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Impact of Human Settlement on Forest Composition and Structure

ABSTRACT

Human settlement in the Sierra Nevada has resulted in a decrease in crown canopy cover, a reduction in tree density, and an introduction of exotic tree species. The decrease in proportion of crown canopy cover, about 30%, was found to be fairly uniform in all forest types. Changes in tree density and species richness were more variable among the forest types. The greatest decrease in tree density was observed in the mixed conifer forest (70%), and the greatest increase in species richness was found in the ponderosa pine forest, where average species richness of trees increased from four to thirty-eight species. Human settlement increases the amount of impervious surface as a result of the building of roads and houses. This effect was greatest in the foothill woodland, where an average of 41% of the ground surface was made impervious on lots less than 1 acre. A detailed analysis of land use was conducted along Highway 49 in the foothill woodland vegetation type. This analysis provides insights into landscape-scale changes that have occurred as a result of human settlement. The significance of these changes for fire hazard, forest hydrology, and wildlife habitat are discussed.

INTRODUCTION

Small populations of Native Americans lived in the forests of the Sierra Nevada for at least 6,000 years. The management practices used by these populations relied on a sophisticated understanding of plant ecology and horticulture. These practices maintained a character of forest composition and structure adjacent to settlements that many twentieth-century Californians have come to regard as the natural condition. Ground fires were used in these areas to maintain visibility into adjacent forests for security, to enhance the collection of plant materials for food and fiber, and to reduce fire hazards (Lewis 1973). This use of fire resulted in somewhat lower tree density, reduced crown canopy cover, and the favoring of fire-resistant species such as ponderosa pine. Because of the absence of any written history during this period, one can only speculate on the magnitude of the change in forest characteristics associated with Native American settlement of the Sierra Nevada.

Modern human settlement began in the Sierra Nevada with the California gold rush in 1849. The population of gold seekers entering the mountains required materials for housing and mining activities. Many of the towns and highways in the Sierra Nevada today date from the gold rush period. The initial population of these towns declined as local reserves of gold were depleted, but the rapid growth of California's population following World War II resulted in renewed population growth in the Sierra Nevada. This growth involved the expansion of existing towns, suburban development, and new town development. The impact of modern human development on the Jeffrey pine–dominated forest at the south end of Lake Tahoe was reported in studies by McBride and Jacobs (1979, 1986). Their studies showed a 66% decrease in tree canopy cover, a 51% decrease in tree density, and an increase in the number of tree species from one to six as a result of the development of suburban areas. The even-aged structure of the presettlement forest at South Lake Tahoe was modified into an uneven-aged structure by tree planting and the natural establishment of Jeffrey pines within the urban forest. McBride and Jacobs compared their findings at South Lake

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Tahoe with similarly collected data from Menlo Park, California, where the presettlement vegetation was a mosaic of oak savanna and oak woodland. The comparison showed a similar trend in the effects of human settlement (decreased tree canopy and density, increased species richness) but significant quantitative differences between the two areas. This comparison indicated that the degree of reduction in tree canopy cover and tree density and the increase in species richness associated with human settlement varies between forest types.

The purpose of this study is to quantify changes in tree canopy cover, tree density, and species richness as a result of human settlement in the forests of the Sierra Nevada. Knowledge of the quantitative nature of these changes can be used to project the effects of various development scenarios on fire hazard, forest hydrology, and wildlife habitat quality. The four forest types selected for the study were the foothill woodland, ponderosa pine forest, mixed conifer forest, and red fir–lodgepole pine forest. Three classes of lot sizes (less than 1 acre, 3–5 acres, 10–20 acres) were studied in the foothill woodland, while only one size class (less than 1 acre) was studied in the other vegetation types because of the lack of available maps showing boundaries of larger properties. A detailed analysis of land use was conducted along Highway 49 in the foothill woodland vegetation type in order to better understand the distribution and juxtaposition of land use associated with human settlement.

STUDY AREA

This study was limited to woodlands and forests occurring in portions of Sacramento, El Dorado, Amador, Nevada, and Calaveras Counties. These counties were selected because of the focus on the central Sierra Nevada by other Sierra Nevada Ecosystem Project researchers interested in the impacts of human settlement. The characteristics of the woodlands and forests in these central Sierra Nevada counties are typical of the woodlands and forests farther north and south. The major human settlements studied were El Dorado Hills, Cameron Park, and Shingle Springs (foothill woodland); Camino, Nevada City, and Forest Springs (ponderosa pine forest); Arnold, Dorrington, and Sly Park (mixed conifer forest), and Bear Valley, Kirkwood, and Echo Lake (red fir–lodgepole pine forest).

