Parcel size, Land Use Ownership and Forest Structure: Part I of a Pilot Study Investigating Drivers of Redwood Forest Change in Four Redwood Reserves and Matrices in Mendocino County, California: A Report to Save-the-Redwoods League

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Parcel size, land use ownership and forest structure:
Part I of a pilot study investigating drivers of redwood forest change in four redwood reserves and matrices in Mendocino County, California

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Report Abstract—
The objective of the pilot study was to examine the relationships between land use, ownership, and change in coastal redwood structure over time while establishing appropriate methods for expanded long-term change analysis. The pilot study focused on four old-growth redwood reserves and their mixed land-use matrices: Jughandle State Reserve, Montgomery Woods State Reserve, Mailliard Redwoods State Park, and Hendy Woods. Each reserve represents a range of forest structures, including old-growth as well as varying land use, unique to the matrix surrounding each reserve. A five-kilometer buffer was placed around each forest reserve to analyze the forest structure with various land use practices in and around the reserve. The time periods of the assessment were 1949 to 1998 for vegetation change and 1960 to 2002 for land use and ownership change. The unit of analysis was the individual parcel, because it is the individual owner who makes land use decisions. The results of this study indicate that, currently, there is no trend in the relationship between parcel-size and conservation of forest structure. Further, traditional, rural, land uses are not associated any more than rural-residential land uses with conservation or production of potential late-seral forest structure. Parcels with agricultural land uses, ranging from farming to grazing, had the least amount of forest structure recovery and the greatest amount of old-growth loss between 1949 and 1998. Most parcels with rural-residential land uses were established later than agricultural land uses, beginning in the 1970's and 1980's. This is the same time period in which massive-scale industrial timber owners were buying up former timber company lands and small timber holder lands. The only land use type or owner to show conservation of old-growth was the California State Parks and Reserves system. Most of the acreage in this class was preserved by the Save-the-Redwoods League.

Introduction

The critical need to study land use and socio-economic factors in human-shaped ecosystems has only recently been acknowledged by conservation biologists and ecosystem scientists (McDonnell and Pickett 1990; McDonnell and Pickett 1993; Pickett and McDonnell 1993; Riebsame, Gosnell et al. 1996; Vitousek, Mooney et al. 1997; Pickett, Cadenasso et al. 2001; Heise and Merenlender 2002; Groffman, Bain et al. 2003). In the past decade, paralleling the development of landscape ecology, an abundance of studies has emerged linking human systems with "natural" systems for use in natural resources management, land use planning, and reserve design (for a comprehensive range of issues and approaches, see Liu and Taylor 2002). The combined results of these studies demonstrate a wide and contradictory range of significant ecosystem responses to land use, ownership, and socio-economic factors. These results suggest that human effects cannot be generalized from one case study to another. In addition, three problems limit the usefulness of most projects attempting to determine the effects of land use and socio-economic variables on landscape pattern and forest structure: 1) they have been conducted at spatial scales too coarse to link specific variables to actual effects (e.g., Turner, Flamm et al. 1993; Flamm, Gottfried et al. 1994; Theobald, Gosnell et al. 1996; Turner, Wear et al. 1996; Wear, Turner et al. 1996; Wear and Bolstad 1998; Pearson, Turner et al. 1999; e.g., Turner, Pearson et al. 2003); 2) they have relied upon over-generalized land use types (e.g., Flamm, Gottfried et al. 1994; Tietje, Myers et al. 1994; Turner, Wear et al. 1996; Foster, Motzkin et al. 1998; e.g., Brown, Pijanowski et al. 2000); or 3) they have substituted a proxy variable for actual land use (e.g., Pan, Domon et al. 2001; e.g., Hansen and Rotella 2002).

Another factor missing from the conservation literature was the cultural values, or attitudes, of landowners. Our recent research tracing the effects of exurban migration in Sierran forestlands showed that attitudes of individual landowners towards conservation and land-use regulation led to a wide range of land use practices and were a greater determinant of forest change than tools currently used for conservation planning and gap analysis, including land-use designation and parcel size (Marvin 2003; Walker, Marvin et al. 2003). Understanding the dynamics between landowner attitudes and land use choices within matrices and their effects on reserves would provide a missing element in current methods of planning conservation strategies for new and existing reserves.

Finally, projections of landscape and habitat change in many conservation projects rely upon relationships between current land use and landscape structure (e.g., Tietje, Myers et al. 1994; Stewart 1997; e.g., Greenwood 1997a). However, our research in the Sierra illustrated that "space-for-time substitution" produced erroneous assumptions about the relationship between current land use and forest condition. Specifically, we found that the strongest predictor of differences in current relative forest cover was historical forest cover(Marvin 2003). Furthermore, for parcels larger than 2.5 acres, parcel size was unrelated to forest cover.

With the increasing use of geographic information systems (GIS) and availability of digital planning and natural environment data, it is becoming easier for conservation planners to visualize and plan conservation goals at landscape scales. In a very short time, conservation planning has grown from a small number of groups with the staffing and monetary resources to produce thorough, McHargian analyses of the landscape to thousands of public agencies and non-profits enjoying the ease of, virtually instantaneously, correlating multiple environmental factors with any number of important conservation indices. The benefit of digital data to conservation planning is especially apparent in the availability of assessor's parcel data and comprehensive, detailed vegetation cover data derived from satellite imagery. These data sets serve two important functions: 1) conservation goals concerned with protecting land that has not yet been, or is in imminent danger of being, developed can be mapped for any given landscape; further, alternatives to development can be mapped to gain public support for conservation; and 2) parcel and vegetation layers can be intersected to produce correlation data and analyze the effects of parcel size on vegetation cover. The availability of digital data has dramatically increased the number of these "natural" experiments (Marvin 2003).

Natural experiments can provide valuable insights into relationships between variables, pointing to ideas promising further study. As with any "natural" experiment (as opposed to a controlled experiment), the dependent and independent variables cannot be controlled. This lack of control can lead to acceptance of false correlations. Natural experiments using GIS technology and digital data can exacerbate the potential for false correlations for three reasons. First, due to the abundance of digitally derived variables and the ease of analysis with GIS, one or more correlations will be "statistically significant" by chance alone. Second, multi-factor data sets give the impression of being comprehensive, when in fact they may be missing the most significant factor because it is not available digitally (this problem is frequent in ecological studies carried out by GIS scientists rather than ecologists). Multiple-regression analyses including all *available* data sets frequently produce algorithms that appear to "explain" great percentages of the variability in a dependent variable and give high explanatory power to individual factors in the analysis. Thorough studies test the regression results on independent data sets. However, if this step is prohibitively expensive it is left out, as is the case when the dependent variable (e.g. biodiversity) was collected with intensive field methods. The third consequence of the increased availability of a limited number of environmental factors for analyses is the same as for any correlation: if a strong correlation is found, is it certain which variable is the dependent variable or if there is true "causation" between the variables?

These questions and sources of potential error are particularly relevant to determining the effects of human settlement on natural systems. In the past five years, the availabilities of digital parcel boundaries and extensive vegetation data sets derived from satellite imagery have made it possible to correlate parcel size and habitat structure. Parcel-size is believed by many to be an appropriate surrogate for most aspects of development. The smaller the parcel size, the greater the percentage of ground area compacted, the greater the human population, and the greater the removal of habitat structure (i.e. native, late-seral vegetation cover). The corollary to this is that habitat structure improves as parcel size improves. Reasonable evidence for these cause-effect relationships between parcel size and habitat structure is simple observation of urban and suburban settlement. But what about parcel sizes that are well outside of "suburban sprawl" sizes? Due to zoning regulations, rural-residential parcels typically vary in size from 5- to 40-acres. However, there is a great degree of variability, with large amounts of areas taken up in rural-residential parcels over 40-acres. And there is even greater variability in what individual owners do with the land and vegetation on these large parcels(Walker, Marvin et al. 2003). Even with this great variability in parcel-size and land use, many conservation scientists and planners equate "rural-residential" parcels with "suburban sprawl." Within this mind-set, parcels with traditional land uses, such as grazing, farming, and timber harvest, are assumed to be better for conservation of habitat than any new, residential-oriented land use.

The evidence supporting the relationship between "rural-residential" sized parcels and impacts on habitat structure comes from correlation studies. In forested regions, the general trend of these studies is correlation between large parcels and timber operating or holding land uses and lots of trees on one end and small parcels, residential land use, and less tree cover on the other end. However, most of these studies include suburban-sized parcels, which make the correlation stronger. Removing parcels smaller than 3-5 acres frequently obscures the correlation. There are two common problems with most correlation studies of parcel-size, generalized land use type (i.e. categories of land use, not specific land use activities), and habitat structure (e.g. vegetation cover). First, the authors assume that land use and parcel-size are the causation variables (or surrogate causation variables) and vegetation cover is the dependent variable. It is rarely considered that vegetation condition may determine land use and parcel size (i.e. timber interests own large parcels with lots of trees, because they buy large amounts of trees to harvest). Second, in the same vein, the authors of these studies assume that current vegetation condition was caused by current land use and parcel size. These problems stem from the availability and ease of analysis of digital data. Good, digital vegetation layers make analyses accessible to researchers with low funding and resources (such as the author of this study), but these data layers do not encompass a time-series of sufficient length to monitor change in habitat structure from land use. This problem is amplified when the history of the landscape is ignored. This is especially important in regions settled and harvested within the past 150 years, such as the western U.S., because forest structure is still in the process of recovering from previous decimations. The "land use legacy" variable is rarely explicitly incorporated in models.

Pilot study objectives

"Conservation of old-growth redwood requires maintaining and restoring relatively large areas of very old trees," (Noss 2000). In fact, as noted by Morrison (1988, *as cited in* (Noss 2000)), "Old-growth stands less than 80 acres in size are not viewed as viable old-growth units because external influences can easily penetrate and because they are vulnerable to disturbances." If old-growth species conservation requires very old trees and stands greater than 80 acres, and the data indicates that 96 percent of the original, old-growth redwood forest have disappeared, then preservation of coastal redwood species must take a broader approach than simply defining and conserving the old-growth. This is especially true in Mendocino County, where old-growth stands were decimated at a scale greater than in Humboldt County to the north.

While restoration -- or even how to create old-growth redwood structure -- is in its infancy stage, studies by Muldavin et al. (1981, *as cited in* (Noss 2000)) have attempted to predict long-term, second-growth stand dynamics, suggesting methods for accelerating development of old-growth structure and composition. With this study in mind, and the fact only 4% or less of Mendocino County's old-growth forest remains, the focus of this study was placed on determining under what circumstances historical land use, current land use, and current ownership size aid or deter the persistence of old-growth stands and regeneration of mature, redwood-dominant forest with the greatest potential to attain late-seral characteristics.

This report documents the relationships between parcel size, land use type, ownership, and forest structure in four protected redwood reserves and surrounding matrices. It is the first of three parts of a pilot study designed to determine the best methods for an expanded study of land use effects on reserves and matrices across California. Part I examines the relationship between parcel size and land use type, common factors used in conservation planning, and change in forest cover and size, which, combined with historical data, were used to estimate seral-stages. Part II will document the findings on patch fragmentation by roads and land use activities on individual parcels. Part III will document all results at an aggregated scale and compare the usefulness of parcel size and land use type between scales.

Summary of methods

1) Recreation of land use history of Mendocino County reserves and matrices.

The basis of the longitudinal study was the discovery of ownership and land use type records collected on index cards for individual parcels by prior scientists in 1948, 1956, and 1967. The ownership records were compiled into Excel spreadsheets and linked to the 2002 Assessor's Parcel GIS layer where geographic locations could be established. The method consisted linking the 1948 and 1956 data to the 1967 data by owner name and ownership ID's created in the original study. Assessor's parcel numbers in the 1967 database were then matched to the 2002 Assessor's Parcel GIS. Most parcel numbers had changed between 1967 and 2002. These holes in the data set were reduced by intensive methods including scanning and individually evaluating parcel change on historical assessor's maps at the Assessor's Office. An additional data layer consisted of a circa 1960's, hand-colored industrial timber ownership and old-growth map received from the U.C. Extension in Ukiah.

2) Recreation of historical landscape and forest structure of Mendocino County reserves and matrices.

