 cm (10 inches) deep.
Water column layer	Layer of water between the surface and the bottom of the water column.
Bottom of the water column layer	Water-terrestrial surface interface under more than 25 cm (10 inches) of water.

Figure 2. The species-habitat matrix used in the development of wildlife guilds.
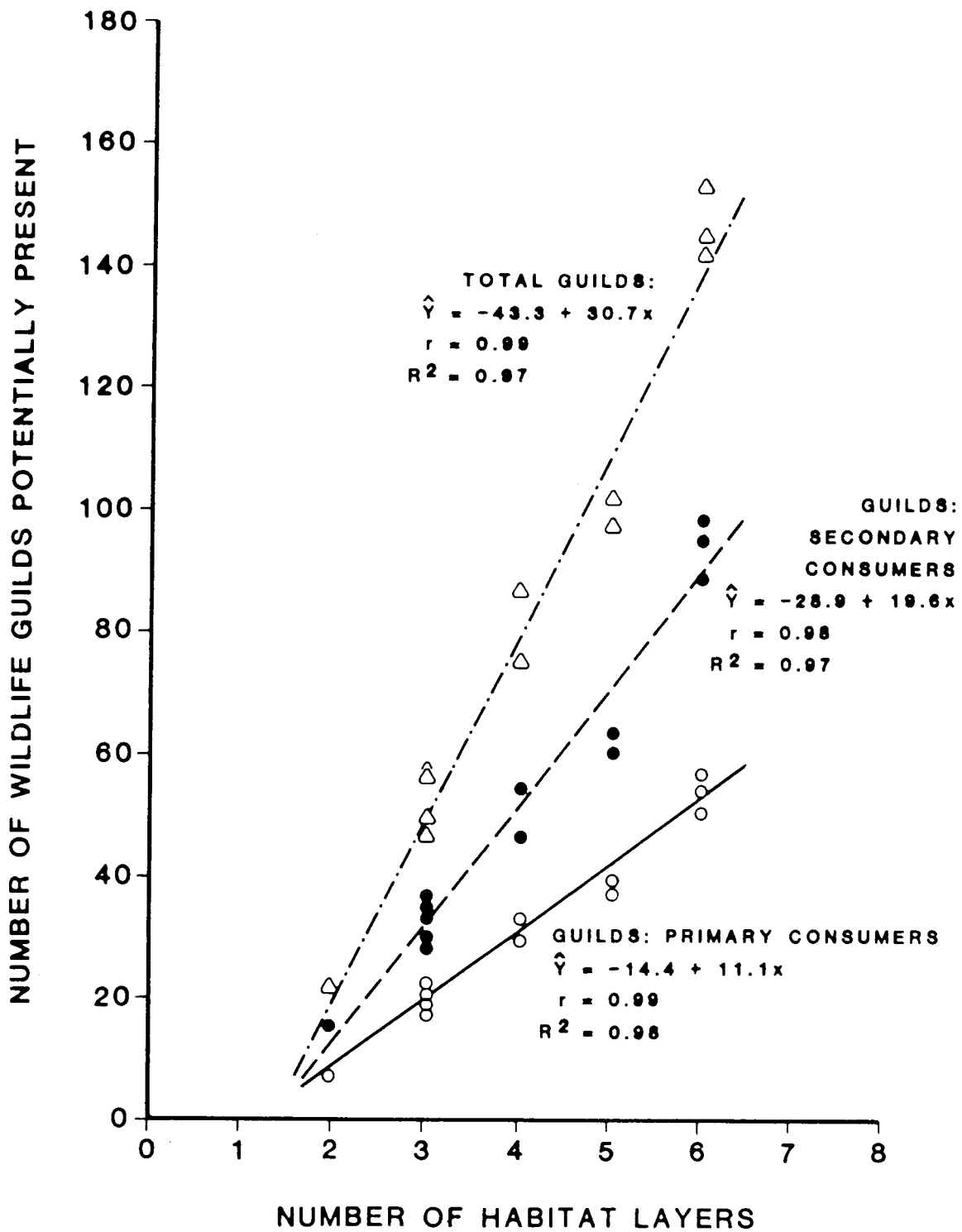
Figure 3. Relationship of wildlife guilds to habitat layers in 13 terrestrial habitats.

HABITAT SUITABILITY INDEX MODELS

Wildlife guilds and layers of habitat in cover types are described below as two different measures that can be used to calculate Habitat Suitability Indices (HSI's) (U.S. Fish and Wildlife Service 1980). These HSI's compare the structure of the wildlife community or of the vegetative community in an area with the structure of the wildlife or vegetative community that could possibly occur in that area.

Determination of an HSI Using Wildlife Guilds

A wildlife species may occur within a habitat if that habitat is within the ecological range of the species, if that habitat is structurally suitable for the species, and if nonhabitat related factors do not adversely impact the species. The structure of habitats or cover types can be represented in terms of layers of habitat. Within the Sonoran Desert different cover types vary in the numbers of layers of habitat that depict the wildlife community (Table 2). Frequently, more wildlife species occur in more structurally complex habitats (i.e., cover types with more layers of habitat (Table 2). Wildlife species can be associated with habitat structure or layers of habitat by using the wildlife guild formation process (Short and Burnham 1982; Short 1983). Relatively few wildlife guilds occur in structurally simple cover types because there are only a few ways in which the available habitat layers can be combined to provide niche spaces for species. The number of wildlife guilds tends to increase as the number of layers of habitat increases (Table 2) because more complex habitats provide more ways for wildlife species to partition habitat resources. Few wildlife guilds occur in desert grassland habitats, more in the structurally complex shrubland cover types (three layers of habitat), and many guilds occur in the very complex riparian treeland habitats (Table 2).

The determination of an HSI using wildlife guilds recognizes this tendency for cover types with simpler structures to have fewer guilds when compared to the number of wildlife guilds occurring in structurally more complex habitats. This HSI model uses the riparian treeland habitat as a standard of comparison. The riparian treeland habitat is the most structurally complex habitat within Ecoregion 3222. The product of the area of each cover type and the number of guilds potentially occurring in that cover type is summed for all the cover types occurring in an evaluation area. This value is expressed as a proportion of the potential area-wildlife guild product which the evaluation area could achieve if the total evaluation area consisted of riparian treeland habitat. This convention provides index values between 0.0 and 1.0. Higher index values indicate an increased similarity between the structure of the evaluation habitat and the structure of a riparian treeland habitat. The symbolic statement of this HSI calculation is:

$$HSI = \frac{\sum_{i=1}^{n} (G_i)(A_i)}{153 \sum_{i=1}^{n} A_i}$$

Table 2. Numbers of wildlife species (birds, mammals, amphibians, and reptiles) and numbers of guilds of primary and secondary consumers potentially present in 13 terrestrial (nonlentic) cover types within the Sonoran Desert of west-central and southwestern Arizona. The wildlife guilds depend on the water surface, terrestrial subsurface, terrestrial surface, shrub midstory, tree bole, and tree canopy layers of habitat, if available, within cover types (from Short 1983).