The foothill woodland in the study area occurs from elevations of 500 ft to 2,500 ft and is dominated by blue oak (Quercus douglasii). Other common tree species include maul oak (Quercus chrysolepis), interior live oak (Quercus wislizenii), and foothill pine (Pinus sabiniana). Much of the foothill woodland has been grazed by cattle and usually supports an understory of annual grasses. On moist sites the understory contains poison oak (Toxicodendron diversiloba), toyon (Heteromeles arbutifolia), and snowberry (Symphoricarpos rivularis). Average annual precipitation in the foothill woodland ranges from 15 in to 25 in. Winters are relatively mild, with temperatures seldom dropping below 25ºF. Summers are very hot, with daytime temperatures often exceeding 105ºF. Summaries of the ecology of the foothill woodland are presented by Griffin (1977), Holland and Keil (1986), Pavlik et al. (1991), Barbour et al. (1993), and Johnston (1994).

The ponderosa pine forest occurs from elevations of about 2,000 ft to 2,500 ft in the central Sierra Nevada. The ponderosa pine forest extended to lower elevations (about 1,500 ft) in portions of the central Sierra Nevada in pre–gold rush times but was largely removed from these lower elevations during the early mining period. The dominant species in this type is ponderosa pine (Pinus ponderosa). California black oak (Quercus kelloggii) is commonly found in the ponderosa pine forest. At higher elevations in the type, incense cedar (Calocedrus decurrens) occurs. Understory shrubs include various species of manzanita (Arctostaphylos spp.) and ceanothus (Ceanothus spp.). Rainfall averages 20 in to 50 in annually. Snow occurs in the winter months, but accumulations seldom exceed 1 foot. Winters are cool, with temperature minimums down to 10–15ºF. The ecology of the ponderosa pine forest has been reported by Rundel et al. (1977) and Holland and Keil (1986).

At elevations of about 2,500 ft, one first encounters the mixed conifer forest type of the central Sierra Nevada. This type extends up to elevations of about 6,000 ft in the central portion of its range. Precipitation averages from 30 in to 60 in, with the bulk falling in the form of snow. Temperatures commonly drop to near or below 0ºF in the winter. Summers are warm, with temperatures often reaching into the 90ºF range. The mixed conifer forest type supports five conifer species: ponderosa pine (Pinus ponderosa), incense cedar (Calocedrus decurrens), white fir (Abies concolor), Douglas fir (Pseudotsuga menziesii), and sugar pine (Pinus lambertiana). California black oak (Quercus kelloggii) is also common. A large variety of shrubs and herbaceous species occur in the understory of less dense stands in the mixed conifer forest. Dense stands support fewer shrubs and herbs. The ecology of the mixed conifer forest has been reviewed by Rundel et al. (1977), Bonnicksen and Stone (1981), Holland and Keil (1986), Barbour et al. (1993), and Johnston (1994).

The red fir–lodgepole pine forest occurs at elevations above 6,000 ft in the central Sierra Nevada. The dominant species of this forest type (red fir [Abies magnifica] and lodgepole pine [Pinus contorta var. murrayana]) extend to elevations above 9,000 ft, but the forest type is generally restricted to elevations of about 8,000 ft. At these high elevations, summers are cool, with day temperatures in the low 70s. Winters are cold, with nighttime temperature readings below zero. Within the red fir–lodgepole forest zone, one encounters pure stands of either species and stands supporting mixtures of both species. Red fir dominates on deeper, more nutrient-rich soils, while lodgepole pine is found on areas either too wet or too dry for red fir. Understory species are few in number. Snow accumulation and dense tree canopy cover inhibits the development of a diverse understory flora. Common shrubs may include huckleberry oak (Quercus vaccinifolia), sticky currant (Ribes viscosissimum), mountain snowberry (Symphoricarpos vacciniodes), and tobacco brush (Ceanothus velutinus). These commonly occur in openings in the forest or at the margins of stands. The ecology of these higher-elevation forests has been reviewed by Oosting and Billings (1943), Rundel et al. (1977), Holland and Keil (1986), Barbour et al. (1993), and Johnston (1994).

METHODS

Three methods were used to sample the characteristics of the woodlands and forests in and adjacent to human settlements in the Sierra Nevada. These included (1) estimation of cover on aerial photographs, (2) measurement of tree density and determination of tree species richness on plots, and (3) point sampling along Highway 49 to determine the frequency and adjacency of different types of land use associated with human settlement.