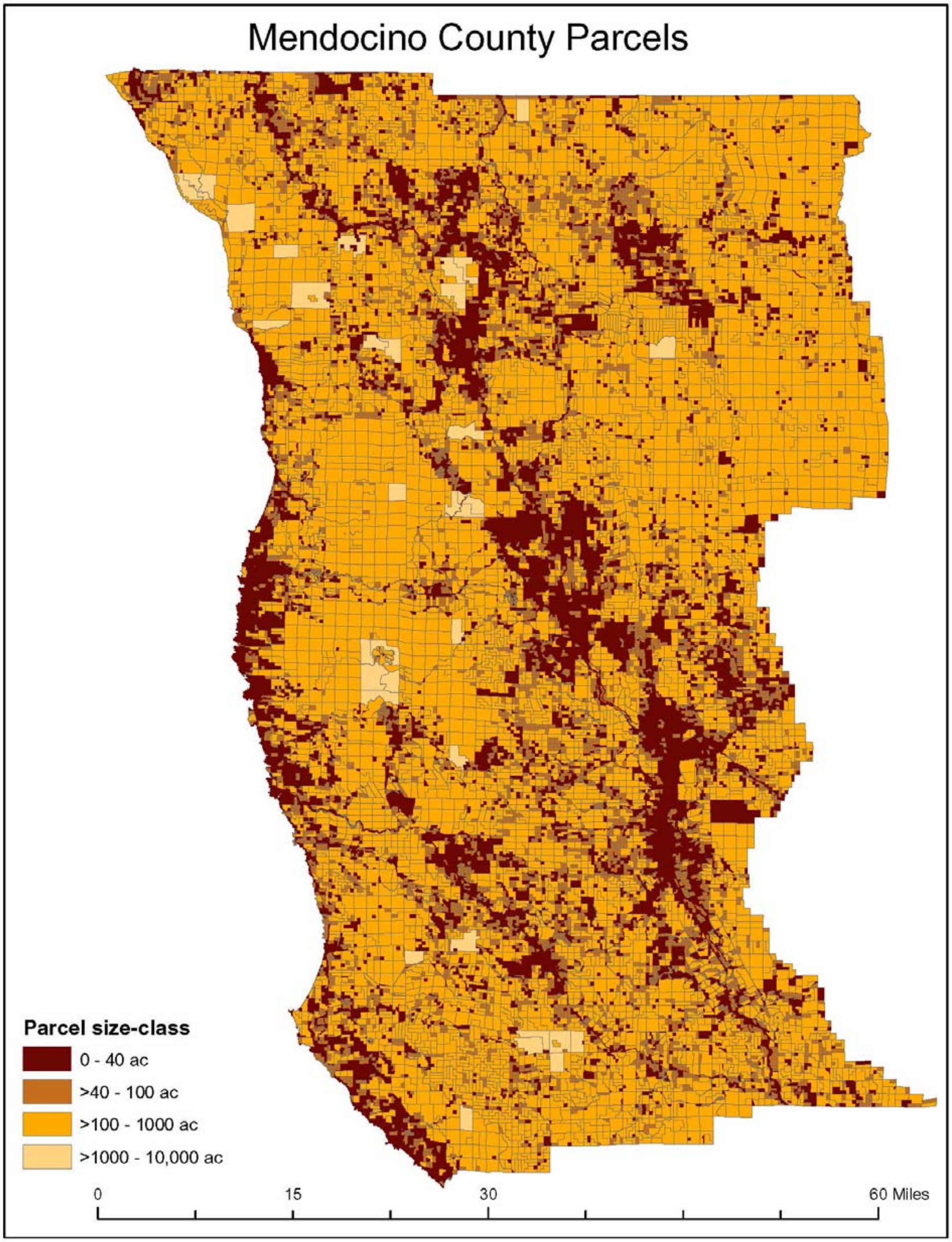
The oldest historical forest structure data set was the "Timber Stand and Vegetation Elements" maps (1:31,680) based on interpretation of 1948 - 1952 aerial photographs (Various 1949). These maps were scanned, digitized, and aligned to resurveyed, 7.5", quadrangle maps. FRAP's vegetation layer (Calveg98), derived from 1998 Landsat TM imagery, was used as the most recent forest structure data. Both the 1949 and 1998 vegetation layers contained detailed information on forest composition, canopy cover, and average stem size. Analyses were also conducted using Fox's 1986 old-growth mapping data set (available through FRAP). However, the scale of the non-old-growth forest type mapping in 1986 proved to be inconsistent with the 1949 and 1998 data sets and produced misleading results.

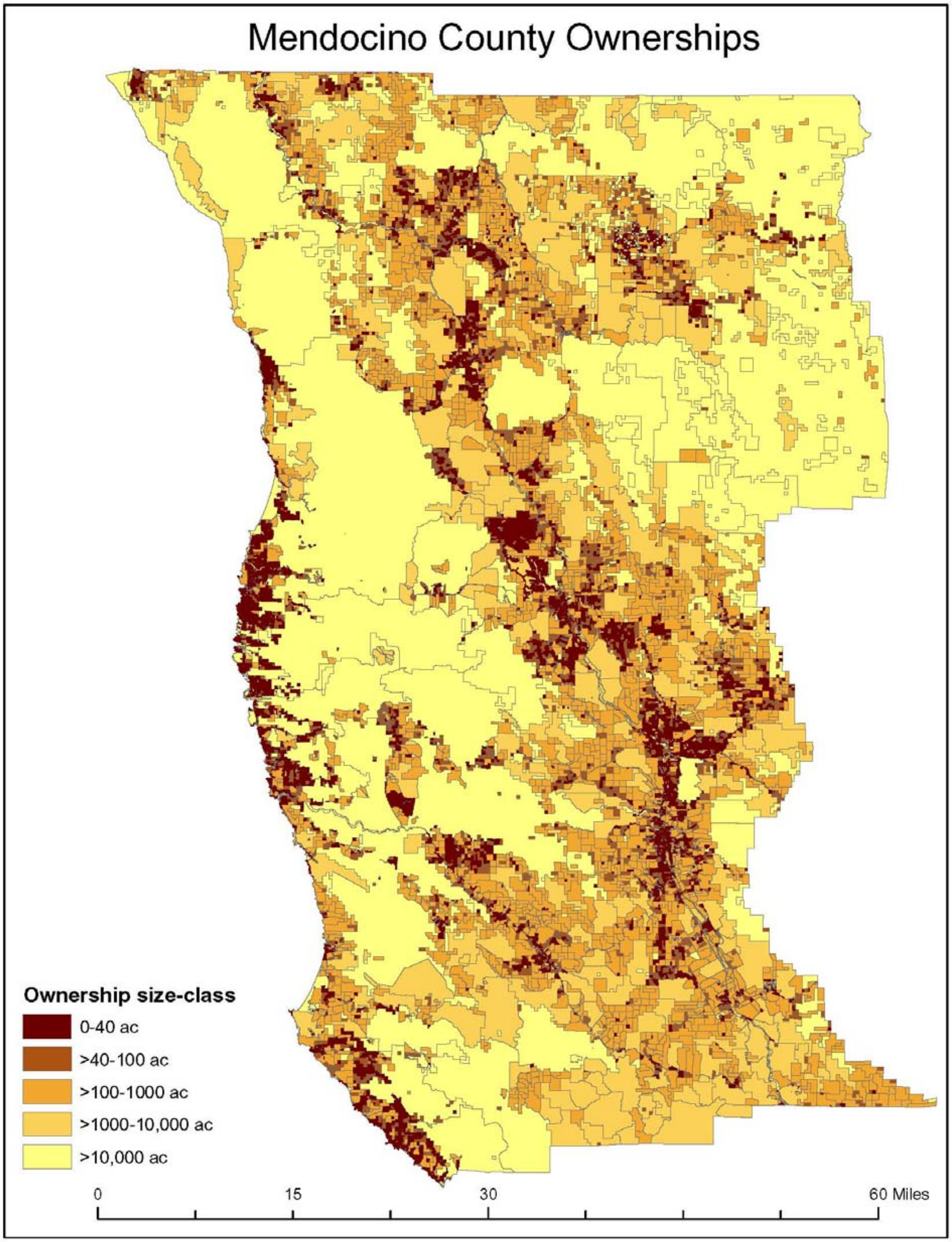
The data sets for each year used different methods for classifying cover. As a result of differing classifications, an in-depth look at the criteria used in the study and the creation of a new classification system that would incorporate the data from the varying sets over the years was necessary. Additional historical maps were used to assess the accuracy of the determination of remaining "old-growth" classified from size and canopy structure in the 1998 Calveg data set. Three maps, from 1921, 1932, and 1945, illustrated the timing, locations, and severity of logging entries into Mendocino County's redwood region.

Roads and patch fragmentation information were interpreted from time-series of aerial photographs from 1978, 1988, and 1998. In addition, 1998 digital orthophotoquads were used to correct for positional and interpretive inaccuracies of the satellite-based vegetation data for use at the individual parcel scale. Although additional aerial photograph series were available for each decade from 1952 to 1996, the County Assessor's Office would not allow duplication in any manner due to copyright laws.

3) Data analyses

All data sets were combined in a GIS using ArcGIS 9. Intersected data were exported to Microsoft Excel for graphical and simple statistical comparisons. Statistical significance testing will be conducted in subsequent steps.


Mendocino County Parcels
Parcel size-class
0 - 40 ac
>40 - 100 ac
>100 - 1000 ac
>1000 - 10,000 ac
0
15
30
60 Miles



Mendocino County Ownerships
Ownership size-class
0-40 ac
>40-100 ac
>100-1000 ac
>1000-10,000 ac
>10,000 ac
0
15
30
60 Miles

SECTION I: SNAPSHOT IN TIME: TRENDS IN AND RELATIONSHIPS BETWEEN CURRENT LAND USE, OWNERSHIP SIZE, AND VEGETATION

Purpose and distribution of parcel and ownership size-classes

Mendocino County land is composed of multiple ownerships and land use types. Currently, the most common method of assessing land use impacts on vegetation cover on private lands is through the use of land ownership plats, or "Assessor's Parcel Maps." Assessor's parcel boundaries must be distinguished from land ownership boundaries when discussing the relationship between "parcel size" and vegetation change or forest condition. Assessor's parcels represent the legal boundaries of land for tax and policy purposes. Conversely, "ownership" boundaries represent the sum area of parcels under a single ownership. Hence, ownership boundaries are a more accurate representation of the "management" landscape. How much do these distinctions matter? If large ownerships consist of primarily large parcels and small ownerships of small parcels, then the distinction is fairly unimportant. However, if one is attempting to assign basic "land fragmentation" or "land disturbance" intensities by parcel size when a single landowner owns 40 acres in four, 10 acre parcels, the categorization of potential impact goes awry.

The maps of parcels and ownerships across Mendocino County (Figures 1 and 2) illustrate the composition of legal parcels and ownership boundaries, respectively, across Mendocino County. The maps are displayed in size-classes as follows: "4" = 0.1 to 4.75 ac., "5"= >4.75 to 9.75 ac., "10" = >9.75 to 17.5 ac., "20" = >17.5 to 37.5 ac., "40" = >37.5 to 77.5 ac., "80" = >77.5 to 155 ac., "160" = >155 to 310 ac., "320" = >310 to 620 ac., "640" = 620-1000 ac., and "1000" = >1000 ac.

The four study sites in Mendocino County cover a total of 77,196 acres. These study sites consist of four protected, primarily old-growth, redwood groves and the surrounding matrix within 5 km radius. The sites were selected to represent four distinct cases of possible land use mixes in the matrices. The data for the four study areas shows that 81% consists of parcels within the largest 5 categories, or parcels greater than 77.5 acres. Ownership class is dominated by these same 5 categories with 93% of the area. A majority (67%) of the total is contained solely in the ownership class owning 1000 acres or more. Parcels of 20 acres or less make up only 7% of the total by parcel size and 5% of owner class totals.

Smaller parcels are mostly concentrated in the valley and coastal regions. These parcels tend to be clustered together with larger parcels in between the clusters. This pattern indicates that individual owners subdivide their large holdings while their neighbors remain in traditional, large-lot land use activities. As with small parcels, the smaller ownership classes tend to be along the coastal areas and in the valley. As with parcel size, the smaller ownership classes tend to be clustered together. Not surprisingly, the largest ownership size classes tend to be correlated with the larger parcel size areas. However, many small parcels are also tied up in these large ownerships.