Cover type	No. of habitat layers	Total no. of wildlife species	Total birds	Total mammals	Total amphibians and reptiles	No. of guilds of primary consumers	No. of guilds of secondary consumers	Total no. of wildlife guilds
Desert grassland	2	136	74	47	15	7	15	22
Creosote bush-white bursage	3	140	74	38	28	17	27	44
Chapparal	3	193	115	47	31	19	28	47
Juniper-mixed shrub	3	209	121	51	37	20	32	52
Mixed riparian scrub	3	161	99	41	21	20	31	51
Joshua tree-creosote bush	3	148	84	38	26	21	32	53
Saguaro-palo verde	4	164	88	41	35	28	44	72
Juniper-pinyon	4	196	122	46	28	33	52	85
Ponderosa pine-mixed conifer	5	144	99	37	8	37	60	97
Ponderosa pine	5	154	103	42	9	39	62	101
Mixed broad leaf riparian treeland	6	233	153	46	34	50	94	144
Mesquite-saltcedar riparian treeland	6	240	167	44	29	54	88	142
Cottonwood-willow riparian treeland	6	243	159	50	34	56	97	153

where G_i = the number of guilds in cover type i (from Table 2)

A_i = the area of cover type i

153 = the number of wildlife guilds potentially present in the structurally complex cottonwood-willow riparian habitat (Table 2)

n = the number of cover types present within the bounded area

The number of guilds in each cover type (e.g., G_1) is obtained from a data base similar to that listed in Table 2. The 153 guild value in the denominator is the number of wildlife guilds potentially present in the structurally complex cottonwood-willow riparian habitat (Table 2). This denominator is a standard denominator for the wildlife guild model in Ecoregion 3222.

An example of an HSI calculation using wildlife guilds is given below. Consider an assessment area that contains 60% chaparral and 40% juniper-mixed shrubs. The numbers of species, layers of habitat, and wildlife guilds that might occur in these cover types are listed in Table 2. The HSI calculation is a proportion where the numerator is a product of area of cover types and numbers of wildlife guilds that can occur in those cover types. Thus the numerator of the proportion is 60 units of chaparral which may contain 47 guilds (Table 2) + 40 units of juniper-mixed shrubs which may contain 52 wildlife guilds (Table 2). The denominator of the proportion is the product of guilds x area that could occur if the total assessment area were a structurally complex riparian treeland habitat. Values for a cottonwood-willow riparian treeland are used in the denominator because species and guild richness is greatest in this cover type (Table 2). The actual HSI calculation is:

$$HSI = \frac{(60 \times 47) + (40 \times 52)}{100 \times 153} = 0.32$$

The numerator of the proportion is 32% of the area x wildlife guild product that could occur if the assessment area had been the structurally very complex cottonwood-willow riparian treeland area.

The 0.32 HSI value can be compared with similarly derived values for other assessment areas or to another evaluation for the same assessment area compared at a different time period.

An HSI can be calculated for future conditions if assumptions can be made about the areas of different cover types likely to be present in the future. Models of vegetative succession developed for the ecoregion can be used in these calculations, when available. Succession models predict the cover types and infer the layers of habitat likely to be present at future dates.

The wildlife guild model is a quick and simple habitat evaluation tool that can be used after the data base necessary for the development of wildlife guilds has been assembled. The data base can be compiled in a workshop format or it may have been compiled for purposes other than the calculation of HSI's because the association of wildlife species with the structure of habitats is a good planning tool for designing inventory and monitoring efforts and for evaluating the impacts of land use change on the wildlife community. The guild model can be used for habitat evaluation throughout an ecoregion once the data base for the ecoregion has been compiled.

Determination of an HSI Using Layers of Habitat

Cover types can be considered as combinations of habitat layers as defined in Table 1. They consist of volumes of space at various levels above or below the air-terrestrial surface or the air-aquatic surface interfaces. A layer of habitat is considered present if it occurs in a polygon above some threshold density. Those threshold densities are defined in Table 1 and are assumed and unproven. A variety of habitat layers may be present if the highest layer is open. Dense cover in upper layers may restrict development of some lower habitat layers. Impacts of some land use practices may affect the presence or absence of some habitat layers. These are conditions that can be described with the layers of habitat model.

The symbolic statement of an HSI calculation using the layers of habitat model is:

$$HSI = \frac{l \sum\limits_{i=1}^{l} A_i}{(6)(5) \sum\limits_{j=1}^{n} A_j}$$

where l = the number of layers of habitat present within some bounded area

   A_i = the area of layer of habitat i within the bounded area

   A_j = the surface area of cover type j within the bounded area

   n = the number of different cover types present within the bounded area

   6 = the maximum number of habitat layers present in a unit of structurally complex riparian treeland

   5 = the maximum number of units of area of habitat layers that can occur within a unit of structurally complex riparian treeland

The numerator is the number of layers of habitat actually present on an area multiplied by the total area of the individual layers of habitat actually present. The denominator is the product of the number of habitat layers potentially present in the most structurally complex cover type that could

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theoretically occur on the assessment area and the area of the layers of habitat that could exist in this structurally complex cover type. An area of riparian treeland habitat can contain six habitat layers (tree canopy, tree bole, midstory, understory, terrestrial subsurface, and aquatic surface). The tree canopy, tree bole, midstory, and understory layer can each extend through-out the riparian treeland area and, if the total surface area = 100 units, provide a total of 400 units of area of habitat layers. The terrestrial subsurface and aquatic surface layers can occur within a riparian treeland area but their total area can only equal 100 units - an animal cannot burrow in the aquatic surface or swim in the subsurface layer. Thus, the denominator of the proportion equals six habitat layers that could occur on the assessment area and 500 units of habitat layers. The value 30 x evaluation area is a standard denominator for the HSI calculation using the layers of habitat model.

An example of the calculation of an HSI using the layers of habitat model is illustrated in Figure 4. The example is for the hypothetical assessment area described in the guild model: a 100-unit area that is 60% chaparral and 40% juniper-mixed shrubs. Both cover types have three layers of habitat (Table 2) and these layers (midstory, understory, and terrestrial subsurface) are assumed to extend throughout the cover types. The HSI calculation for the example in Figure 4 is 3 habitat layers x 300 units of habitat area divided by 6 habitat layers x 500 units of area of habitat layers or 0.30. This value is similar to the HSI calculated for the same area with the guild model (HSI = 0.32). The two models should result in similar relative assessments between habitats or for the same habitat under different management conditions. HSI's calculated for the same area using the layers of habitat model and the guild model may differ somewhat because the two models are based on different criteria, although the process of determining the HSI in the two models is similar.

The layers of habitat model emphasizes the structural diversity of a habitat and provides a measure of this diversity. Consider a treeland habitat in Figure 5. The habitat is a treeland as evidenced by the presence of an overstory, but that treeland is composed only of pole-sized trees as indicated by the absence of a tree bole layer. The HSI calculation using the layers of habitat model will not distinguish between the habitat condition in Example A where the understory layer is missing and the habitat condition in Example B where the midstory layer is missing. The HSI in both A and B is 0.3 because three layers and 300 units of area are present even though the layers actually present differ in the two examples. Example C in Figure 5 is a condition with increased diversity because the 300 units of area occurs in four habitat layers. More guilds and wildlife species would be expected to occur in the more structurally complex habitat of Example C even though the midstory and understory layers do not extend throughout the assessment area.