Cover Estimation on Aerial Photographs

Black-and-white aerial photography (1991, scale 1:35,000), available in the Map Library of the University of California at Berkeley, was used to estimate the percentage of the ground covered by (1) tree canopy, (2) structures, (3) paved surfaces (roads, driveways, sidewalks, patios), and (4) plants other than trees (lawns, shrubs, vegetable gardens, hedges). Dot grids on transparent acetate were dropped at random onto the area of each photograph where cover estimates were needed, and the dots superimposed on each category of cover were counted. The percentage of dots “falling” on each cover category was then calculated. The number of samples taken to estimate cover varied with woodland or forest type because of the frequency of human settlements and the availability of maps showing individual lot boundaries. From three to ten settlements (areas of urban development), referred to as sites, were selected for each lot (individual home owner’s property) size in each vegetation type. For each site, three lots were sampled (table 46.1) with the dot-grid sampling encompassing an area greater than the selected lot. An area of 3 to 5 acres was sampled for lots less than 1 acre (samples ranged from twelve to twenty adjacent lots), 20 acres for lots from 3 to 5 acres (samples ranged from three to four adjacent lots), and 10 to 20 acres for lot sizes of 10 to 20 acres (samples ranged from a single to two adjacent lots).

For the largest lot size class (10 to 20 acres), samples were taken for the entire lot and for the “developed areas” immediately around structures on the lot. For each site, three adjacent control areas were chosen that occurred on a similar aspect and slope and supported a similar woodland or forest type as the developed area. Control areas ranged from 5 to 20 acres in each vegetation type. Cover estimates were made using the dot grid on these control areas.

Measurement of Tree Density and Species Richness

Ten ground plots were located in developed areas with lot size less than 1 acre, and three control plots were located in adjacent control (undeveloped) areas at three sites (three separate human settlements) in each vegetation type. In developed areas, each plot was located at an intersection of two streets. The initial intersection at each site was chosen at random, and subsequent intersections were selected at points on a three-by-three block grid, moving out from the initial intersection. Plots at intersections were used to allow observation of trees in the backyards of lots. It was not possible to accurately observe backyard trees from the street in front of a house. All observations were made without entering private property, with the exception of the control plots and on occasions when the field crew was invited by a home owner to go into a backyard. Some corner lots initially chosen for sampling were rejected when it was not possible to see from the side street into the backyard. Some bias was no doubt involved in only sampling corner lots. These sites may be more open to wind-dispersed seeds, and they may have been planted to provide visual privacy from adjacent streets. No evidence was

TABLE 46.1

Number of sites (human settlements) and samples used in various woodland and forest types to estimate canopy cover.

Type	Less than 1 Acre		1–3 Acres		10–20 Acres	
	Number of Settlements	Number of Samples	Number of Settlements	Number of Samples	Number of Settlements	Number of Samples
Foothill woodland	10	30	10	30	10	30
Ponderosa pine forest	3	9	0	0	0	0
Mixed conifer forest	6	18	0	0	0	0
Red fir–lodgepole pine forest	3	9	0	0	0	0

observed of a bias toward wind-dispersed species on these corner lots, however. Corner lots that were densely planted with screening trees were rejected as sample lots. All trees over 4 in in diameter at breast height occurring on the sampled lots were recorded by species. The dimensions of each lot were determined by pacing the property lines along the two streets. All control plots were circular and 1/10 acre in area. As with the developed lots sampled, all trees over 4 in in diameter at breast height were recorded by species. Tree density was calculated on a per acre basis.

Species richness was calculated by summing the number of tree species in the total sample of developed lots. In this study, species richness is defined as the total number of tree species found in a sample. Species richness for control plots was also calculated by summing the number of species on the three sample plots. Comparison of the species richness on developed lots and control plots is seen as a measure of the effect of human settlement on the diversity of trees.

Point Sampling Along Highway 49

A point sample was taken every mile along Highway 49 from Sonora to Grass Valley, California. This procedure was designed to provide more information on the character of land use and vegetation within the foothill woodland type. This concentration of sampling was deemed necessary because of the potential for development in this vegetation type. At each point the land use adjacent to the highway on each side was recorded, and notes were made concerning the condition of the vegetation associated with each type of land use. In all, 116 points were sampled, giving 116 paired samples of land use for the area between the two towns. The data was summarized by calculating the relative frequency of occurrence of each land-use type and the relative frequency of pairing of any two land-use types.

RESULTS AND DISCUSSION

Tree Canopy Cover, Density, and Species Richness

Tree canopy cover and tree density were reduced by human settlement in all four vegetation types, while species richness was increased. Changes in cover associated with human settlement are summarized in table 46.2. Figure 46.1 compares the tree canopy cover on developed and control plots in each of the four vegetation types for lots less than 1 acre.

The differences in tree canopy cover between developed and control plots in all lot size classes were significant at the 0.01% level (ANOVA [analysis of variance]; F-test). No significant difference was found in the percentage of reduction in crown canopy cover among the four vegetation types. The percentage of the surface covered by impervious materials (structures, roads, sidewalks) was significantly greater in the less-than-1-acre lot size class in foothill woodlands (41%) than in the larger lot size classes (7.5%). No significant difference in impervious surface cover occurred between the 3-to-5 and the 10-to-20-acre lot size classes. The category "other" refers to ground covered by plants other than trees. The area covered by "other" was not significantly different among the lot sizes or vegetation types. The character of this vegetation was, however, different when developed areas were compared with control sites and when developed areas in different vegetation types were compared. In the less-than-1-acre lot size class, the "other" cover consisted primarily of irrigated lawn in the foothill woodland and ponderosa pine forest, while the control sites in these vegetation types were primarily annual grassland. In the mixed conifer and red fir–lodgepole pine types, the "other" cover was primarily native shrubs or montane meadows, for both developed and control sites. Little evidence was seen of lawn installation and irrigation in the developed areas of this higher-elevation zone.