The relationships between current parcel/ownership size and land use. Can parcel size predict land use?

Parcel size can only be used as a surrogate for land use and management activities if land management strongly correlates with parcel size. While the extremely small legal parcels are limited in use, an individual landowner's total ownership can include multiple parcels in land uses commonly exclusive to larger parcel size. Larger assessor's parcels are dedicated primarily to land uses that require large areas, e.g. timber and ranching, and are located where demand for smaller management units is less realized. As larger parcels are subdivided the land use is altered to fit the new owners' purposes. This transition to consideration of ownership class instead of parcel size reflects a more accurate image of current land use.

What is not accurately reflected in current parcel or ownership size is historical land use. The disparity is caused by the biologic implications in removing late-seral vegetation just before changing the land use on a parcel. Where most privately held old-growth currently exists on timber operating and timber holding lands, it can be observed that the vast majority of these lands have, at one time, been cut-over. Since the sites that have never been classified as timber sites were probably lacking trees when the originally recognized use was recorded, modern land use cannot be used as an indicator of current or past vegetation type. Larger timber parcels that were converted to non-timber land uses would leave those land uses with a false appearance of being detrimental to mature forest persistence or regeneration. In order to accurately assess the effects of current non-timber land use types, especially rural-residential land use, on vegetation, it is necessary to determine how vegetation has changed since the changes caused by timber use on large parcels and large ownership classes. The errors associated with this type of cause-and-effect are the reason this study was conducted. The relationships between current parcel size, historical land use, and changes in forest structure are the focus of this study.

Consideration of the processes of land use change and how those changes affect vegetation cover may provide insight as to how current land use may or may not reflect current vegetation type, and therefore the usefulness of correlations between current land use and current vegetation as a model to predict vegetation change in the future is dubious. Here the historical vegetation types must be considered to establish when and to what extreme a particular land use change affected vegetation change. Since some changes in vegetation types will mandate a recovery period exceeding the period of time between the land use change and identifying of the vegetation type associated with said land use.

SECTION II: CHANGE OVER TIME

FOREST STATUS: PROGRESSION OF LOGGING

The encroachment of logging and agricultural activity into redwood stands of southern Mendocino County can be seen in the series of maps titled "Forest Status" (Figures 3, 4, 5, and 6) Significant disturbance from logging and agriculture began in the middle of the 19th century. By 1921, about half of the redwood forests of southern Mendocino had been entered (Figure 3). The greatest boon in logging occurred following the 1906 earthquake to rebuild San Francisco. Mendocino County was the nearest redwood region to San Francisco with significant amounts of large timber.

Forests along the coast were the first to be entered and were the most significantly disturbed by severe harvest practices, including broadcast burning. On the tail of logging and construction of mills, dairies, ranches, and residential development sprang up along the coast. In 1921, there were nine mill towns established along the southern Mendocino coast. These early communities became the locations of Mendocino's most popular recreation resorts resulting in intensive coastal development.

By 1945, over half of the land designated "cut-over" in 1921 had regenerated young growth stands (Figure 4). Due to the Depression and a reduction in labor caused by WWII, lumber production did not increase during the period 1921 to 1945. Therefore, roughly half of the original old-growth stands remained. The period from 1945 to 1959 saw unprecedented rates of logging. By the mid-1960's, old-growth in southern Mendocino County had been reduced to small stands, preserved primarily through the efforts of the Save-the-Redwoods League, and a few, sparsely distributed, large stands on industrial timber land owned by Masonite, Union, and Mailliard Ranch. By 1986, all of the large stands had been broken up (Figure 5). About 4% of Mendocino County's original old-growth stands remained. At the same time, all of the area surrounding the Jughandle study site designated "cut-over" in 1921 had regenerated to medium sized second-growth (12-24 in dbh). The remaining cut-over area at the far southern end remained small regeneration (i.e. 7-11 in dbh).

This series of maps helped to interpret the vegetation data for 1998 created from Landsat imagery by the California Department of Forestry and Fire Protection (CDF; Figure 6). The 1998 data makes no distinction between old-growth and very large second-growth. Therefore, the historical maps helped to estimate the probability that a given large-stemmed, multi-storied redwood stand was old-growth or second-growth.

LAND OWNERSHIP CHANGES: 1960 – 2002

All sites combined
When all the data for all the study sites are combined we found that in 1960 just over 54% of the land-use consisted of either timber operating companies or timber holding companies whereas in 2002 these up for nearly 60 In 1960 there was almost no rural residential in the any of the study sites and as of 2002 it 4% which is about a 100-fold change. Range livestock was

exclusively individually owned in 1960 and in 2002 it decreased from 15% to about 4%, however a new category of company owned range livestock springs up at nearly 7%.

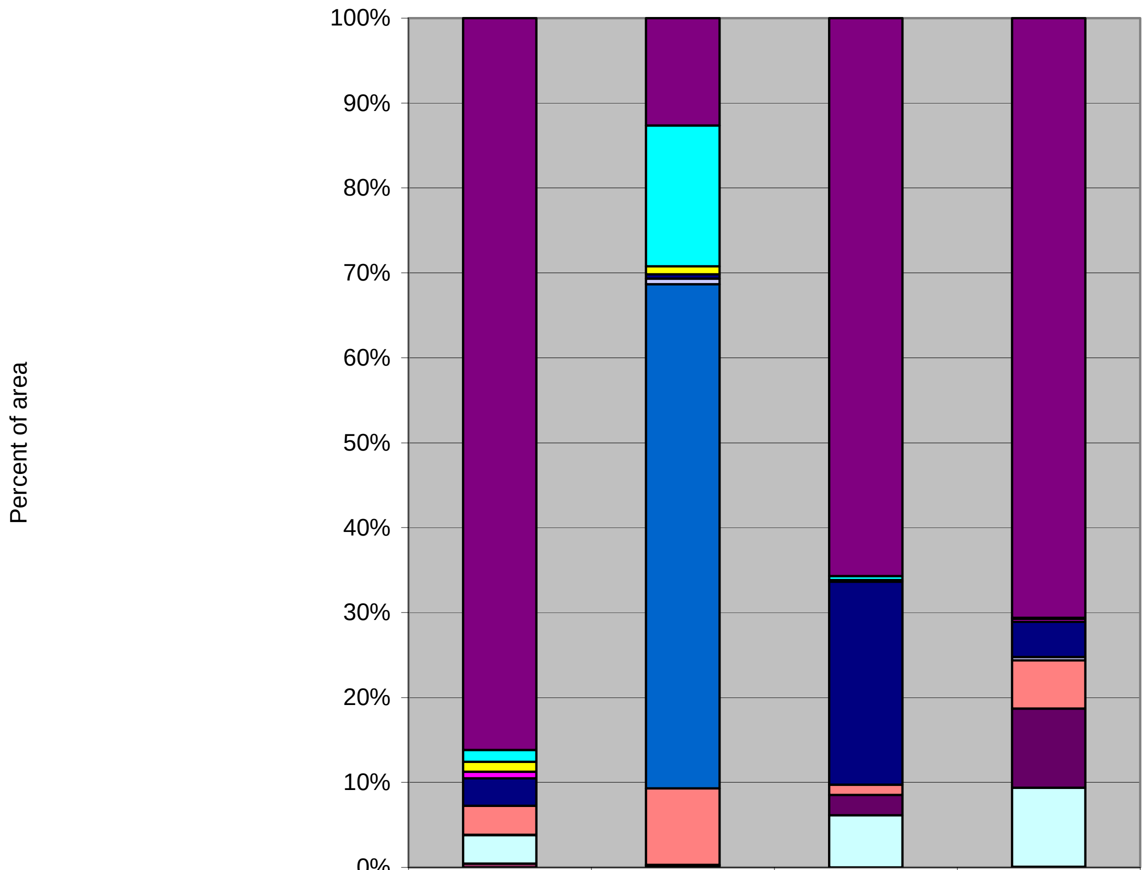
By study area

In 1960 the dominant land use in Hendy and Montgomery was land use labeled Timber Operating (1) making up in excess of 70% of land use in each area. By 2002 this figure had fallen to 30% and 45% respectively. Over the same time span Mailliard saw a decrease in Timber Operating lands from 20% to none. Jughandle also had a decrease from 30% to 5%.

Inverse to this trend is the increase of land designated as Timber Holding Company (2). Mailliard had the most significant increase from 5% to 70%. Hendy saw a rise from 10% to 45% while Montgomery's rate was of similar magnitude. (30%) Jughandle had no land recognized as Timber Holding Company in 1960 and only 1% in 2002.

Timber Holding Individual class land use (4) Showed a pointed decrease in one area and slight increases in all the others. In Mailliard, where Timber Holding Company showed the greatest increase, the Timber Holding Individual class had a most dramatic reduction. In 1960 40% of land use was dedicated to private wood lots. This land use goes to 0 in 2002. Jughandle and Montgomery together showed an increase to 5% from 0. Hendy also had 0 to start with and increased to 10%.

Jughandle is the only one with Jackson State Forest on it. About 17% of Jughandle has been converted to rural residential. Hendy only has 1% change in rural residential and Mailliard and Montgomery have nearly none. Jughandle converted more timber to rural residential (16%) than timber to no change (12%). Land use in the Mailliard study area transitioned from timber to rangeland and agriculture than to any other land-use change 24% that is 300% more than the other three sites combined. However, the primary ownership in this study area is the "Mailliard Ranch", which was classified as "livestock grazing" in 1948 and "timber holding individual" in 1957.



	Hendy	Jughandle	Mailliard	Montgomery
Timber, no change	86.18%	12.63%	65.70%	70.60%
Timber to Rural Residential	1.39%	16.58%	0.46%	0.04%
Timber to RMR undeveloped	1.19%	0.94%	0.21%	0.08%
Timber to RMR speculator	0.78%	0.00%	0.00%	0.35%
Timber to Rangeland & Agriculture	3.23%	0.50%	23.88%	4.15%
Timber to Other public	0.00%	0.68%	0.00%	0.41%
Timber to Jackson State Forest	0.00%	59.36%	0.00%	0.00%
State of California, no change	3.39%	8.99%	1.21%	5.66%
Rangeland & Agriculture, no change	0.05%	0.00%	2.39%	9.34%
Rangeland & Agriculture to Timber	3.37%	0.00%	6.14%	9.30%
Rangeland & Agriculture to Other	0.00%	0.00%	0.00%	0.05%
Other to State of CA	0.43%	0.05%	0.00%	0.00%
Other to Rural Residential	0.00%	0.25%	0.00%	0.00%

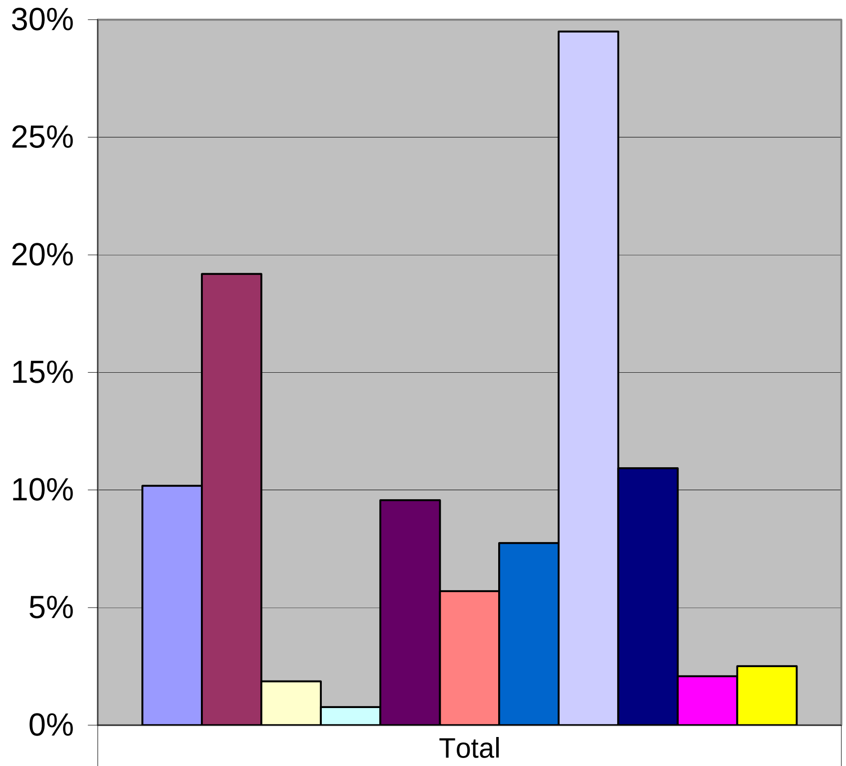
Figure 7. Change in land use from 1960 to 2002 by study site.