The layers of habitat model may be very useful in evaluating the impacts of land use change on the wildlife habitat value of an area because many land use changes affect the presence of habitat layers within cover types. For example, consider a condition in Figure 6 where 50 units of area contain juniper trees as the dominant vegetation. The trees are stunted so their canopies occur within the midstory layer and their boles are not large enough

juniper-mixed shrubs

| 40 units midstory |
| 40 units understory |
| 40 units terrestrial subsurface |

chaparral

| 60 units midstory |
| 60 units understory |
| 60 units terrestrial subsurface |

cottonwood-willow riparian treeland

| 100 units overstory |
| 100 units tree bole |
| 100 units midstory |
| 100 units understory |
| 50 units terr. subs. | 50 units aquatic sur. |
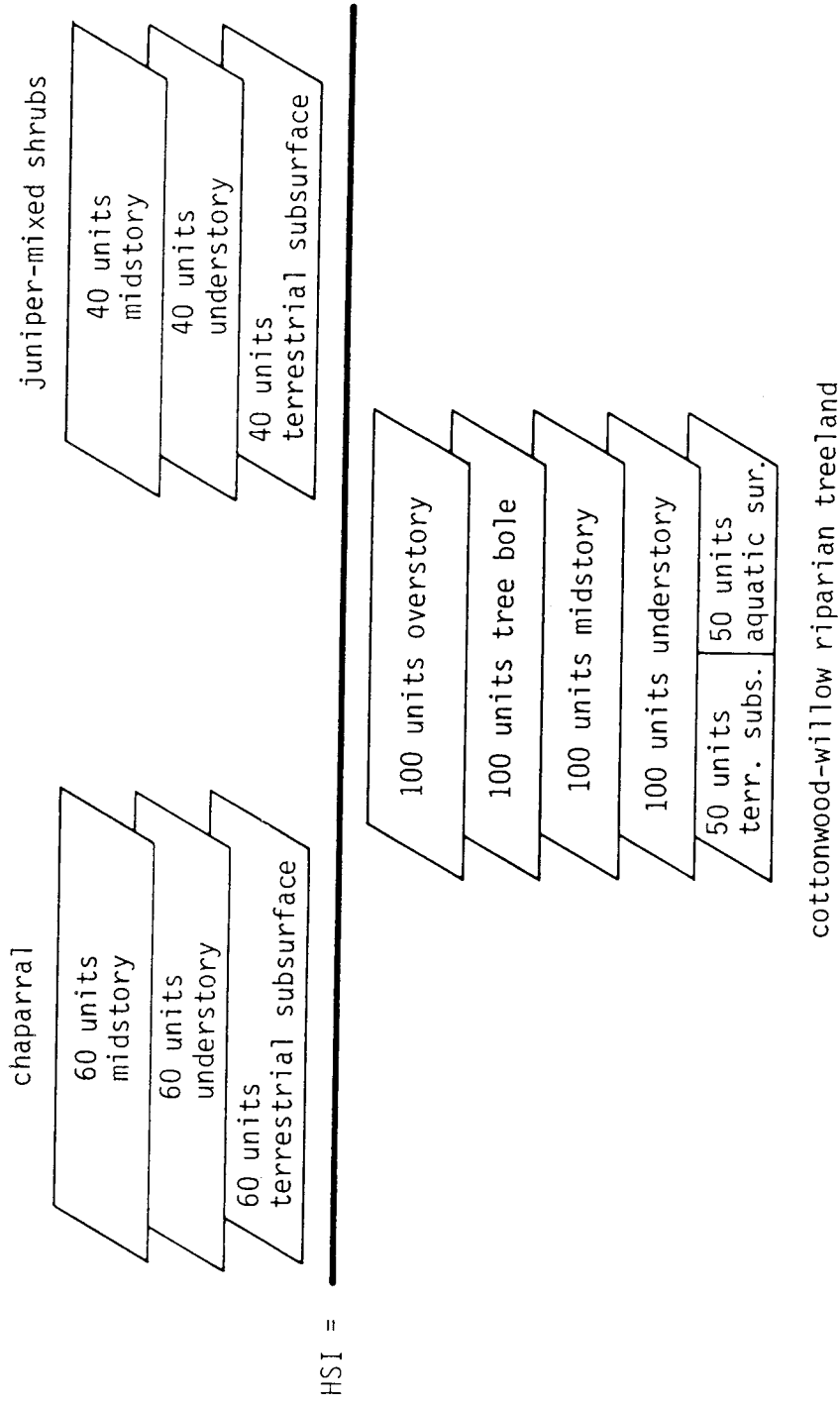
$$HSI = \frac{\text{number of layers actually present} \times \text{area of each of those layers actually present}}{\text{number of layers potentially present} \times \text{area of each of those layers potentially present}}$$

$$= \frac{3 \times (60 + 60 + 60 + 40 + 40 + 40)}{6 \times (100 + 100 + 100 + 100 + 50 + 50)}$$

$$= \frac{3 \times 300}{6 \times 500} = \frac{900}{3000} = 0.30$$

Figure 4. The calculation of an HSI using layers of habitat.
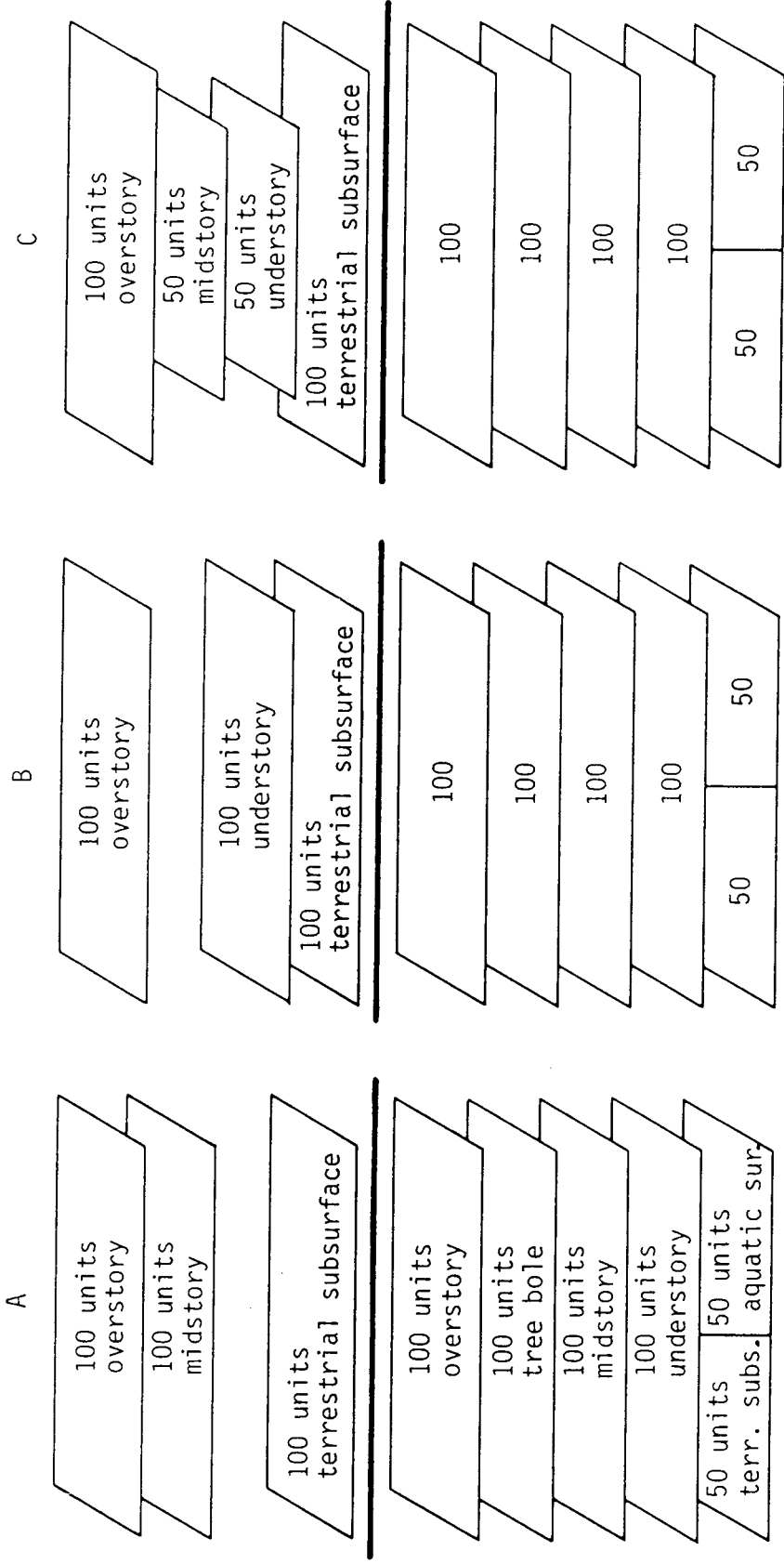
A

100 units
overstory

100 units
midstory

100 units
terrestrial subsurface

100 units
overstory

100 units
tree bole

100 units
midstory

100 units
understory

50 units
terr. subs.