Tree density was decreased by human settlement in all four vegetation types, as shown in table 46.3 and figure 46.2. Average tree density on developed sites versus control sites was significantly different in all vegetation types except the ponderosa pine forest (ANOVA; F-test; 0.01%).

Species richness increased as a result of human settlement in all vegetation types on less-than-1-acre lots. Species rich-

TABLE 46.2

Percentage cover on developed and nondeveloped property associated with human settlement.

	Percentage Cover			
Property	Tree	Other	Structure[a]	Road
Foothill Woodland				
Less than 1 acre				
Developed	43	16	25	16
Control	69	31	0	0
3-5 acres				
Developed	70	22	3	5
Control	90	10	0	0
10-20 acres				
Structures[a]	48	41	7	4
Lot[b]	56	37	4	3
Control	74	24	0	0
Ponderosa Pine				
Less than 1 acre				
Developed	62	9	13	16
Control	90	10	0	0
Mixed Conifer				
Less than 1 acre				
Developed	64	11	9	16
Control	92	8	0	0
Red Fir–Lodgepole Pine				
Less than 1 acre				
Developed	59	22	6	13
Control	79	21	0	0

[a]Area immediately around structures (houses, farm buildings, sheds, etc.).
[b]Portion of property not adjacent to structures.

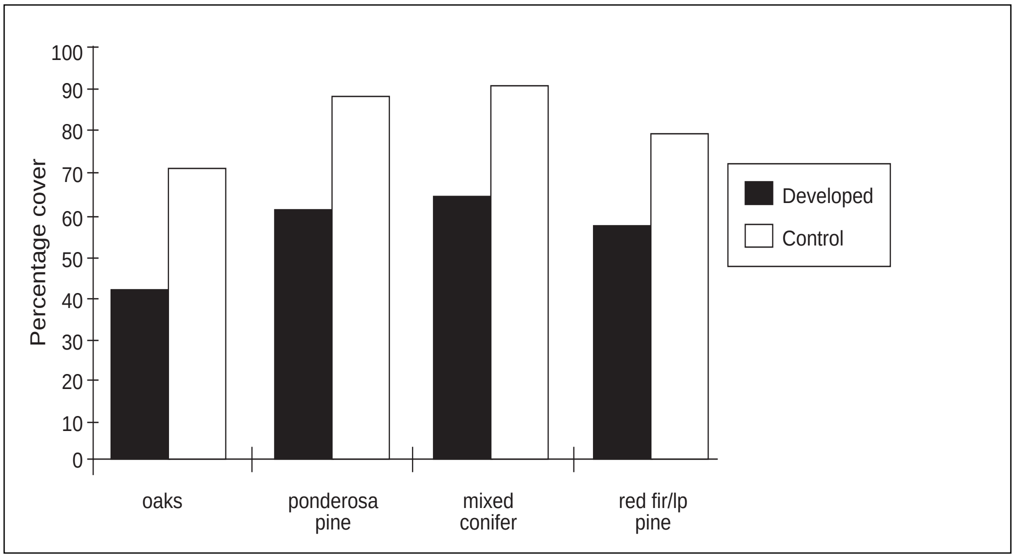


FIGURE 46.1

Forest canopy cover on developed and control sites in the less-than-1-acre lot size class.

ness is summarized in table 46.4 and figure 46.3. The increase in species richness was statistically significant (ANOVA; F-test; 0.01%) in developed areas in the foothill woodland and ponderosa pine forest but not in the mixed conifer and red fir–lodgepole pine forests. A large number of exotic tree species contributed to the increase in species richness in the foothill woodland and ponderosa pine forest. The increase in species richness in the red fir–lodgepole pine forest was due entirely to the planting of native species.