DISTRIBUTION OF FOREST COVER TYPES: 1949 and 1998

The dominant forest cover types across all study sites in 1949 were "other" and moderate-density old-growth, with relative cover of 30% and 19%, respectively (Table 1 and Figure 8). With old-growth categories combined, stands containing at least 40% old-growth cover contributed almost 30% of total vegetation cover. All mature redwood-dominant forest of at least 40% canopy cover made up only 40% of total vegetation cover in 1949. Based upon soil maps and historic vegetation maps, it is estimated that mature redwood-dominant forest would have covered about 85% of the study area.

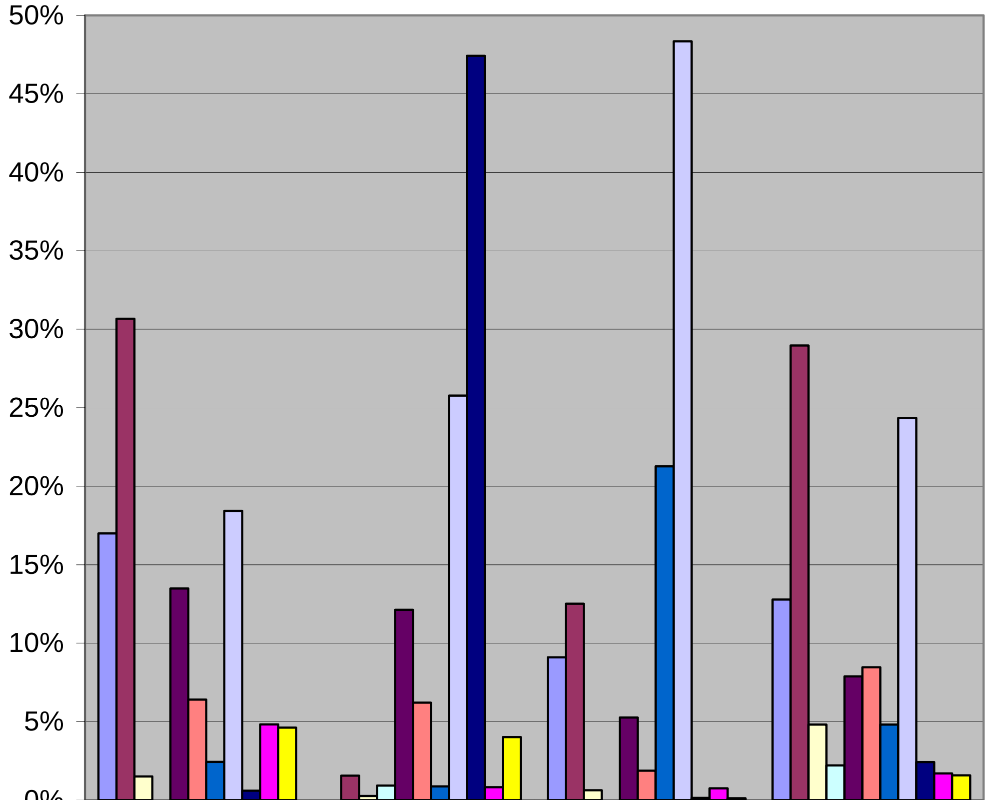
Table 1. Forest cover type definitions

Type name	Description	Rdwd stem size (dbh)	Density (%)
1abc	Highest probability old-growth redwood, virgin or not, multi-layered canopy structure, largest stems >50% of composition.	>= 40 in	a = >70% rdwd b = 40 – 70% rdwd c = 10 – 39% rdwd
2abc	Second-growth redwood, redwood-dominant, multi- or single-layered canopy structure, mixed medium and large to all large redwood stems, any size associated species	>=12 in and < 40 in	a = >70% rdwd b = 40 – 70% rdwd c = 10 – 39% rdwd
SecHdwDom	Second-growth redwood, hardwood-dominant	>=12 in and < 40 in	>10% and <50% rdwd
SecDFDom	Second-growth redwood, Doug fir-dominant	>=12 in and < 40 in	>10% and <50% rdwd
SRsmall	Second-growth redwood, redwood-dominant, small stems	< 12 in	>=50% rdwd
SRsmall-hdw	Second-growth redwood, hardwood-dominant, small stems,	< 12 in	>10% and <50% rdwd
DF	Douglas fir-dominant	>12 in DF	>50% conifer and <10% rdwd
Other (non-redwood forest)	All vegetation types that are not a previously defined class of redwood forest. This includes Pygmy forest, shrubland, annual grassland, and new plantations. The "other" category represents the lowest potential to evolve late-seral redwood characteristics in the next few decades.	<12 in rdwd	Varies



	Total
1a	10.18%
1b	19.19%
1c	1.87%
2a	0.77%
2b	9.56%
2c	5.69%
DF	7.74%
other	29.50%
SecDFDom	10.92%
SecHdwDom	2.08%
SRsmall	2.51%

Figure 8. Distribution of forest types in 1949; all sites combined. Read legend top-to-bottom to match bars from left-to-right.



	Hendy	Jughandle	Mailliard	Montgomery
1a	16.99%	0.00%	9.09%	12.79%
1b	30.67%	1.55%	12.51%	28.97%
1c	1.51%	0.26%	0.63%	4.81%
2a	0.00%	0.94%	0.00%	2.21%
2b	13.49%	12.14%	5.26%	7.89%
2c	6.42%	6.21%	1.87%	8.46%
DF	2.45%	0.87%	21.27%	4.82%
other	18.43%	25.78%	48.34%	24.35%
SecDFDom	0.60%	47.41%	0.15%	2.43%
SecHdwDom	4.82%	0.82%	0.75%	1.70%
SRsmall	4.62%	4.02%	0.13%	1.58%

Figure 9. Distribution of forest types in 1949 by study site. Match legend top-to-bottom to bars left-to-right.

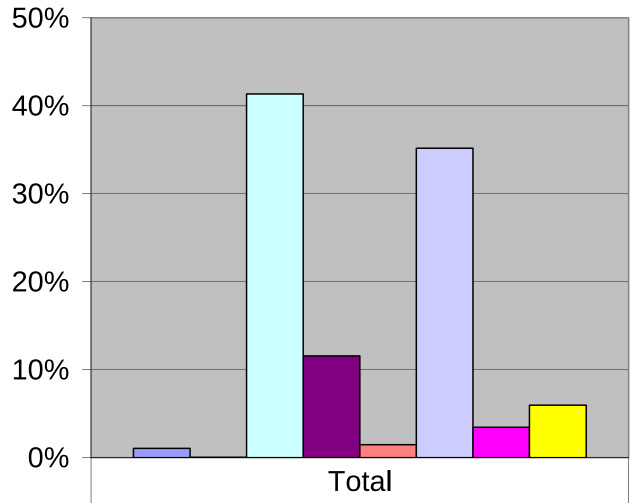
By study site, the greatest remaining old-growth occurred in the Hendy and Montgomery areas, with 48% and 42%, respectively (Figure 9). Mailliard soils indicated that close to 100% of the area could have supported redwood stands. If this is an accurate assumption, almost half of the Mailliard area was completely converted to hardwood rangeland by 1949 and persists today. This possible conversion occurred on south-facing slopes, indicating that ranchers' and farmers' conversion attempts were more successful on dry sites. The almost complete conversion from old-growth to second-growth in the Jughandle site is explained by intensive logging since 1852. Forty-seven percent of the regeneration in Jughandle was redwood-forest with Douglas fir dominant. The second greatest cover type in Jughandle was “other,” consisting primarily of pygmy forest species. Therefore, the “other” class in Jughandle is unique in that it does not indicate a loss of old-growth either currently or historically.

By 1998, the dominant cover type across all study sites was dense (>70% canopy cover), mature, second-growth, redwood dominant, which composed 41% of the study area, a tremendous increase from less than 1% in 1949 (Figure 10). The “other” vegetation class remained high with 35% cover, an increase of 5%. The apparent, most significant, change between 1949 and 1998 was the replacement of a variety of cover types with second-growth redwood-dominant forest. This second-growth class is characterized by the largest diameter trees and multi-layered structure, and therefore, was identified in this study as having the greatest potential to evolve into late-seral or old-growth structure.

The increase in dense, mature redwood occurred in each study site, with 69% in Jughandle, 44% in Montgomery, 41% in Hendy, and 17% in Mailliard (Figure 10). The “other” cover type increased to nearly 70% in Mailliard. Combining all mature, redwood-dominant stands with at least 40% cover indicates that Hendy and Jughandle study areas experienced the greatest redwood forest regeneration: 70% in Hendy, 71% in Jughandle, 26% in Mailliard, and 49% in Montgomery. This result is not surprising for Jughandle, as more than half the study area was severely cut-over by 1949. Although Jackson State Forest is roundly criticized by ecologists for management not conducive to regenerating late-seral forest conditions, in comparison to its former land owners and current land owners in other sites, Jackson now has the greatest potential to develop late-seral conditions.

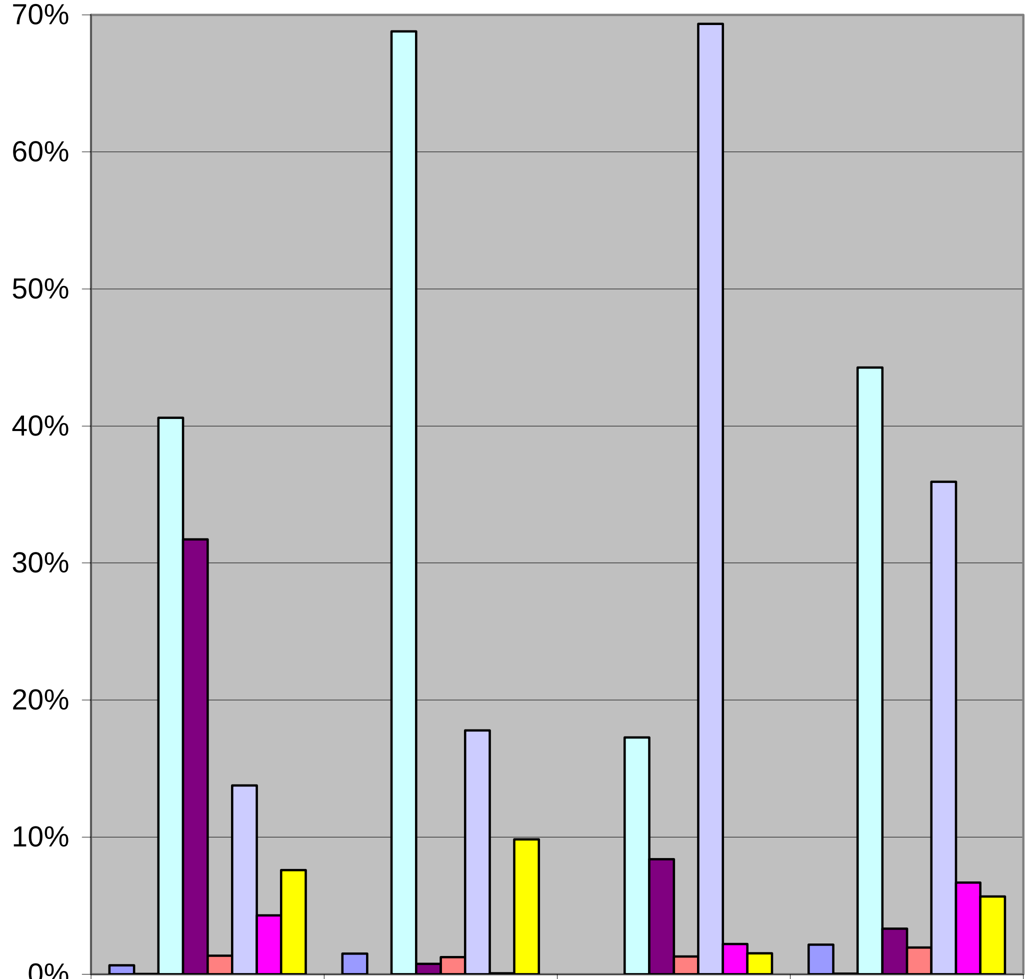
Forest type data from 1986 (Fox 1988) was not used in this comparison due to the mismatch of spatial resolution. Although the old-growth stands from the 1986 data had a high spatial resolution, the remaining types were too coarse to integrate with the 1949 and 1998 data. However, distribution of 1986 forest types across the four study sites may be conditionally compared to 1998. Fox reported 7.5% old-growth in 1986 which is significantly greater than the 1.1% found using the 1998 data set with the current study’s classification system. The 1986 data indicated 57% mature second-growth with redwood dominant which is similar to the 54% reported in this study. The definitions of the remaining cover categories were not similar enough to compare distributions.