50 units
aquatic sur.

$$HSI = \frac{3(100 + 100 + 100)}{6(100 + 100 + 100 + 100 + 50 + 50)}$$

$$= \frac{3 \times 300}{6 \times 500}$$

$$= 0.30$$

B

100 units
overstory

100 units
understory

100 units
terrestrial subsurface

100

100

100

100

50

50

$$= \frac{3(100 + 100 + 100)}{6(100 + 100 + 100 + 100 + 50 + 50)}$$

$$= \frac{3 \times 300}{6 \times 500}$$

$$= 0.30$$

C

100 units
overstory

50 units
midstory

50 units
understory

100 units
terrestrial subsurface

100

100

100

100

50

50

$$= \frac{4(100 + 50 + 50 + 100)}{6(100 + 100 + 100 + 100 + 50 + 50)}$$

$$= \frac{4 \times 300}{6 \times 500}$$

$$= 0.40$$

Figure 5. The calculation of HSI's for habitats that vary in structure.

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Before land use change

50 units midstory

50 units understory

50 units terr. subsurf.

50 units overstory

50 units tree bole

50 units midstory

50 units understory

| 25 units terr. subs. | 25 units aquatic surf. |
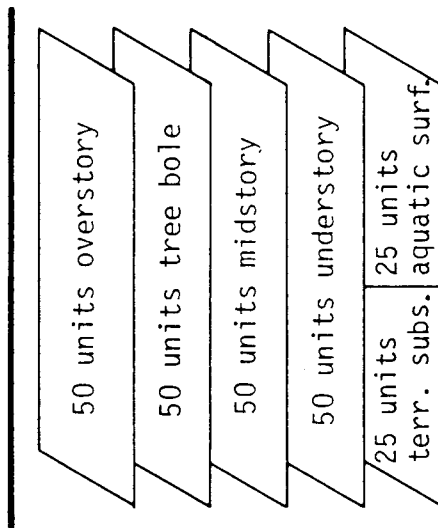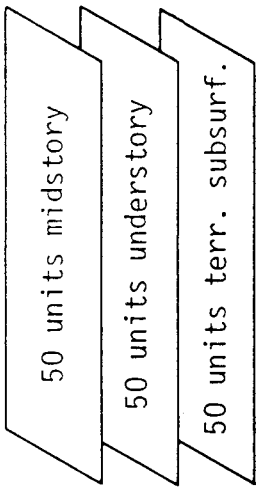
$$\text{HSI} = \frac{3(50 + 50 + 50)}{6(50 + 50 + 50 + 50 + 25 + 25)}$$

$$= \frac{3 \times 150}{6 \times 250}$$

$$= 0.30$$

After land use change (see text)

40 units midstory

40 units terr. subsurf.

50 units overstory

50 units tree bole

50 units midstory

50 units understory

| 25 units terr. subs. | 25 units aquatic surf. |
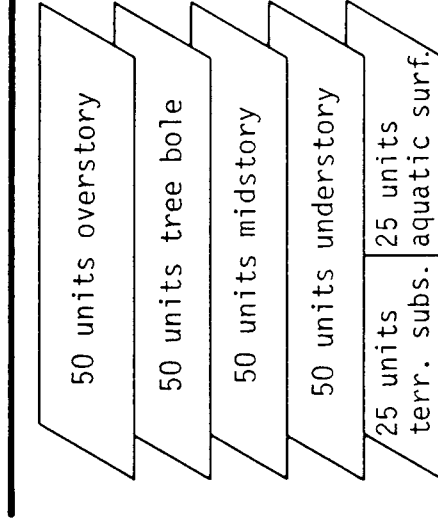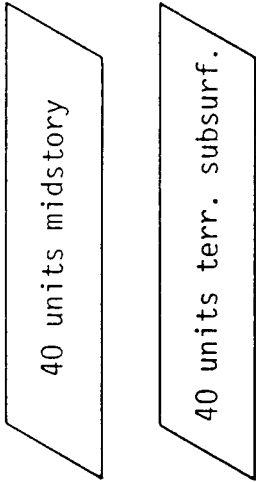
$$= \frac{2(40 + 40)}{6(50 + 50 + 50 + 50 + 25 + 25)}$$

$$= \frac{2 \times 80}{6 \times 250}$$

$$= 0.11$$

Figure 6. The calculation of a HSI value that illustrates how a land use change might affect the presence of habitat layers and the HSI calculation.

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to be used by excavators and cavity nesters so this layer of habitat is not considered to be present. There are three layers of habitat present (terrestrial subsurface, understory, and midstory) and 50 units of area for each habitat layer. The HSI calculation for the assessment area is 0.30 (Fig. 6). If a proposed land use is to remove 10 of the 50 units of area and to destroy the understory layer in the remaining 40 units of land, then 40 units of subsurface habitat, 0 units of understory vegetation, and 40 units of midstory vegetation would remain. The HSI for this future condition, 0.11, is calculated with a numerator that is a product of two layers of habitat and 80 units of habitat area (Fig. 6). The difference in the two HSI values before and after the land use change occurs because the size of the block of habitat is reduced and one habitat layer (the understory) in the remaining land area is no longer suitable for some members of the wildlife community.

The layers of habitat model, like the wildlife guild model, can be used to evaluate habitats when the size of blocks of cover types will change or when one cover type will be converted to a second cover type with different layers of habitat. The layers of habitat model cannot presently evaluate changes in habitat quality caused by changes in the density of vegetation within individual layers of habitat.

The layers of habitat model provides a low resolution HSI for a study site. It does not require the prior determination of wildlife guilds. It is particularly applicable to the early planning stage of new development projects because a variety of options can be quickly and easily evaluated to predict the impacts of the proposed development on the structure of habitat available to the wildlife community.

Both the wildlife guild model and the layers of habitat model can be used to evaluate mitigation decisions about wildlife habitat lost because of land use changes. Riparian treeland areas in arid regions, for example, provide a unique combination of habitat layers: tree overstory; tree boles; midstory; understory; terrestrial subsurface; and aquatic surface. Wildlife guilds that depend on specific habitat layers, like the tree canopy and tree bole layers, will no longer exist in the region if these unique layers are lost in riparian treeland habitats. Adequate mitigation may not be possible when these habitat layers cannot be replaced elsewhere in the region because of environmental constraints.

The type of HSI calculation described in these examples provides an estimate of the relative quantity of habitat structure within a study site that is available for the total vertebrate wildlife community that could potentially occur there. These HSI values can be used to compare the structural diversity of various habitats at the same time or of the same habitat at different times. HSI calculations based on either the wildlife guild model or the layers of habitat model provide an index between 0.0 (no structural diversity) and 1.0 (high structural diversity). The HSI tends to increase as habitat structure becomes more complex; habitats with greater structural diversity receive higher HSI's. A grassland habitat will receive a low HSI value which indicates it is of limited structural diversity. That low index value does not imply that grasslands are poor habitats or that structural diversity is good or bad. The index provides a way to measure structural

diversity. If wildlife guilds have been described for an area then a process is available to measure changes in structural diversity and to describe the guilds and species that may be impacted by changes to the structure of habitats.