The changes in cover, tree density, and species richness observed in this study are similar in direction to those reported by McBride and Jacobs (1979, 1986) for areas of human settlement in Jeffrey pine forests in the Lake Tahoe Basin. Construction of structures, roads, and other infrastructure elements in forests often necessitates the removal of trees and results in reduction of canopy cover and tree density. Trees may also be removed to facilitate access to sunlight, especially in more densely wooded areas. Conversion of tree cover to lawn also contributes to the decrease in tree canopy cover and density. The increase in species richness in developed areas is primarily due to tree planting by home owners. Some of the increase in species richness may be due to the invasion of exotics. The greater number of exotic tree species observed in developed areas in the foothill woodland and ponderosa pine forest may be related to the more moderate winter temperatures, use of lawn irrigation around structures, and the year-round nature of residency in communities in these lower-elevation zones. Moderate winter temperatures allow a greater number of species to be used without fear of frost damage; lawn irrigation provides summer moisture to many exotic tree species that could not be established or survive without supplemental water; year-round residency encourages the planting of trees and other gardening activities. Year-round residents in the Lake Tahoe area studied by McBride and Jacobs (1986) indicated that they had time for and interest in gardening. Seasonal residents who were using their homes in the mountains for recreational activities, often for short stays in midsummer and winter, did not wish to devote time to gardening. Lots in the higher-elevation forests are typically steeper than lots in the lower-elevation forest types. These steeper lots tend to be less maintained and stay in something closer to a "wild state," which accounts in part for the lower species richness. In addition, nursery supplies of trees are more limited in species variety in the high-elevation zones compared with the lower-elevation zone. Tree establishment in human settlements in the higher-elevation forest often involved transplanting or invasion of native trees from adjacent or nearby forests.

The decrease in crown canopy cover in developed areas has implications for fire hazard, hydrology, and wildlife habitat value. Most fire models involve canopy cover as a measure of vegetation associated with increased fire hazard (Andrews and Burgan 1985). These models predict an increase

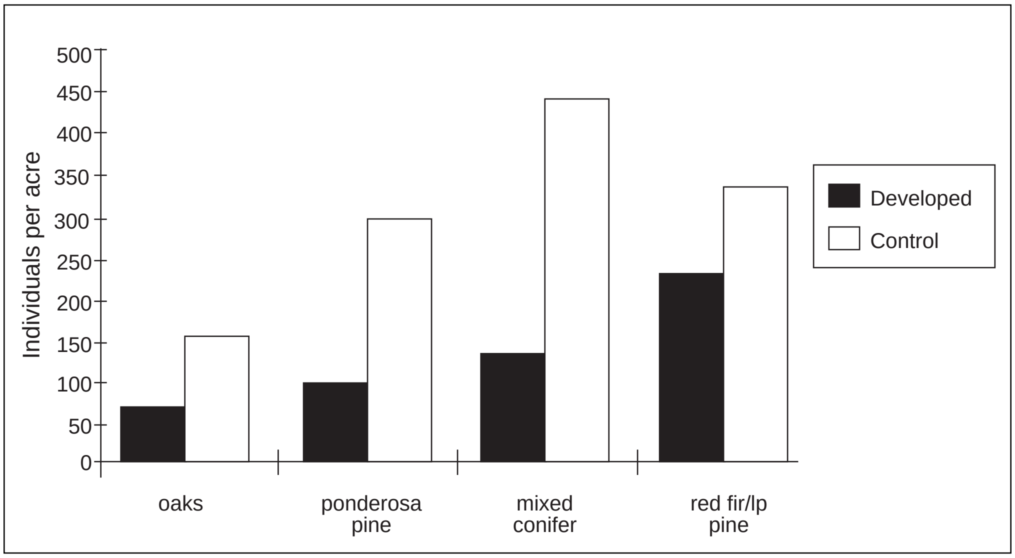
TABLE 46.3

Tree density on less-than-1-acre lots and control plots.

Type of Plot	Trees per Acre
Foothill Woodland	
Developed	78
Control	156
Ponderosa Pine	
Developed	100
Control	278
Mixed Conifer	
Developed	134
Control	454
Red Fir–Ponderosa Pine	
Developed	234
Control	361

FIGURE 46.2

Tree density on less-than-1-acre lots and control plots.



in fire hazard with increasing crown canopy cover. The fragmentation that is occurring in the forest canopy of the Sierra Nevada as a result of human settlement could lead to a reduction in fire hazard, however, if development extended over sizable areas. This reduction is augmented in the lower-elevation woodland and forest types by the maintenance of higher fuel-moisture levels in trees due to lawn irrigation. Fuel ladders are often eliminated as a result of development. Large, woody ground fuels have also disappeared following development. These changes in the quantity and structure of natural fuels must be balanced against the overall change in the fire hazard of a landscape when structures and people become a part of the fuel/ignition complex. It should be noted that, along with the changes in the reduction of fire hazard, the increased human population increases fire risk associated with arson and accidental fires.

The change in cover from native forest to human settlement has important ramifications for the hydrology of the woodlands and forests of the Sierra Nevada. This change will affect the runoff of precipitation from the landscape. Values of the rational runoff coefficient for impervious surfaces in urban areas are on the order of 0.70 to 0.95, while woodlands and forests have coefficients of 0.30 to 0.40 (American Society of Civil Engineers 1969; Rantz 1971). The reduction in tree canopy cover influences the runoff coefficients by reducing the interception of rainfall. The increase in impervious surface found on less-than-1-acre lots decreases the infiltration of precipitation and contributes to greater and more rapid runoff, thus higher runoff coefficients. Lawn irrigation also contributes to greater quantities of runoff from developed areas by maintaining a higher level of soil moisture storage.