Specific transitions, from one cover type to another, and their relationships to land use and ownership size, will be examined in the following sections.



	Total
1a	1.05%
1b	0.01%
2a	41.34%
2b	11.56%
2c	1.47%
other	35.17%
SecHdwDom	3.45%
SRsmall	5.95%

Figure 10. Distribution of forest types in 1998, all sites combined.



	Hendy	Jughandle	Mailliard	Montgomery
1a	0.66%	1.50%	0.00%	2.15%
1b	0.02%	0.00%	0.00%	0.04%
2a	40.60%	68.80%	17.29%	44.27%
2b	31.72%	0.77%	8.39%	3.32%
2c	1.35%	1.25%	1.28%	1.94%
other	13.77%	17.79%	69.33%	35.93%
SecHdwDom	4.29%	0.05%	2.19%	6.68%
SRsmall	7.59%	9.83%	1.51%	5.66%

Figure 11. Distribution of forest types in 1998 by study site.

MAJOR CHANGES IN FOREST TYPES

A total of twenty-five, aggregated, transition types were recorded. Three transition types occurred on greater than 10% of the study area: 1) transition from old-growth redwood of any density to mature, second-growth redwood-dominant of any density occurred on 20% of the study area; 2) "other" to "other", or no change, occurred on 18% of the study area; and 3) mature, second-growth redwood-dominant of any density to the same, with minimum 40% density occurred on 11% of the study area (Figure 12).

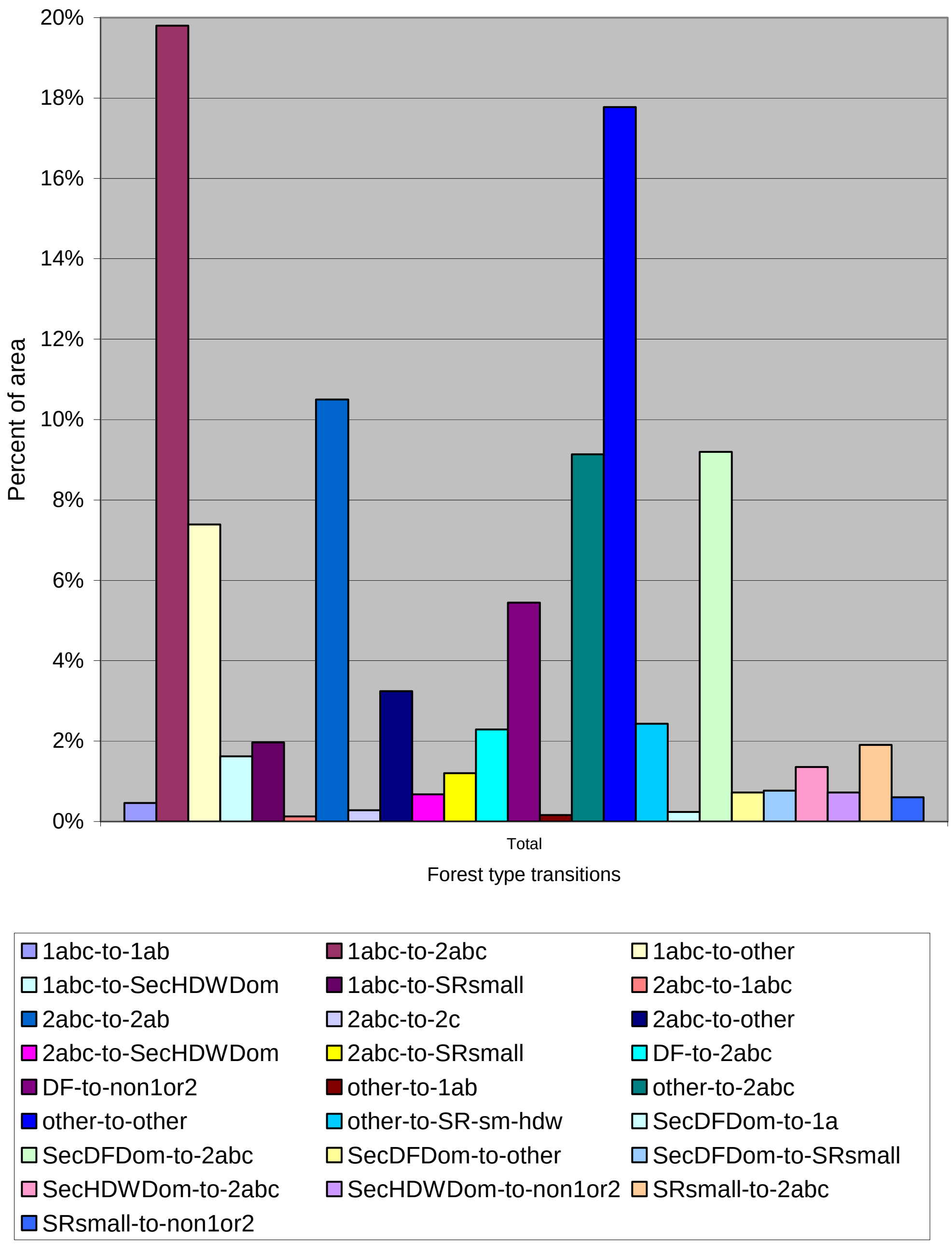


Figure 12. All documented changes in forest type from 1949 to 1998, all study sites combined. Read legend left-to-right to match legend order to bar order.

THE FATE OF OLD-GROWTH: 1949 - 1998

Persistence of old-growth occurred on less than 1% of the study area, or 1.5% of the total old-growth area in 1949. This represents a 98.5% loss of old-growth between 1949 and 1998. Twenty-four percent of the 1949 old-growth converted to the "other" type, deemed the lowest potential to generate late-seral structure in the next few decades. On the positive side, 63% transitioned to mature, second-growth redwood-dominant, the type judged to have the highest potential to generate late-seral structure (Figure 13).

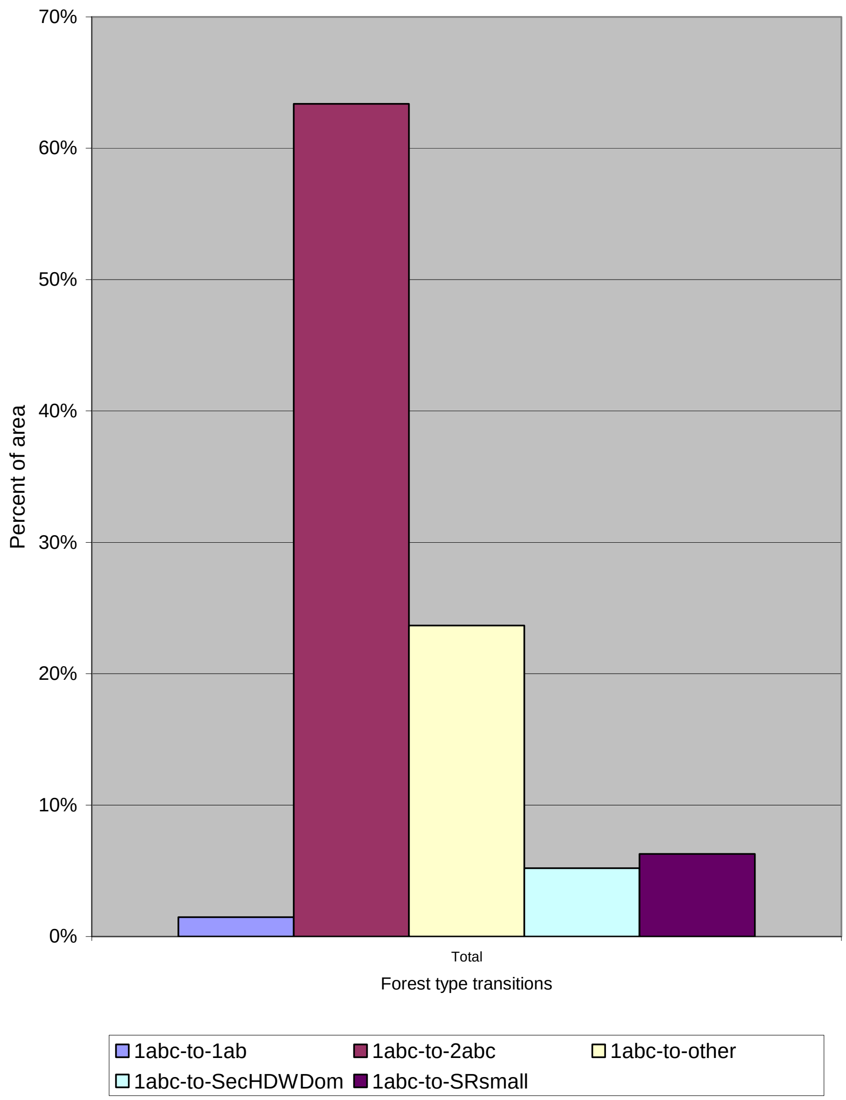
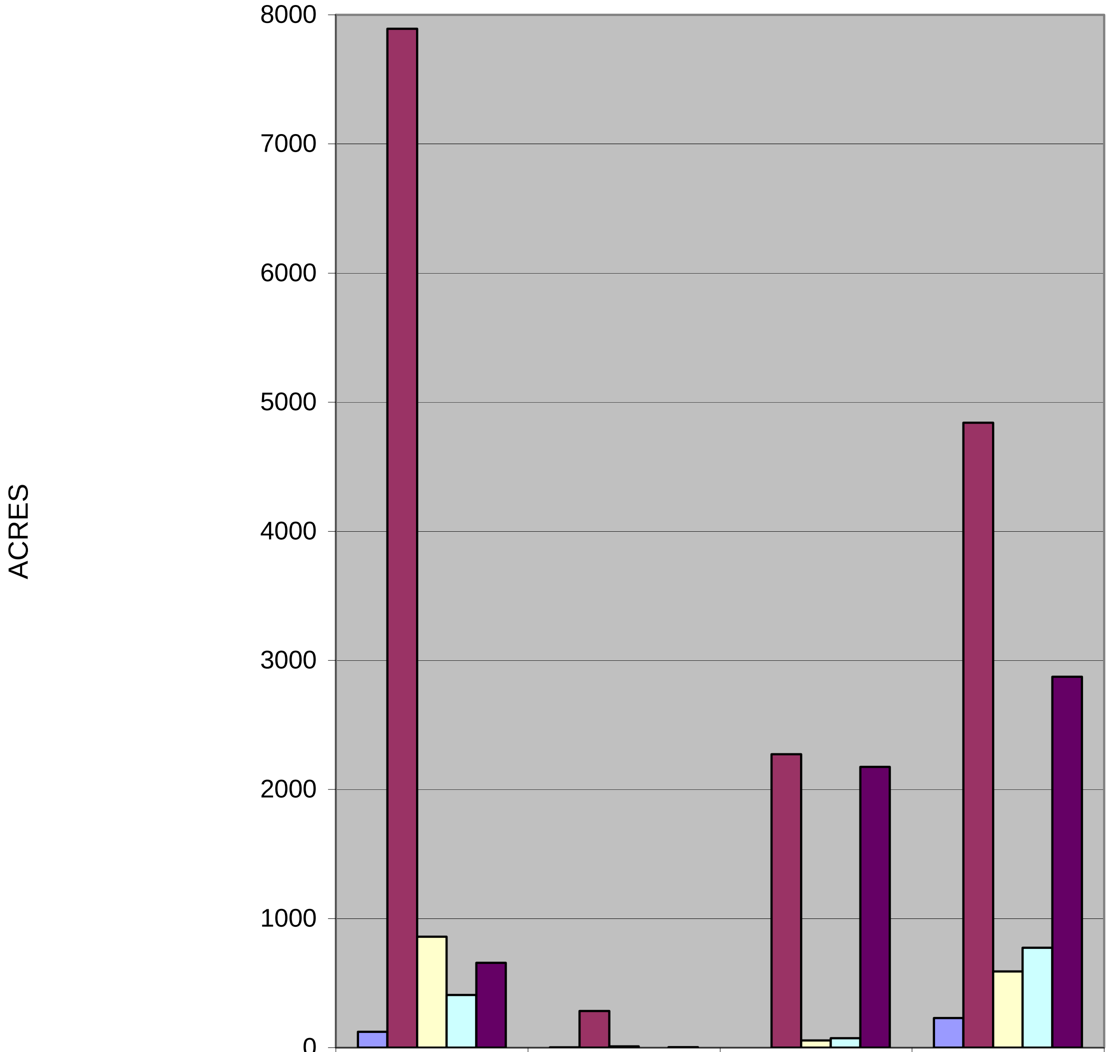


Figure 13. All recorded changes in forest type from 1949 to 1998, all study sites combined.