Application of the Models

Guidance for use of the models. The models described above were developed from a data base that organized the wildlife community in the Sonoran Desert of west-central Arizona. The wildlife guilds are specific for Ecoregion 3222 (Fig. 1). However, similar relationships can be developed for other ecoregions (Bailey 1978).

Wildlife guild model. The application of the wildlife guild model to evaluate an assessment area requires the mapping of cover types on the assessment area and the determination of the wildlife guilds that could occur in each of the cover types. Mapping of cover types can be efficiently accomplished by the photointerpretation of recent, good quality, aerial photographs and the ground truthing of those interpreted photographs to verify the presence of cover types that have been predicted to be present. The determination of wildlife guilds is listed in the Appendix Section as dependent on: (1) the ecological range of individual wildlife species; (2) the association of wildlife species with different cover types; and (3) more specifically, the dependencies of wildlife species on particular layers of habitat. The calculation of an HSI is simple, once areas of cover types and the identify of guilds per cover type are known.

The additional steps required when the wildlife guild model is used to predict the impacts of a proposed land use change on the wildlife community requires: (1) delineating the area to be modified on the aerial photograph; and (2) predicting the cover types that are expected to be present after the land use change. The predicted HSI for the assessment area, after the proposed land use change has occurred, is determined from the product of the presumed new cover type areas and the wildlife guilds that can occur in those cover types compared to the standard denominator for the area. The impacts of land use change can be estimated if the successional pattern of vegetation change is known or can be assumed for an area in order to predict the cover types present at a future date.

Layers of habitat model. The first step in an application of the layers of habitat model is to delineate the study area on a recent, good quality, aerial photograph. The second step is to determine the layers of habitat present in the study area and their respective areas through photointerpretation. The third step is ground truthing to verify the presence of the habitat layers predicted from the aerial photograph. After the ground truthing has been completed, the areas of layers of habitat present in the study area are calculated and compared to the standard denominator for the area.

The following additional steps are required when the layers of habitat model is used to predict the impacts of a proposed land use change on the structure of wildlife habitat: (1) delineate on the aerial photograph the area that would be modified by the land use change; and (2) determine the habitat layers, and the areas of those habitat layers, expected after the land

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use change has occurred. The predicted HSI for the area is determined by comparing the number and the areas of the habitat layers assumed to be present after the change with the standard denominator for the area. The impacts of land use change can be predicted for various future dates if the successional pattern of vegetative change is known or can be assumed for an area. The layers of habitat present at future points in time is extrapolated from information about the vegetative cover that is expected to be present at different stages of vegetative succession.

SOURCES OF OTHER MODELS

Anderson et al. (1978) developed a model that associated bird populations with the structure of riparian vegetation in the lower reaches of the Colorado River in southwestern Arizona. Horizontal and vertical foliage diversity and the presence of particular plant species influenced the number of bird species present and the abundance of birds in riparian habitats. The model was developed as a planning tool for use in revegetating riparian habitats to favor the wildlife community. No other models were located in the literature that utilized the structure of vegetation to evaluate habitat quality in west-central and southwestern Arizona.

The wildlife guild model and the layers of habitat model are based on the association of species with the structure of cover types. The life form concept of Thomas (1979) and the California Wildlife Habitat Relationships Program (Salwasser et al. 1980; Verner and Boss 1980) also associated species with the structure of habitats and were developed to evaluate impacts of land-use and habitat change on the wildlife community (Olson 1984). Only the wildlife guild and layers of habitat models, however, have been incorporated into the HSI assessment process to predict baseline and future assessments of habitat conditions for wildlife.

REFERENCES

Anderson, B. W., R. D. Ohmart, and J. Disano. 1978. Revegetating the riparian floodplain for wildlife. Pages 318-331 in R. R. Johnson and J. F. McCormick, tech. coord. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. Proc. Symp. Dec. 11-13, 1978, Callaway Gardens, GA. U.S. For. Serv. Gen. Tech. Rep. WO-12. 410 pp.

Bailey, R. G. 1978. Description of the ecoregions of the United States. U.S. For. Serv., Intermountain Reg., Ogden, UT. 77 pp.

Geibert, E. H. 1979. Songbird diversity along a powerline right-of-way in an urbanizing Rhode Island environment. Trans. Northeastern Sect. Wildl. Soc. 36:32-44.

Heatwole, H. 1982. A review of structuring in herpetofaunal assemblages. Pages 1-19 in N. J. Scott, Jr., ed. Herpetological communities. U.S. Fish Wildl. Serv. Wildl. Res. Rep. 13. 239 pp.

Karr, J. R. 1971. Structure of avian communities in selected Panama and Illinois habitats. Ecol. Monogr. 41(3):207-233.

MacArthur, R. H., and J. W. MacArthur. 1961. On bird species diversity. Ecology 42(3):594-598.

MacArthur, R., H. Recher, and M. Cody. 1966. On the relation between habitat selection and species diversity. Am. Nat. 100(913):310-332.

Martin, N. D. 1960. An analysis of bird populations in relation to forest succession in Algonquin Provincial Park, Ontario. Ecology 41(1):126-140.

Maser, C., B. R. Mate, J. F. Franklin, and C. T. Dyrness. 1981. Natural history of Oregon coast mammals. U.S. For. Serv. Gen. Tech. Rep. PNW-133. 496 pp.

Olson, T. E. 1984. The utilization of community ecology in habitat and land-use evaluation procedures. Draft report prepared by Colo. Coop. Wildl. Res. Unit for U.S. Fish Wildl. Serv., Western Energy and Land Use Team. 109 pp.

Pflieger, W. L. 1975. The fishes of Missouri. Missouri Dept. Conserv., Jefferson City. 343 pp.

Rabenold, K. N. 1978. Foraging strategies, diversity, and seasonality in bird communities of Appalachian spruce-fir forests. Ecol. Monogr. 48(4):396-424.

Salwasser, H., J. C. Capp, H. Black, and J. F. Hurley. 1980. The California wildlife habitat relationships program: an overview. Pages 369-378 in R. M. DeGraaf, tech. coord. Management of western forests and grasslands for nongame birds. U.S. Dept. Agric., For. Serv., Gen. Tech. Rep. INT-86. 535 pp.

Short, H. L. 1983. Wildlife guilds in Arizona desert habitats. U.S. Bur. Land Manage. Tech. Note 362. 258 pp.

Short, H. L., and K. P. Burnham. 1982. Technique for structuring wildlife guilds to evaluate impacts on wildlife communities. U.S. Fish Wildl. Serv. Spec. Sci. Rep. - Wildl. 244. 34 pp.

Thomas, J. W. (ed.) 1979. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. U.S. For. Serv., Agric. Handb. 533. 512 pp.

U.S. Fish and Wildlife Service. 1980. Habitat Evaluation Procedures (HEP). ESM 102. U.S. Fish Wildl. Serv., Div. Ecol. Serv. n.p.

Verner, J., and A. S. Boss, tech. coord. 1980. California wildlife and their habitats: western Sierra Nevada. U.S. For. Serv., Gen. Tech. Rep. PSW-37. 439 pp.

APPENDIX

This section provides background information about how wildlife guilds were formed for the Arizona study area and the relationship between wildlife guilds and layers of habitat. This information is important but not essential for the application of either the habitat layers model or the wildlife guild model if wildife guilds have already been developed for an ecoregion. It is essential information if wildlife guilds have not previously been developed for an ecoregion where the wildlife guild model will be applied.