TABLE 46.4

Species richness on less-than-1-acre lots and control plots.

Type of Plot	Native	Exotic	Total
Foothill Woodland			
Developed	5	24	29
Control	3	0	3
Ponderosa Pine			
Developed	8	32	40
Control	4	0	4
Mixed Conifer			
Developed	6	3	9
Control	5	0	5
Red Fir–Lodgepole Pine			
Developed	4	0	4
Control	2	0	2

The changes in canopy cover, tree density, and species richness associated with development will mean a change in the characteristics of the food and cover available to wildlife species. Studies of the effects of urbanization on wildlife have generally shown a shift in the species using an area following development (Noyes and Porgulske 1973; Adams and Dove 1989; Mills et al. 1989). In general, wildlife species diversity declines along gradients of increasing urbanization, while the population density of some well-adapted urban species increases. A significant factor in this relationship is the proximity of the developed area to undeveloped woodlands and forests.

Pattern of Land Use in the Foothill Woodland Along Highway 49

Thirty-two vegetation and land-use types were observed in the survey of land use along Highway 49. Of these, twenty-nine were tallied at the point samples taken every mile along the 116-mile survey from Sonora to Grass Valley. The three additional types were observed along the highway but did

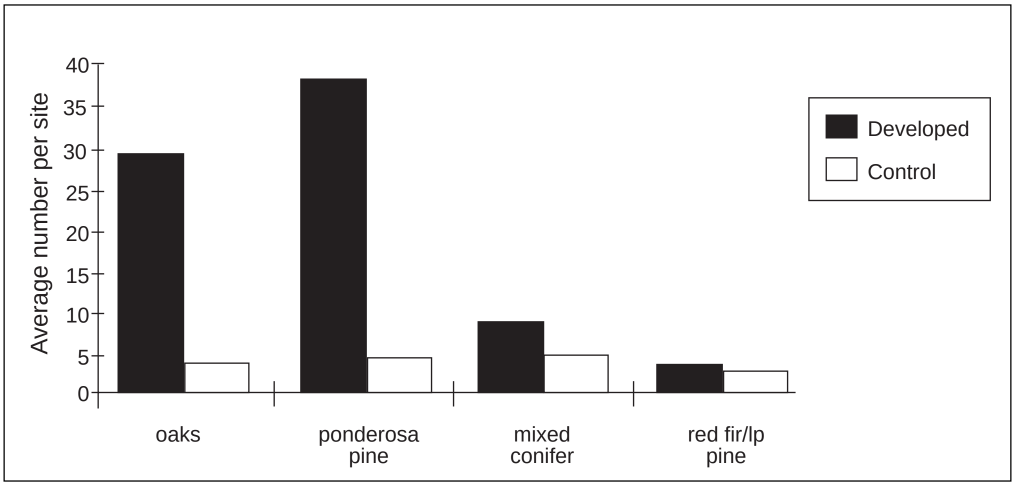


FIGURE 46.3

Species richness on less-than-1-acre lots and control plots.

not occur at any of the 116 sample points. These vegetation and land-use types are listed in table 46.5 with their relative frequency of occurrence. The relative frequency of natural vegetation types along Highway 49 was 59.2%. Agriculture, rural residential, urban, and other land uses had frequencies of 11.6%, 15.9%, 10.7%, and 2.5%, respectively. The five most frequently encountered types were blue oak woodland (11.2%), pasture (10.3%), residential (1–3-acre lot, 9.9%), blue oak–foothill pine (9.5%), and urban (commercial, 9.0%). This method has probably overestimated the relative frequency of urban (commercial) development on the landscape because this land use is situated along roads for the purpose of commerce; while other land uses are to be found along roads, they do not need to be adjacent to a road or highway. Similarly, urban (quarter-acre lot), trailer park, and residential (less-than-1-acre lot) land uses are probably overrepresented in the sample.

With a total of thirty-two vegetation and land-use types, there would be 512 possible pairs. At the 116 sample points along Highway 49, only 70 of the 512 potential pairs were recorded (at each sample point the "pair" consisted of the two types, one on each side of the road). The small number of pairs recorded compared with the 512 potential pairs is due to the lack of randomness in the distribution of vegetation and land-use types, the difference in the relative frequency of occurrence of each type, and the compatibility of different land uses. The majority of the vegetation and land-use pairs were encountered only one time in the 116-point sample. The most frequently encountered pairs were

- urban commercial:urban commercial, 6.8% of the 188 pairs
- blue oak savanna:pasture, 5.1%
- black oak–ponderosa pine forest:black oak–ponderosa pine forest, 4.2%

TABLE 46.5

Relative frequencies of vegetation and land-use types along Highway 49.