As discussed above, even by 1949, old-growth stands had been cut-over in all of the study areas, but none as much as in the Jughandle study area with only 293 acres of old-growth within the 5 km radius buffer (Figure 14). Due to its proximity to the coast, most of the Jughandle matrix had been entered for logging by 1920. Jackson State Forest, comprising most of the study area, was owned by the Caspar Lumber Company and almost completely cut-over before the State purchased the land in 1947. The Jughandle area contains virtually all of the rural-residential parcels in this study. This combination of low, baseline old-growth and concentration of rural-residential parcels makes it difficult to assess the effects of rural-residential land use on old-growth stands. While it is tempting to correlate the low baseline old-growth with concentration of rural-residential parcels, the fact is that the dominant land management activity prior to rural-residential development was well-documented, destructive, logging practices.



	Hendy	Jughandle	Mailliard	Montgomery
1abc-to-1ab	123	1		230
1abc-to-2abc	7892	283	2274	4842
1abc-to-SRsmall	860	10	57	590
1abc-to-SecHDWDom	409		72	773
1abc-to-other	658	4	2174	2873

Figure 14. Changes in old-growth stands from 1949 to 1998 by study site.

TRANSITIONS IN OLD-GROWTH STANDS BY OWNERSHIP SIZE & LAND USE CHANGE

There is no clear relationship between ownership size-class and loss or persistence of old-growth stands between 1949 and 1998 (Figure 15). Minute persistence of old-growth stands occurs in the smallest and the largest ownership size-classes. Conversion from old-growth to mature, second-growth redwood-dominant stands was the dominant dynamic among all ownership size-classes. The greatest amount of conversion from old-growth to "other" cover type occurred in the 40-acre and 640-acre size classes, both with ~35%, illustrating the lack of trend with size. Clearly, ownership size is a poor indicator of old-growth conversion, at least for the period 1949 to 1998. The lack of trend with ownership size is similar to the author's work in Nevada County. Another similarity is the apparent variability within the 40-acre ownership size-class. In Nevada County, the middle-range parcels, from ~20 acres to 40 acres, had the greatest variability in owner activities because this range of acreage is at the margin between rural-residential use and "hobby farm" use. Even more so in Mendocino County, this acreage range is valuable for conversion to vineyards.

Conversions between land uses appear to partition more of the variability in old-growth loss and retention (Figure 16). Most significantly, land held in State Parks and Reserves preserved 25-times more old-growth than any other land use type. Since the ownership data establishes ownership only from 1960 and the vegetation data measures change from 1949, the remaining 75% conversion of old-growth in the State Parks and Reserves occurred prior to ownership change.

The greatest conversion from old-growth to "other," the type with the lowest potential for succession to late-seral, occurred where the land use remained in or converted to rangeland and agriculture, with 58% and 51% respectively. Conversely, the lowest rate of conversion from old-growth to "other" occurred where the land use converted to rural-residential. Conversion from timber to developed, rural-residential resulted in a 99% retention or development of mature second-growth redwood-dominant stands[1].

Due to the 10-year difference in time-lines of the ownership and vegetation data, it is possible that the conversion from old-growth to "other" reported for agricultural lands first occurred when the land was under timber land use. It is (and was) common for timber companies and individuals to high-grade their land and sell it off. However, the lack of regeneration is directly attributable to the subsequent land use. This conclusion is especially likely given the opposite trend on rural-residential and State Park parcels. Clearly, rangeland and agricultural land use are more detrimental to redwood forest than either rural-residential land use or small parcel size.

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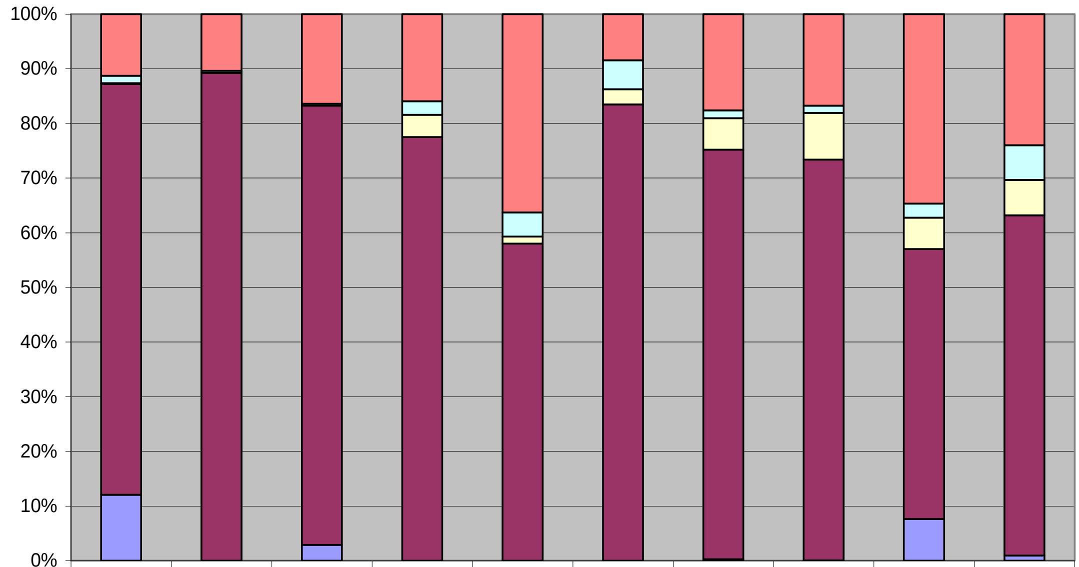
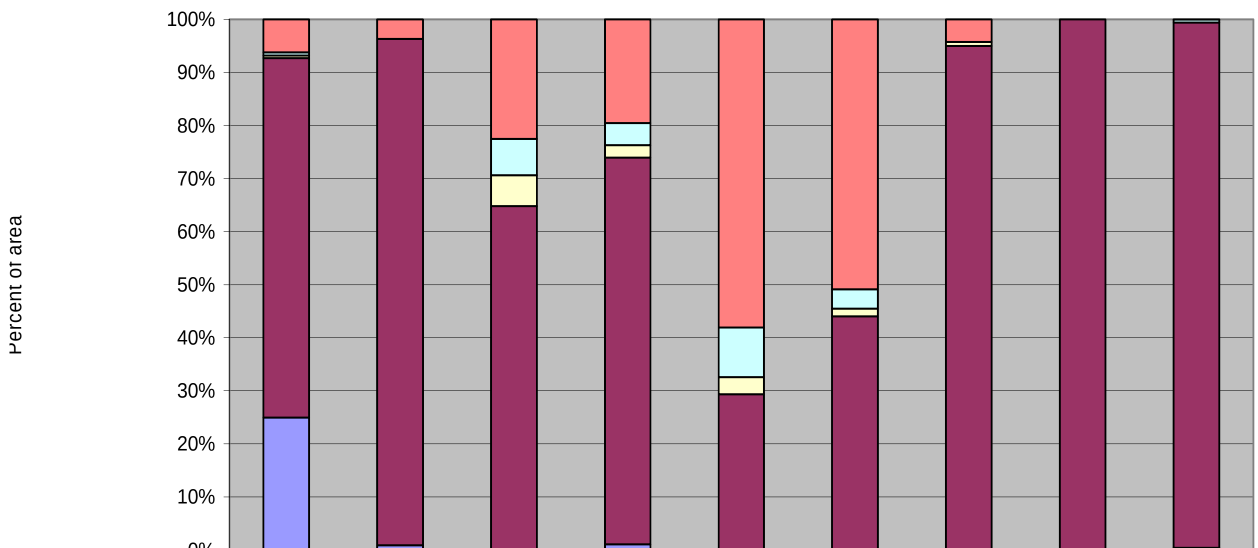
[1] "Rural-residential" includes any developed parcel that is not being used significantly for timber production or rangeland or agriculture; size is not a determinant or rural-residential land use; "RMR speculator" includes undeveloped parcels that are zoned "remote rural residential" and are not actively being managed for timber or agriculture and are owned by an individual or company with significant holdings throughout the county; "RMR undeveloped" is the same as "RMR speculator" except that it is owned by an individual with small total ownership.

The predominance of conversion of old-growth stands to mature, second-growth, redwood-dominant stands requires further analysis. If these sites were clear-cut in large blocks, the regeneration within 50 years could not be of mature size. Therefore, it is more likely that the 1949 old-growth stands consisted of mixed-age-classes from multiple, prior, logging events and transitioned to mature second-growth by virtue of high-grading the old-growth component combined with maturation of young growth.



	4	5	10	20	40	80	160	320	640	1000
1abc-to-other	11.29%	10.38%	16.37%	15.94%	36.28%	8.44%	17.63%	16.77%	34.66%	23.95%
1abc-to-SecHDWDom	1.34%	0.37%	0.38%	2.49%	4.40%	5.28%	1.41%	1.31%	2.57%	6.37%
1abc-to-SRsmall	0.12%	0.00%	0.00%	4.08%	1.33%	2.78%	5.79%	8.56%	5.72%	6.50%
1abc-to-2abc	75.21%	89.25%	80.34%	77.50%	57.99%	83.50%	74.93%	73.34%	49.41%	62.27%
1abc-to-1ab	12.04%	0.00%	2.91%	0.00%	0.00%	0.00%	0.25%	0.02%	7.64%	0.92%

Figure 15. Change in old-growth stands from 1949 to 1998 by ownership size-class; all land use types.

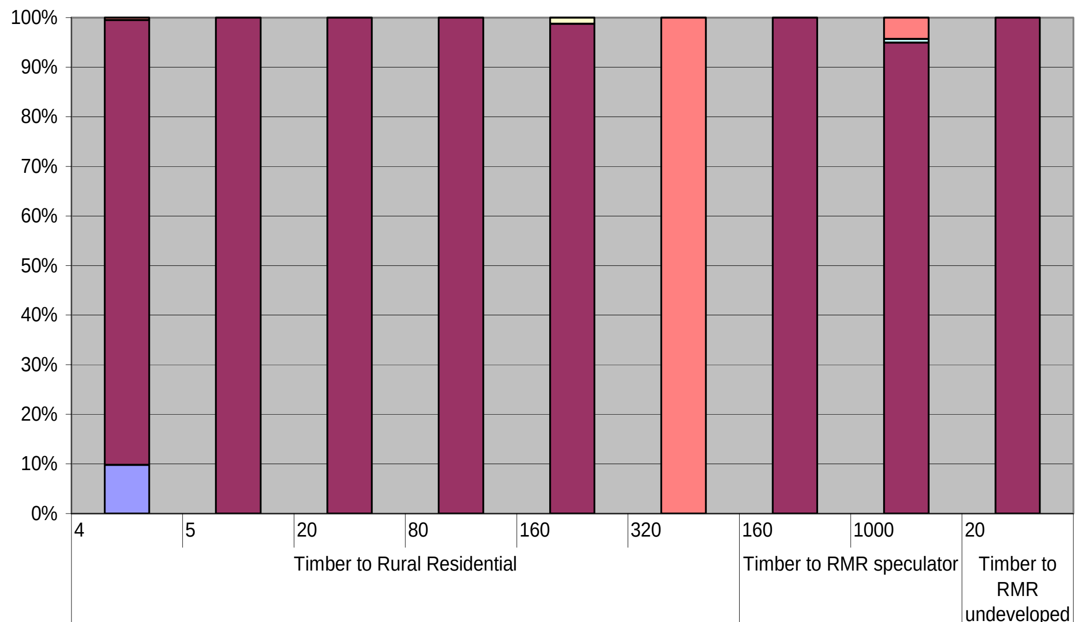


	State of California, no change	Timber to Jackson State Forest	Timber, no change	Rangeland & Agriculture to Timber	Rangeland & Agriculture, no change	Timber to Rangeland & Agriculture	Timber to RMR speculator	Timber to RMR undeveloped	Timber to Rural Residential
1abc-to-other	6%	4%	23%	20%	58%	51%	4%	0%	0%
1abc-to-SRsmall	1%	0%	7%	4%	9%	4%	0%	0%	1%
1abc-to-SecHDWDom	0%	0%	6%	2%	3%	1%	1%	0%	0%
1abc-to-2abc	68%	95%	65%	73%	29%	44%	95%	100%	99%
1abc-to-1ab	25%	1%	0%	1%	0%	0%	0%	0%	0%

Figure 16. Change in old-growth stands from 1949 to 1998 by land use conversion; all ownership size-classes.