Field studies that demonstrate, for the Sonoran Desert, the association between avian guilds and cover types with different numbers of layers of habitat are described in Short (1983). Those studies describe the capability of layers of habitat to predict avian guilds present in southwestern cover types.

THE RELATIONSHIP BETWEEN COVER TYPE AND THE VEGETATION STRUCTURE PROVIDED FOR WILDLIFE

A variety of cover types occurred in the Hualapai-Aquarius Planning Units, including the chaparral, cottonwood (Populus spp.)-willow (Salix spp.) riparian, creosote bush (Larrea tridentata)-white bursage (Ambrosia dumosa), desert grassland, juniper (Juniperus spp.)-mixed shrubs, joshua tree (Yucca brevifolia)-creosote bush, lentic, mixed riparian scrub, mesquite (Prosopis spp.)-saltcedar or tamarisk (Tamarix chinensis) riparian, pinyon (Pinus edulis)-juniper, saguaro (Cereus giganteus)-palo verde (Cercidium microphyllum), mixed broad-leaf riparian, ponderosa pine (Pinus ponderosa), and ponderosa pine-mixed conifer associations. These cover types contain different layers of habitat (Fig. A-1) in which wildlife species can live. Wildlife guilds and species vary between cover types because vegetation structure varies between cover types. For example, the desert grassland type provides only terrestrial subsurface and terrestrial surface layers of habitat. Creosote bush-white bursage, chaparral, joshua tree-creosote bush, juniper-mixed shrub; and mixed riparian scrub cover types provide subsurface, terrestrial surface, and midstory layers of habitat. Pinyon-juniper and saguaro-palo verde habitats may provide an additional "tree-bole" layer of habitat. Areas of riparian habitat with mature trees can provide still more layers of habitat, including tree canopy and water surface layers. Cover types are considered in terms of the number of habitat layers they provide for wildlife species.

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Cover Types

Ponderosa pine-mixed conifers
Ponderosa pine

Lentic

Mixed broad-leaf riparian
Cottonwood-willow
Mesquite-tamarisk

Pinyon-juniper
Saguaro-palo verde

Juniper-mixed shrub
Creosote bush
Chaparral
Joshua tree-creosote
Mixed riparian scrub

Desert
grassland

Habitat Layers

Tree canopy

"Tree bole"

Shrub or midstory

Terrestrial surface

Terrestrial subsurface

Water surface

Water column

Figure A-1. Cover types within the Sonoran Desert and the habitat layers they provide for wildlife.

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ASSOCIATING WILDLIFE SPECIES WITH THE STRUCTURE OF HABITATS

The wildlife species that occur in the different cover types within the Sonoran Desert were identified (for example, as in Table A-1). Each of these wildlife species was positioned within the species-habitat matrix (Fig. 2) developed for that cover type by determining the layer(s) of habitat required for feeding and the layer(s) of habitat required for reproduction.

The intersection of lines demarcating habitat layers on the x- and y-axes of the species-habitat matrix in Figure 2 forms "guild blocks". The use of different cover types by wildlife species can be considered in terms of these guild blocks. For example, the cover types present in the Hualapai-Aquarius planning units provide six different types of habitat structure for the wildlife community. These six structural configurations are represented by the six species-habitat matrices in Figures A-2 to A-7. Guild blocks marked by an "x" in these figures are those used by wildlife species in each cover type.

There are, for example, a limited number of ways in which wildlife species can use desert grassland habitats (Fig. A-2). A species can breed in a burrow (subsurface layer or stratum) and feed within burrows, on the surface, in the air, or some combination of these alternatives. Likewise, a species can breed on the terrestrial surface and feed in the subsurface layer, on the terrestrial surface, in the air, or some combination of these alternatives. Migrant species that breed elsewhere but use the desert grassland as feeding habitat, at least part of the year, can also feed in the subsurface, on the terrestrial surface, in the air, or some combination of these alternatives. An additional guild block is occupied by Couch's spadefoot toad (Scaphiopus couchi) in some low elevation desert grassland habitats. This toad can be a localized breeder in temporary pools of water following heavy rains during summer and is a secondary consumer on the terrestrial surface.

The 10 guild blocks marked with an "x" in the upper half of the habitat matrix in Figure A-2 represent the guild blocks used by vertebrate wildlife species in desert grassland habitats that provide only a surface layer of vegetative cover. Secondary consumers generally use more guild blocks than do primary consumers because they also utilize a layer of air as a feeding substrate.

Lentic habitats (Fig. A-3) provide an entirely different group of guild blocks for use by wildlife species. The vertebrate species in these habitats include fish that breed and feed within the lake; amphibians that breed in the aquatic system and use surrounding land areas as feeding habitats; and reptilian, avian, and mammalian species that breed elsewhere and feed within or above the aquatic system.

The importance of habitat structure to the wildlife community is illustrated by the number of guild blocks available to wildlife in creosote bush-white bursage habitat (Fig. A-4). Except for the guild block occupied by Couch's spadefoot toad (which breeds in temporary waters and feeds on the terrestrial surface), the guild blocks for this habitat type also characterize the structure of the wildlife community in chaparral, joshua tree-creosote bush, juniper-mixed shrub, and mixed riparian scrub communities in the study

Table A-1. Partial list of wildlife species occurring in some of the different cover types within the Hualapai-Aquarius Planning Units in Ecoregion 3222.

Species	Chaparral	Cottonwood-willow	Creosote bush-white bursage	Desert grass-land	Juniper-mixed shrub	Joshua tree-creosote bush	Lentic
Birds:							
Abert's towhee (Pipilo aberti)	X	X					
Acorn woodpecker (Melanerpes formicivorus)	X	X			X		
American avocet (Recurvirostra americana)							X
American bittern (Botaurus lentiginosus)		X					
American coot (Fulica americana)		X					X
American goldfinch (Carduelis tristis)	X	X		X	X		
American kestrel (Falco sparverius)	X	X	X	X	X	X	
American redstart (Setophaga ruticilla)		X					
American robin (Turdus migratorius)	X	X		X	X		
American wigeon (Anas americana)							X

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Feeding loci		1. Temporary water sources	2. Bottom of water column	3. Water column	4. Water surface	5. Terrestrial subsurface	6. Terrestrial surface	7. Shrub layer	8. Tree bole	9. Tree canopy	10. Breeds elsewhere
Secondary consumers	10. Feeds elsewhere										
	9. Air					X	X				X
	8. Tree canopy										
	7. Tree bole										
	6. Shrub layer										
	5. Terr. surface	X				X	X				X
	4. Terr. subsurface					X	X				X
	3. Water surface										
	2. Water column										
	1. Bottom water column										
Primary consumers	8. Tree canopy										
	7. Tree bole										
	6. Shrub layer										
	5. Terr. surface					X	X				X
	4. Terr. subsurface					X	X				X
	3. Water surface										
	2. Water column										
	1. Bottom water column										

Breeding loci

Figure A-2. Use of guild blocks by wildlife species in desert grassland habitats.

Feeding loci		1. Temporary water sources	2. Bottom of water column	3. Water column	4. Water surface	5. Terrestrial subsurface	6. Terrestrial surface	7. Shrub layer	8. Tree bole	9. Tree canopy	10. Breeds elsewhere
Secondary consumers	10. Feeds elsewhere		X		X						
	9. Air				X						X
	8. Tree canopy										
	7. Tree bole										
	6. Shrub layer										
	5. Terr. surface										
	4. Terr. subsurface										
	3. Water surface		X	X	X						X
	2. Water column		X	X	X						X
	1. Bottom water column		X	X	X						X
Primary consumers	8. Tree canopy										
	7. Tree bole										
	6. Shrub layer										
	5. Terr. surface										
	4. Terr. subsurface										
	3. Water surface		X	X	X						X
	2. Water column		X	X	X						X
	1. Bottom water column		X	X	X						X

Breeding loci

Figure A-3. Use of guild blocks by wildlife species lentic habitats.