Type	Relative Frequency (%)
Natural Vegetation	**59.2**
Blue oak savanna	11.2
Blue oak–foothill pine woodland	10.6
Blue oak woodland	6.9
Black oak–ponderosa pine woodland	6.5
Riparian woodland	5.1
Maul oak–foothill pine woodland	4.3
Maul oak woodland	3.9
Grassland	3.4
Valley oak savanna	2.1
Maul oak savanna	1.7
Foothill pine–chaparral	0.9
Maul oak–ponderosa pine woodland	0.9
Ponderosa pine forest	0.9
Foothill pine woodland	0.4
Mixed broadleaf forest	0.4
Agriculture	**11.6**
Pasture	10.3
Orchard	0.9
Vineyard	0.4
Christmas tree farm[a]	0.0
Hay field[a]	0.0
Rural Residential	**15.9**
Residential (1–3-acre lots)	9.9
Residential (1-acre lots)	4.3
Trailer park	1.7
Urban	**10.7**
Commercial	9.0
Residential (quarter-acre lots)	1.3
Institutional property (school, fire station, etc.)	0.4
Industrial[a]	0.0
Other	**2.5**
State park	0.9
Mine	0.4
Reservoir	0.4
Himalayan blackberry (erosion-control planting)	0.4
Scotch broom (invasion on disturbed land)	0.4

[a]Land-use types observed along Highway 49 that did not occur at sample points.

- blue oak–foothill pine:rural residential (1–5-acre lot), 3.4%
- Pasture:residential, 3.4%.

These frequencies may be put into some perspective by comparing them to the probability of occurrence of any possible pair at any point, assuming random distribution and equal frequency of occurrence of each type. That random probability is 0.19%.

The purpose of the Highway 49 survey was to provide information to other SNEP investigators who were interested in the relationship between human settlement and wildlife habitat in the foothill woodland type. The thirty-two types observed along Highway 49 can be combined into fewer categories for the purpose of habitat evaluation. Table 46.6 presents combinations of the thirty-two types that are considered to have similar structural characteristics and, therefore, may be considered similar wildlife habitats. This table reduces the thirty-two vegetation and land-use types to fourteen habitat types, many of which are habitats recognized in the California Wildlife Habitat Relationship Program (Mayer and Laudenslayer 1988). The relative frequency of these habitat types is shown in table 46.7. The habitat types with the highest relative frequencies were blue oak woodland (28.8%), annual grassland (14.3%), blue oak–foothill pine (13.7%), rural residential (13.4%), and urban (11.5%). The fourteen habitat types could potentially be combined into 105 pairs. Only 33 of these potential pairs occurred at the sampling points along Highway 49. The number of these pairs tallied at the sampling points, and their relative frequencies are shown in table 46.8. Knowledge of the frequency of pairing between various land-use types and vegetation types may provide some insights into the character of future wildlife habitats in the foothill woodland. For example, pairing of rural residential development with blue oak woodland would produce a landscape that would support a different mosaic of habitats than the pairing of rural residential with annual grassland.

Table 46.9 conveys a sense of the fragmentation of the natural cover as a result of human settlement along Highway 49. Of the 116 pairs of land use sampled, 46% could be categorized as natural cover, suggesting slightly less than one-half of the area of natural vegetation along the highway has suffered fragmentation (excluding the fragmentation caused directly by the highway). The other 54% of the pairs were combinations of natural cover and land uses resulting from human settlement. Just under 16% of the pairs were the result of juxtaposition of natural cover and rural development for housing. The other major source of fragmentation was agriculture. Urban development accounted for almost 13% of the 116 pairs of samples along Highway 49. This direct loss of wildlife habitat, combined with habitat fragmentation along a major state route through the foothill woodland vegetation type, may be representative of the potential impact of human settlement patterns along new highways through the foothill woodland type. The impacts of human settlements along highways through other forest types in the Sierra Nevada are not

TABLE 46.6

Wildlife habitats and vegetation and land-use types along Highway 49.

Wildlife Habitat	Vegetation or Land-Use Type
Blue oak woodland[a]	Blue oak woodland
	Blue oak savanna
	Maul oak woodland
	Maul oak savanna
	Regenerating blue oak woodland
Blue oak–foothill pine[a]	Blue oak–foothill pine woodland
	Blue oak–foothill pine woodland (recently burned)
	Black oak–foothill pine woodland
	Foothill pine woodland
	Maul oak–foothill pine woodland
	State historic park
Montane hardwood[a]	Mixed broadleaf forest
Valley oak woodland[a]	Valley oak savanna
Valley foothill riparian[a]	Riparian woodland
Ponderosa pine[a]	Ponderosa pine forest
	Ponderosa pine forest (recently burned)
	Maul oak–ponderosa pine woodland
	Black oak–ponderosa pine woodland
Mixed chaparral[a]	Foothill pine–chaparral
	Himalayan blackberry erosion-control planting
	Scotch broom scrub
	Christmas tree farm
Annual grassland[a]	Grassland
	Pasture
	Hayfield
Urban[a]	Industrial
	Urban residential (quarter-acre lot)
	Urban commercial
	Trailer park
	Institutional property
Rural residential	Rural residential (less-than-1-acre lot)
	Rural residential (1–3-acre lot)
Orchard	Orchard
Vineyard	Vineyard
Mine	Mine
Reservoir	Reservoir

[a]California Wildlife Habitat Relationship Program type.