TIMBER TO RURAL-RESIDENTIAL

When land use conversion and ownership size-class are combined, the trends in old-growth change remain essentially the same as for land use alone. Due to the small sample size in the rural-residential land use category, further subdividing by ownership size can result in pronouncement of outliers. For example, the old-growth retention in ownership sizes smaller than 5 acres (Figure 17, bar "4") is due to a single parcel. The same is true for the 320-acre parcel. However, the remaining classes and results have a large enough sample size to conclude that ownership size does not have an effect on conversion of old-growth on parcels that converted from timber to rural-residential.

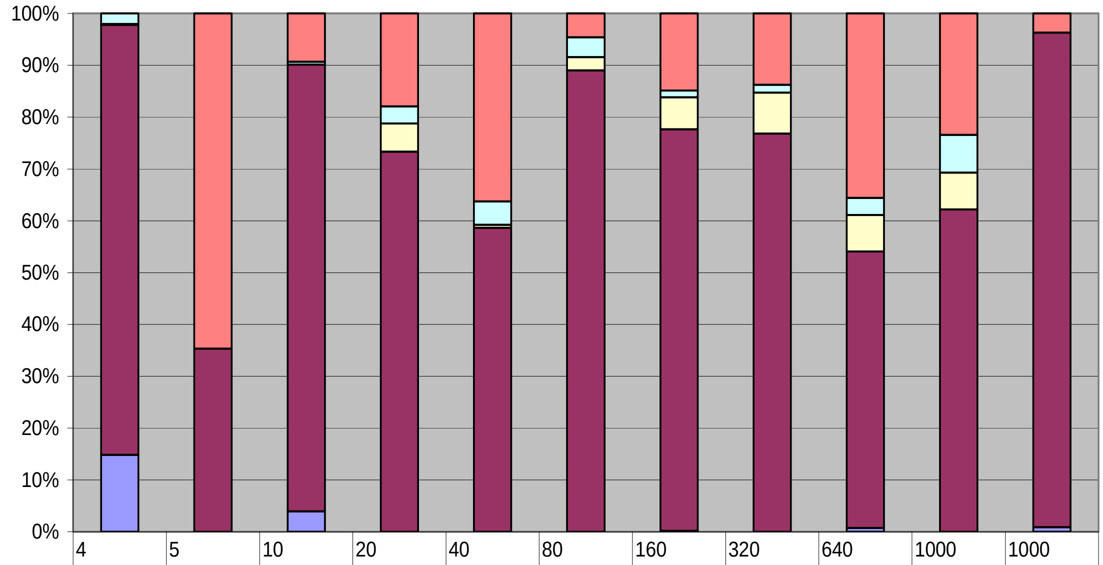


	4	5	20	80	160	320	160	1000	20
	Timber to Rural Residential						Timber to RMR speculator		Timber to RMR undeveloped
1abc-to-other	0.47%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	4.28%	0.00%
1abc-to-SecHDWDom	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.75%	0.00%
1abc-to-SRsmall	0.00%	0.00%	0.00%	0.00%	1.22%	0.00%	0.00%	0.00%	0.00%
1abc-to-2abc	89.70%	100.00%	100.00%	100.00%	98.78%	0.00%	100.00%	94.97%	100.00%
1abc-to-1ab	9.83%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Figure 17. Change in old-growth stands from 1949 to 1998 by: ownership size-class for land use change from timber to rural-residential (1960 to 2002).

CONTINUOUS TIMBER

Old-growth conversion on land under continuous timber ownership also shows no apparent relationship with ownership size, unless the retention of old-growth with small ownership size is a trend instead of an anomaly or error in the data (Figure 18). The retention of old-growth occurred on only three parcels. The fact that a timber land use could be assigned to such a small ownership suggests that these parcels are, more likely, undeveloped rural-residential or recreational parcels within a timber production zone. There are a total of 18 ownerships smaller than 10 acres.

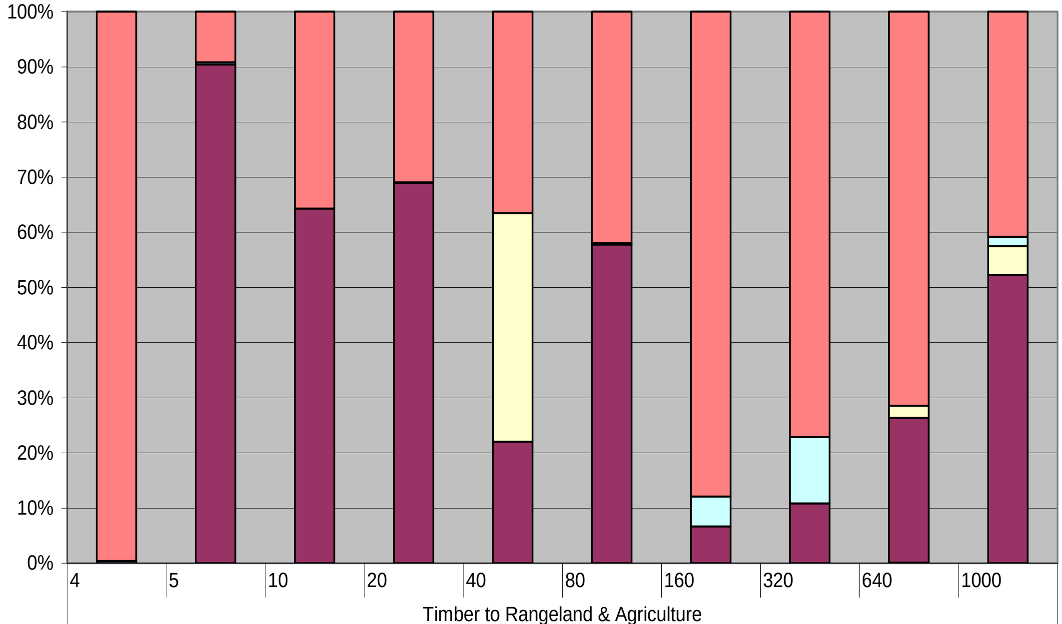


	Timber, no change										Timber to Jackson State Forest
	4	5	10	20	40	80	160	320	640	1000	1000
1abc-to-other	0.00%	64.69%	9.33%	17.93%	36.27%	4.59%	14.88%	13.75%	35.58%	23.41%	3.68%
1abc-to-SecHDWDom	2.04%	0.00%	0.52%	3.30%	4.49%	3.84%	1.27%	1.51%	3.30%	7.29%	0.00%
1abc-to-SRsmall	0.19%	0.00%	0.00%	5.41%	0.57%	2.57%	6.18%	7.89%	7.06%	7.10%	0.00%
1abc-to-2abc	82.95%	35.31%	86.19%	73.35%	58.67%	89.00%	77.49%	76.85%	53.32%	62.18%	95.42%
1abc-to-1ab	14.82%	0.00%	3.97%	0.00%	0.00%	0.00%	0.18%	0.00%	0.74%	0.02%	0.90%

Figure 18. Change in old-growth stands from 1949 to 1998 by ownership size-class for continuous timber land use (1960 to 2002).

TIMBER TO RANGELAND & AGRICULTURE

As with the rural-residential and timber land use classes, there appears to be no relationship between ownership size and change in old-growth (Figure 19). The <= 5 acre class has only two parcels, making it too small to establish a relationship. Rangeland occurs in the largest ownership sizes and is frequently mixed with timber production or logging. This relationship is apparent in the 1000 acre and greater size-class.



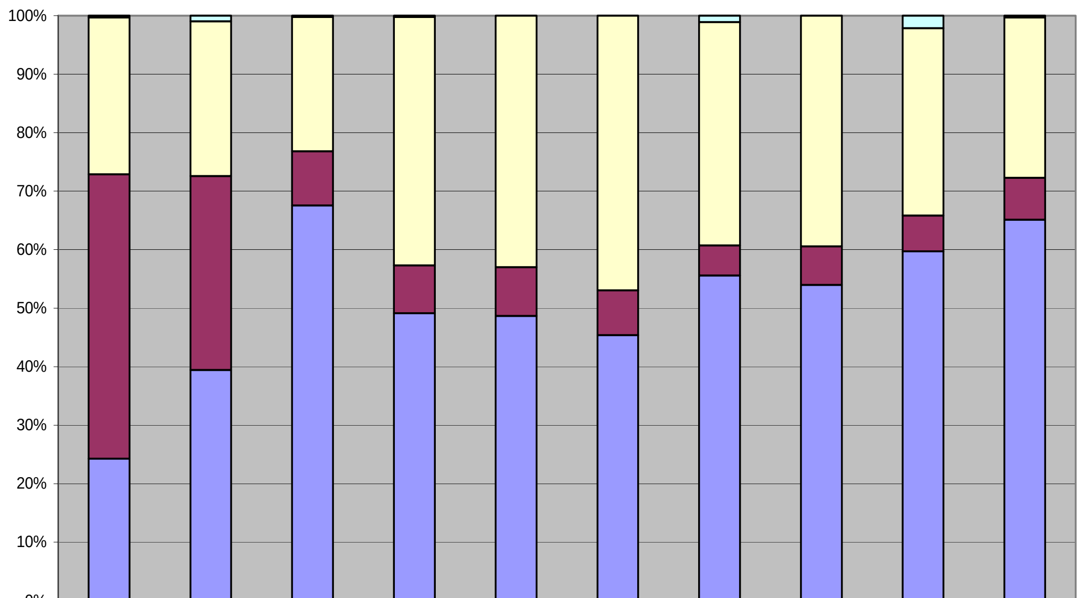
	4	5	10	20	40	80	160	320	640	1000
1abc-to-other	99.62%	9.19%	35.73%	30.96%	36.52%	41.97%	87.93%	77.12%	71.47%	40.82%
1abc-to-SecHDWDom	0.00%	0.41%	0.00%	0.00%	0.00%	0.26%	5.42%	12.04%	0.00%	1.68%
1abc-to-SRsmall	0.00%	0.00%	0.00%	0.07%	41.47%	0.00%	0.00%	0.00%	2.15%	5.18%
1abc-to-2abc	0.00%	90.41%	64.27%	68.97%	22.00%	57.77%	6.65%	10.85%	26.29%	52.32%
1abc-to-1ab	0.38%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.09%	0.00%

Figure 19. Change in old-growth stands from 1949 to 1998 by ownership size-class for land use conversion from timber to rangeland & agriculture (1960 to 2002).