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	Feeding loci	1. Temporary water sources	2. Bottom of water column	3. Water column	4. Water surface	5. Terrestrial subsurface	6. Terrestrial surface	7. Shrub layer	8. Tree bole	9. Tree canopy	10. Breeds elsewhere
Secondary consumers	10. Feeds elsewhere										
	9. Air					X	X	X			X
	8. Tree canopy										
	7. Tree bole										
	6. Shrub layer					X	X	X			X
	5. Terr. surface	X				X	X	X			X
	4. Terr. subsurface					X	X				X
	3. Water surface										
	2. Water column										
	1. Bottom water column										
Primary consumers	8. Tree canopy										
	7. Tree bole										
	6. Shrub layer					X	X	X			X
	5. Terr. surface					X	X	X			X
	4. Terr. subsurface					X	X				X
	3. Water surface										
	2. Water column										
	1. Bottom water column										

Breeding loci

Figure A-4. Use of guild blocks by wildlife species in creosote bush-white bursage habitats.

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area. Therefore, the guild blocks describe the similarity in general structure of the wildlife community in these habitats. The wildlife guilds potentially present in these cover types are reasonably similar, because guilds are based on the ways that wildlife species use layers of habitat. Wildlife species are usually more dependent on the structure of habitat than on the specific plant species present. Any action that impacts the same layer of habitat in all of these cover types presumably impacts the same portion of the wildlife community in each type.

The saguaro cactus in saguaro-palo verde or desert-scrub habitats acts as a tree without a canopy because it provides a bole suitable for excavators and cavity users. This plant community, which would otherwise be similar in structure to creosote bush-white bursage habitats, has an additional layer of habitat because of the presence of this giant cactus (Fig. A-5). The structure of this community is not unlike that of many pinyon-juniper woodlands, where there is a tree bole of suitable dimensions for excavators and cavity users and a midstory canopy.

Ponderosa pine habitats in the higher mountain elevations in the study area can provide five layers of habitat (subsurface, surface, shrub or mid-story, tree bole, and tree canopy layers) (Fig. A-6). This habitat matrix is similar to that for ponderosa pine-mixed conifer habitat. Areas of riparian habitats, like mature cottonwood-willow, mesquite-saltcedar, and mixed broad-leaf riparian cover types can potentially provide layers of habitat associated with both aquatic and terrestrial treeland systems. A large number of guild blocks are potentially used by vertebrate wildlife species in the mixed broad-leaf riparian type (Fig. A-7).

FORMATION OF WILDLIFE GUILDS

The process of guild formation sorts out and groups together those species that use the same guild block or the same group of guild blocks. The process thus aggregates those species that have similar broad dependencies on habitat structure.

Guild blocks for a cover type contain lists of wildlife species that have been associated with the layers of habitat in that cover type. This is illustrated in Figure A-8 for six guild blocks in the creosote bush-white bursage habitat in west-central Arizona. The sorting of lists of species into wildlife guilds can be done either manually (a very tedious process) or by using a simple computerized merge-sort routine. The computer analysis is accomplished in the following way. The layers of habitat where breeding and feeding occur are considered as x,y coordinates that identify the appropriate guild blocks in the matrix (for example, in Fig. A-8, the x,y coordinates are 6,5 for the guild block defined as breeds on the terrestrial surface, feeds on the terrestrial surface). The x,y coordinates that identify each of the guild blocks used by a species in a cover type are entered into the computer. The sort-and-merge routine groups species that use the same guild block or series of guild blocks. These groups of species represent wildlife guilds. The two wildlife guilds formed from the lists of species occupying the guild blocks in Figure A-8 are listed in Table A-2. Guilds of both primary and secondary

Feeding loci			1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Secondary consumers	10.	Feeds elsewhere										
	9.	Air					X	X	X	X		X
	8.	Tree canopy										
	7.	Tree bole					X	X	X	X		X
	6.	Shrub layer					X	X	X	X		X
	5.	Terr. surface					X	X	X	X		X
	4.	Terr. subsurface					X	X				
	3.	Water surface										
	2.	Water column										
	1.	Bottom water column										
Primary consumers	8.	Tree canopy										
	7.	Tree bole					X	X	X	X		X
	6.	Shrub layer					X	X	X	X		X
	5.	Terr. surface					X	X	X	X		X
	4.	Terr. subsurface					X	X				
	3.	Water surface										
	2.	Water column										
	1.	Bottom water column										

Breeding loci:
1. Temporary water sources
2. Bottom of water column
3. Water column
4. Water surface
5. Terrestrial subsurface
6. Terrestrial surface
7. Shrub layer
8. Tree bole
9. Tree canopy
10. Breeds elsewhere

Figure A-5. Use of guild blocks by wildlife species in saguaro-palo verde habitats.

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Feeding loci			1. Temporary water sources	2. Bottom of water column	3. Water column	4. Water surface	5. Terrestrial subsurface	6. Terrestrial surface	7. Shrub layer	8. Tree bole	9. Tree canopy	10. Breeds elsewhere
Secondary consumers	10.	Feeds elsewhere									X	
	9.	Air					X	X	X	X	X	X
	8.	Tree canopy					X	X	X	X	X	X
	7.	Tree bole					X	X	X	X	X	X
	6.	Shrub layer					X	X	X	X	X	X
	5.	Terr. surface					X	X	X	X	X	·X
	4.	Terr. subsurface					X	X				X
	3.	Water surface										
	2.	Water column										
	1.	Bottom water column										
Primary consumers	8.	Tree canopy					X	X	X	X	X	X
	7.	Tree bole					X	X	X	X	X	X
	6.	Shrub layer					X	X	X	X	X	X
	5.	Terr. surface					X	X	X	X	X	X
	4.	Terr. subsurface					X	X				
	3.	Water surface										
	2.	Water column										
	1.	Bottom water column										

Breeding loci

Figure A-6. Use of guild blocks by wildlife species in ponderosa pine habitats.

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	Feeding loci	1. Temporary water sources	2. Bottom of water column	3. Water column	4. Water surface	5. Terrestrial subsurface	6. Terrestrial surface	7. Shrub layer	8. Tree bole	9. Tree canopy	10. Breeds elsewhere
Secondary consumers	10. Feeds elsewhere					X	X		X	X	
	9. Air					X	X	X	X	X	X
	8. Tree canopy					X	X	X	X	X	X
	7. Tree bole					X	X	X	X	X	X
	6. Shrub layer					X	X	X	X	X	X
	5. Terr. surface			X	X	X	X	X	X	X	X
	4. Terr. subsurface					X	X		X		
	3. Water surface		X	X	X	X	X	X	X	X	X
	2. Water column		X	X	X	X	X	X	X	X	X
	1. Bottom water column		X	X	X	X	X	X	X	X	X
Primary consumers	8. Tree canopy					X	X	X	X	X	X
	7. Tree bole					X	X	X	X	X	X
	6. Shrub layer				X	X	X	X	X	X	X
	5. Terr. surface				X	X	X	X	X	X	X
	4. Terr. subsurface				X	X	X				
	3. Water surface		X	X	X	X	X				X
	2. Water column		X	X	X		X				X
	1. Bottom water column		X	X	X		X				X

Breeding loci

Figure A-7. Use of guild blocks by wildlife species in mixed-leaf riparian habitats.