TABLE 46.7

Relative frequency of wildlife habitat types along Highway 49.

Habitat Type	Relative Frequency (%)
Blue oak woodland	28.8
Blue oak–foothill pine	13.7
Montane hardwood	0.4
Valley oak woodland	0.9
Valley foothill riparian	3.4
Ponderosa pine	9.7
Mixed chaparral	1.7
Annual grassland	14.3
Urban	11.5
Rural residential	13.4
Orchard	0.9
Vineyard	0.4
Mine	0.4
Reservoir	0.4

expected to be similar to that along Highway 49 because of the limited use of land for agricultural purposes in other forest types. In addition, the common siting of highways along ridges at higher elevations in the Sierra Nevada may tend to concentrate development along the highway corridor because of slope limitations. Analyses of development patterns along highways in other Sierra Nevada forest types would be appropriate to better understand their patterns of human settlement in relation to highways.

FUTURE RESEARCH DIRECTION

Additional data are needed to round out our understanding of the changes in forest conditions on larger-sized lots in the ponderosa pine, mixed conifer, and red fir–lodgepole pine forests. In order to obtain these data, it would be necessary to have access to maps showing private property boundaries (lot boundaries) in these forest types. It would also be valuable to extend data collection into both the northern and the southern Sierra Nevada and to the east-side vegetation and land-use types. If the technique used along Highway 49 has provided useful data to the wildlife experts associated with the SNEP project, this technique could be applied to other forest types in the Sierra Nevada.

TABLE 46.8

Relative frequencies of habitat pairs along Highway 49.

Habitat Pair	Relative Frequency (%)
Blue oak woodland:blue oak–foothill pine woodland	11.9
Blue oak woodland:annual grassland	10.2
Blue oak woodland:blue oak woodland	9.3
Urban:urban	9.3
Ponderosa pine forest:ponderosa pine forest	5.1
Rural residential:blue oak woodland	5.1
Annual grassland:annual grassland	4.2
Rural residential:annual grassland	4.2
Blue oak woodland:ponderosa pine forest	3.4
Rural residential:blue oak–foothill pine woodland	3.4
Blue oak woodland:valley foothill riparian woodland	2.5
Rural residential:ponderosa pine forest	2.5
Rural residential:rural residential	2.5
Blue oak–foothill pine woodland:valley foothill riparian woodland	2.5
Urban:rural residential	2.5
Blue oak–foothill pine woodland:blue oak–foothill pine woodland	1.7
Blue oak–foothill pine woodland:annual grassland	1.7
Valley oak woodland:valley foothill riparian woodland	1.7
Rural residential:valley foothill riparian woodland	1.7
Orchard:annual grassland	1.7
Blue oak–foothill pine woodland:ponderosa pine forest	0.8
Valley oak woodland:valley oak woodland	0.8
Valley foothill riparian woodland:ponderosa pine forest	0.8
Ponderosa pine forest:mixed chaparral	0.8
Ponderosa pine forest:annual grassland	0.8
Mixed chaparral:mixed chaparral	0.8
Mixed chaparral:annual grassland	0.8
Urban:blue oak woodland	0.8
Vineyard:blue oak–foothill pine woodland	0.8
Mine:valley foothill riparian woodland	0.8
Reservoir:blue oak woodland	0.8
Reservoir:blue oak–foothill pine woodland	0.8

TABLE 46.9

Relative frequencies of land-use pairs along Highway 49.

Land-Use Pair	Relative Frequency (%)
Natural cover:natural cover (e.g., blue oak woodland:blue oak woodland)	46.0
Natural cover:rural development (e.g., blue oak woodland:rural residential)	15.7
Urban:urban (e.g., commercial:urban residential)	12.6
Natural cover:agriculture (e.g., blue oak woodland:pasture)	12.4
Agriculture:agriculture (e.g., pasture:orchard)	4.2
Agriculture:rural development (e.g., pasture:rural residential)	4.2
Natural cover:other (e.g., blue oak woodland:reservoir)	2.4
Rural development:rural development (e.g., rural residential:trailer park)	1.7
Other:other (e.g., mine:reservoir)	0.8

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