PATTERNS OF REGENERATION: 1949 – 1998

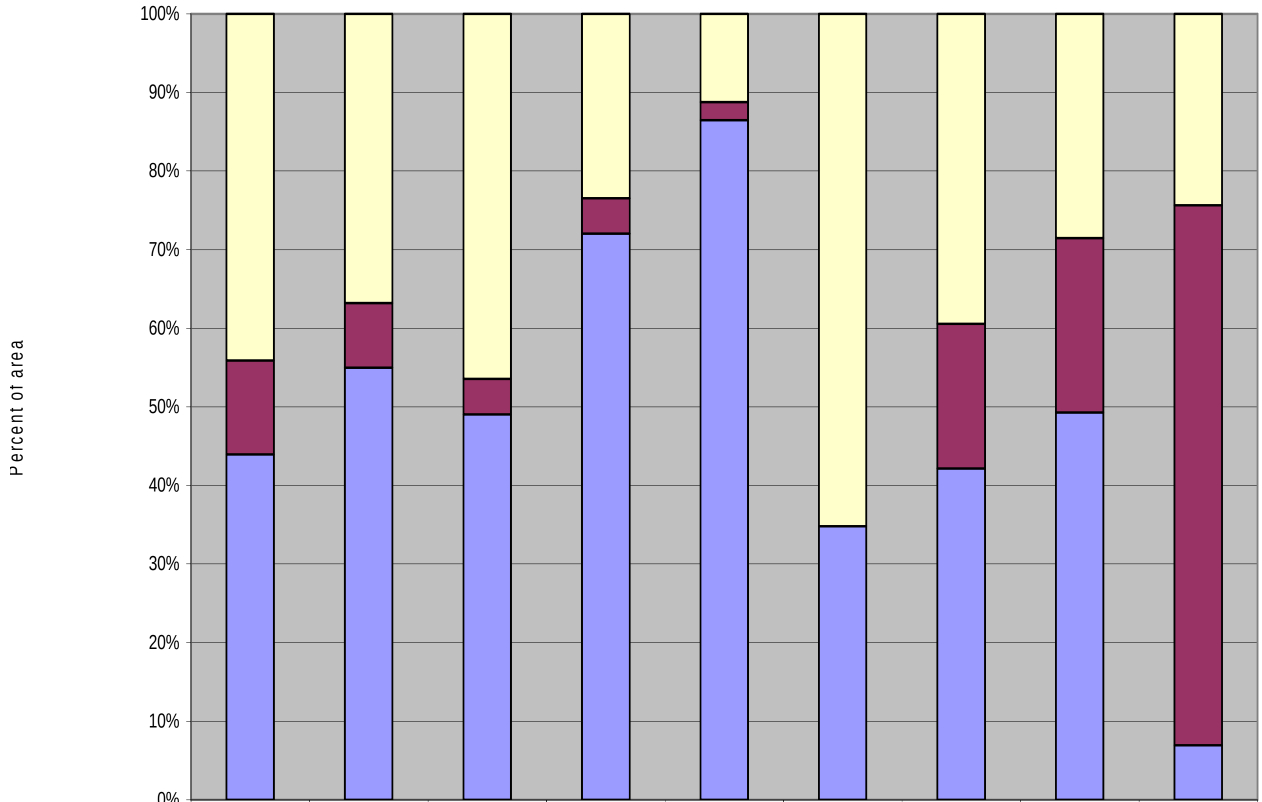
The “other” vegetation category stayed primarily the same, further supporting the assumption that conversion to “other” results in the least potential for regeneration of late-seral stands. The most apparent trend in vegetation change from “other” is conversion to some type of redwood regeneration in ownerships less than 10 acres. This relationship is due to the rural-residential land use predominant in the smaller ownership classes (Figure 20). Once again, land use is not only the dominant factor, but ownership size is relatively unrelated to vegetation change.

Land use conversion from “other” to rural-residential is associated with an astounding 94% transition from “other” vegetation to redwood regeneration (Figure 21). Sixty-nine percent of the transition was to small redwood with hardwood the dominant component. The greatest amount of transition to mature second-growth redwood-dominant, 65%, occurred on parcels changing from timber to RMR-speculator. The greatest amount of unchanged “other” vegetation occurred on land converted from timber to rangeland and agriculture (86%) and vice-versa, land converted from rangeland and agriculture to timber (72%). Not surprisingly, land either formerly or currently under rangeland or agricultural land use, regardless of ownership size, has the least potential to develop late-seral redwood stands in the next few decades.



	4	5	10	20	40	80	160	320	640	1000
other-to-1ab	0.29%	0.96%	0.19%	0.22%	0.00%	0.02%	1.06%	0.00%	2.11%	0.29%
other-to-2abc	26.80%	26.43%	22.95%	42.45%	42.98%	46.91%	38.20%	39.44%	32.04%	27.39%
other-to-SR-sm-hdw	48.62%	33.17%	9.32%	8.19%	8.31%	7.69%	5.15%	6.58%	6.10%	7.15%
other-to-other	24.28%	39.43%	67.55%	49.13%	48.70%	45.38%	55.59%	53.99%	59.75%	65.16%

Figure 20. Change in "other" vegetation type 1949 to 1998 by ownership size-class; all land use types; all study sites combined.

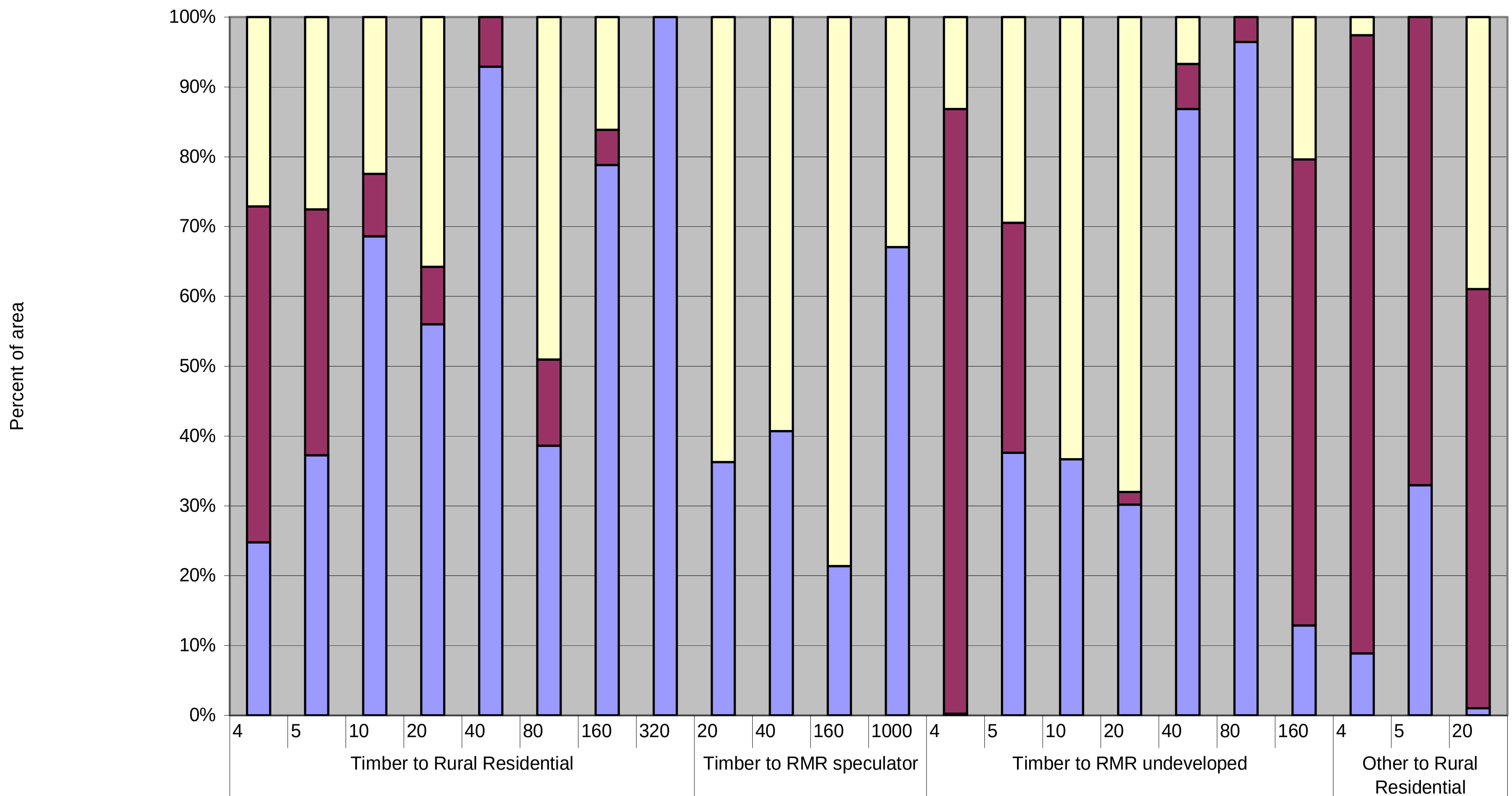


	State of California, no change	Timber, no change	Timber to Jackson State Forest	Rangeland & Agriculture to Timber	Timber to Rangeland & Agriculture	Timber to RMR speculator	Timber to RMR undeveloped	Timber to Rural Residential	Other to Rural Residential
other-to-2abc	44%	37%	46%	23%	11%	65%	39%	29%	24%
other-to-SR-sm-hdw	12%	8%	4%	4%	2%	0%	18%	22%	69%
other-to-other	44%	55%	49%	72%	86%	35%	42%	49%	7%

Figure 21. Change in "other" vegetation type from 1949 to 1998 by major land use conversion types.

TIMBER AND OTHER TO RURAL RESIDENTIAL

When each type of land use conversion was graphed by ownership size-class, there was no correlation with ownership size, whatsoever. For example, Figure 22 shows land use conversions from other and timber to rural-residential. Across each land use conversion, there are no trends by ownership size for persistence of "other" vegetation or its transition to redwood forest. This same complete lack of trend occurred for every land use type. The relationships between ownership size and regeneration of forest are unique to each ownership size class. This is either because there are no consistent relationships or because different land management activities occur on the same ownership size-classes, obscuring an underlying relationship. This possibility will be explored in the next phase of the project.



	Timber to Rural Residential								Timber to RMR speculator				Timber to RMR undeveloped							Other to Rural Residential		
	4	5	10	20	40	80	160	320	20	40	160	1000	4	5	10	20	40	80	160	4	5	20
other-to-2abc	27%	28%	22%	36%	0%	49%	16%	0%	64%	59%	79%	33%	13%	29%	63%	68%	7%	0%	20%	3%	0%	39%
other-to-SR-sm-hdw	48%	35%	9%	8%	7%	12%	5%	0%	0%	0%	0%	0%	87%	33%	0%	2%	6%	4%	67%	89%	67%	60%
other-to-other	25%	37%	69%	56%	93%	39%	79%	100%	36%	41%	21%	67%	0%	38%	37%	30%	87%	96%	13%	9%	33%	1%

Figure 22. Change in "other" vegetation type from 1949 to 1998 by ownership class-size for land use conversion to rural-residential (1960 to 2002).

SUMMARY

Although many factors remain to be examined, some important and surprising conclusions may be drawn from this research. The first finding is that parcel and ownership size are not useful predictors of the fate of old-growth stands or of regeneration of redwood forest following conversion to non-redwood forest, either through logging or agricultural land uses. The second finding is that historical land use and vegetation condition at the time of ownership change are essential to accurately determine the effects of land use on forest structure. If either prior land use or vegetation condition is not known, any correlation between current land use, parcel size, and current vegetation condition is likely to be spurious. Given the common practice by timber holders and operators of high-grading existing forest followed by selling-off of smaller parcels, the more accurate way of analyzing a correlation between rural-residential land use and low canopy cover is that the low canopy cover "caused" the rural-residential land use (i.e. rural-residential owners purchase cut-over land).

This segues to the third significant finding: for the parcels included in this study, conversion to rural-residential land use was associated with the highest probability of regenerating depleted forest to second-growth redwood-dominant forest compared to timber and agricultural land uses. The land use with the greatest potential to convert forest to non-forest was agriculture and rangeland. Even with the potential fragmenting influence of smaller parcels under rural-residential land use, forest structure improved. The small sample size of the rural-residential land use class and the lack of fragmentation as a factor in this first analysis indicates that the potentially positive effect of land use conversion needs to be more fully explored. A fragmentation data set, including change in roads and delineation of fragmented cover from 1978 and 1988 to the present, was produced as a part of this pilot study and will be the focus of the next analysis.

The last finding is also the most significant. Only one land use type was responsible for persistence of 99% of the remaining old-growth in the study sites: California State Parks and Reserves consisting primarily of lands purchased by the Save-the-Redwoods League.

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