Layers where feeding occurs

	Terrestrial subsurface (5)	Terrestrial surface (6)	Shrub or mid-story layer (7)
Shrub or midstory layer (6)	Coachwhip Rock wren Canyon wren Banded gecko California king snake Desert spiny lizard	Coachwhip Rock wren Canyon wren Banded gecko California king snake Desert spiny lizard Bendire's thrasher Cactus wren Western harvest mouse Curve-billed thrasher Brown-headed cowbird Mockingbird	Bendire's thrasher Cactus wren Western harvest mouse Curve-billed thrasher Brown-headed cowbird Mockingbird
Terrestrial surface (5)	Coachwhip Rock wren Canyon wren Banded gecko California king snake Desert spiny lizard	Coachwhip Rock wren Canyon wren Banded gecko California king snake Desert spiny lizard Bendire's thrasher Cactus wren Western harvest mouse Curve-billed thrasher Brown-headed cowbird Mockingbird	Bendire's thrasher Cactus wren Western harvest mouse Curve-billed thrasher Brown-headed cowbird Mockingbird

Layers where breeding occurs

Figure A-8. Layers of habitat used for reproductive and foraging activities by 12 secondary consumers in creosote bush-white bursage habitats.

Table A-2. Two guilds of secondary consumers that occur in creosote bush-white bursage habitats. The guilds are formed from lists of wildlife species grouped together in the species-habitat matrix in Fig. A-10.

Guild no.	Guild members	Feeding loci[a]										Breeding loci[a]									
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
11	Coachwhip					5	6									5	6				
	Rock wren					5	6									5	6				
	Canyon wren					5	6									5	6				
	Banded gecko					5	6									5	6				
	California king snake					5	6									5	6				
	Desert spiny lizard					5	6									5	6				
12	Bendire's thrasher					5	6										6	7			
	Cactus wren					5	6										6	7			
	Western harvest mouse					5	6										6	7			
	Curve-billed thrasher					5	6										6	7			
	Brown-headed cowbird					5	6										6	7			
	Mockingbird					5	6										6	7			

[a]Numbers correspond to feeding and breeding loci listed in Figure A-3 and Table A-3.

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consumers are determined for a cover type. Wildlife species with omnivorous food habits are identified as members of appropriate guilds of both primary and of secondary consumers within a cover type. A listing of the species within wildlife guilds of primary consumers for chaparral habitats in the Sonoran Desert is provided in Table A-3. Similar lists of wildlife guilds were formed for primary and secondary consuming vertebrate wildlife species occurring in each of 13 terrestrial and one aquatic cover types that occurred on the Hualapai-Aquarius planning units (Short 1983).

Table A-3. Wildlife guilds of primary consumers in chaparral habitats of west-central Arizona (from Short 1983).

Guild no.	Guild members	Feeding loci[a]										Breeding loci[a]									
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	Black bear				4	5	6									5	6				
	Collared peccary				4	5	6									5	6				
	Deer mouse				4	5	6									5	6				
	Cactus mouse				4	5	6									5	6				
	Coyote				4	5	6									5	6				
2	Striped skunk				4	5										5	6				
	Hog-nosed skunk				4	5										5	6				
3	Botta's pocket gopher				4	5										5					
4	White-throated woodrat					5	6									5	6	7			
5	Bighorn sheep					5	6									5	6				
	Gray fox					5	6									5	6				
	Stephen's woodrat					5	6									5	6				
	Ringtail					5	6									5	6				
	Brush mouse					5	6									5	6				
6	Harris' antelope squirrel					5	6									5					
7	Brown-headed cowbird					5	6										6	7			
	House finch					5	6										6	7			
	Mockingbird					5	6										6	7			
	Cactus wren					5	6										6	7			
	Costa's humming-bird					5	6										6	7			
	Western harvest mouse					5	6										6	7			
	Crissal thrasher					5	6										6	7			
8	Mule deer					5	6										6				
	Rock squirrel					5	6										6				
	Cattle					5	6										6				

Guild no.	Guild members	Feeding loci[a]										Breeding loci[a]									
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
9	Scrub jay					5	6											7			
	Bushtit					5	6											7			
10	Scott's oriole					5	6														10
	American robin					5	6														10
	Lesser goldfinch					5	6														10
	Townsend's solitaire					5	6														10
	Anna's hummingbird					5	6														10
	Lewis' woodpecker					5	6														10
	Blue grosbeak					5	6														10
	Black-chinned hummingbird					5	6														10
	Acorn woodpecker					5	6														10
	Broad-tailed hummingbird					5	6														10
	Cassin's kingbird					5	6														10
	Mountain bluebird					5	6														10
	Rufous hummingbird					5	6														10
	Starling					5	6														10
	Pinon jay					5	6														10
	Calliope hummingbird					5	6														10
	Green-tailed towhee					5	6														10
	Black-headed grosbeak					5	6														10
	American goldfinch					5	6														10
	Common flicker					5	6														10
	Steller's jay					5	6														10
	Ladder-backed woodpecker					5	6														10
	Lazuli bunting					5	6														10
	Yellow-rumped warbler					5	6														10
	Western kingbird					5	6														10
	Swainson's thrush					5	6														10
	Elk					5	6														10
	Hermit thrush					5	6														10

Table A-3. (continued).

Guild no.	Guild members	Feeding loci[a]										Breeding loci[a]									
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
10 (concluded)																					
	White-winged dove					5	6														10
	Western bluebird					5	6														10
11	Desert spiny lizard					5										5	6				
	Canyon mouse					5										5	6				
	Western spotted skunk					5										5	6				
	Cliff chipmunk					5										5	6				
	Arizona woodrat					5										5	6				
12	Southern grasshopper mouse					5										5					
	Ord's kangaroo rat					5										5					
	Northern grasshopper mouse					5										5					
	Desert tortoise					5										5					
13	Mourning dove					5											6	7			
14	Rufous-sided towhee					5											6				
	Eastern cottontail					5											6				
	Black-tailed jack rabbit					5											6				
	Common raven					5											6				
	Rock dove					5											6				
	Gambel's quail					5											6				
	House mouse					5											6				
	Desert cottontail					5											6				
	Rufous-crowned sparrow					5											6				
15	Brown towhee					5												7			
	Black-chinned sparrow					5												7			
	Black-throated sparrow					5												7			

Table A-3. (concluded).

Guild no.	Guild members	Feeding loci[a]										Breeding loci[a]									
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
16	Western meadow- lark					5															10
	Lark sparrow					5															10
	Chipping sparrow					5															10
	Fox sparrow					5															10
	Purple finch					5															10
	Brewer's sparrow					5															10
	Dark-eyed junco					5															10
	White-crowned sparrow					5															10
	Water pipit					5															10
17	Say's phoebe						6									5	6				
18	Verdin						6											7			
19	Hooded oriole						6														10
	Warbling vireo						6														10
	Phainopepla						6														10
	Ruby-crowned kinglet						6														10
	Plain titmouse						6														10
	Ash-throated flycatcher						6														10
	Wied's crested flycatcher						6														10
	Northern oriole						6														10
	Yellow-bellied sapsucker						6														10
	Hermit warbler						6														10

[a]Feeding habitat layer or condition:

1 = Bottom of water column
2 = Water column
3 = Water surface
4 = Terrestrial subsurface
5 = Terrestrial surface
6 = Shrub or midstory layer
7 = Tree bole
8 = Tree canopy
9 = Air
10 = Feeds elsewhere

[b]Breeding habitat layer or condition:

1 = Temporary water sources
2 = Bottom of water column
3 = Water column
4 = Water surface
5 = Terrestrial subsurface
6 = Terrestrial surface
7 = Shrub or midstory layer
8 = Tree bole
9 = Tree canopy
10 = Breeds elsewhere