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A Geographic Analysis of the Burrowing Owl Population in Santa Clara County, California

A Thesis

Presented to

The Faculty of the Department of Geography

and Environmental Studies

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Janis Taylor Buchanan

December 1996

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ABSTRACT

A GEOGRAPHIC ANALYSIS OF THE

BURROWING OWL POPULATION

IN SANTA CLARA COUNTY, CALIFORNIA

by Janis Taylor Buchanan

This spatial analysis of burrowing owls (*Speotyto cunicularia*) and their associated habitat features in Santa Clara County, CA was considered from a geographic perspective. Owl nest site locations within the county before and during the years 1991-1993, derived from census data from the Institute for Bird Populations, were digitally recorded in ARC/INFO, a Geographic Information System (GIS). Habitat was assessed with the use of a 1990 Landsat Thematic Mapper scene classified by land cover. This analysis shows that the spatial distributions of owl locations throughout the study area are clumped into distinct groups. Future land uses for areas used by groups of owls were reviewed and suggestions were made to reduce continuous population decline. The final product, digital data and hard copies of maps and definitions, will be available to agencies and municipalities to aid in making decisions which impact burrowing owls in the county.

ACKNOWLEDGMENTS

I would like to acknowledge the support and assistance of many people. Foremost, the thanks to my committee members, Dr. Leonard Gaydos, Dr. Michael Kutilek, and especially Dr. Lynne Trulio as chairperson who provided endless support and encouragement, and most importantly friendship. This study would not have been possible without the generous support of the staff of the NASA-Ames Research Center Ecosystem Science and Technology Branch. Special thanks to Sheri Dister for sharing her knowledge of ARC/INFO and William Acevedo for all his help with my endless stream of questions.

Several groups and individuals supplied data for this study. David DeSante and Eric Ruhlen at the Institute for Bird Populations supplied the burrowing owl census data. Craig Prada from the City of San Jose made a digital copy of the vacant lands inventory available for this study. Thank you all very much, it couldn't have been done without this information.

Many others have contributed valuable time, energy, and guidance to this study all of whom receive my deepest thanks and appreciation. Finally, I would like to acknowledge my friends and family, especially my husband, Matt, for their consistent encouragement and understanding over the years.

TABLE OF CONTENTS

LIST OF FIGURES

Figure

LIST OF TABLES

Table

INTRODUCTION

The burrowing owl (*Speotyto cunicularia*) (figure 1), a grassland species, utilizes open, sparsely vegetated areas with available burrows (Zarn 1974). Historically, owls were found in natural areas of open prairies or shrub-steppe habitat (Butts 1971, Coulombe 1971). Increasing human populations and continuous land use changes have resulted in burrowing owls utilizing man-altered habitats more frequently, which include everything from agricultural irrigation ditches (Coulombe 1971) to vacant lands in urban areas (Thomsen 1971, Collins & Landry 1977, Wesemann & Rowe 1987, Trulio 1995). The burrowing owls' flexible behavior allows them to be tolerant of human presence near their burrows, given suitable nesting and foraging habitat (Trulio 1992).

Nesting and foraging habitat requirements for the burrowing owl include sparse vegetative cover, availability of suitable burrows built by an associated fossorial mammal, and the presence of perches for horizontal visibility. The amount of vegetative cover and overall plant height are significant factors in predator avoidance and prey location behavior of the burrowing owl (Zarn 1974, Coulombe 1971, Green & Anthony 1989, Trulio 1992). In general, vegetative cover and height that allows the owl to stand near the burrow entrance and watch for approaching predators from any direction is most desirable. Burrows built and abandoned by fossorial mammals are taken over by burrowing owls in most of the owls' range throughout North America, excluding Florida, where burrowing owls dig their own burrows (Zarn 1974). The burrow provides protection from both predators (Green & Anthony 1989, Butts 1971) and adverse weather conditions (Coulombe 1971), and creates a

Figure 1. The burrowing owl (*Speotyto cunicularia*), a grassland species. Photo by J.T. Buchanan.

microhabitat for arthropods (such as earwigs and crickets) which may form the owls' primary food source (Coulombe 1971). Perches adjacent to the burrow entrance increase horizontal visibility for the burrowing owl while it watches for predators or prey (Green & Anthony 1989).

The burrowing owl is considered a rare animal throughout most of its range. In Minnesota, British Columbia and Iowa the burrowing owl is listed as an endangered species. In Manitoba and Saskatchewan it is listed as threatened, and in California, Florida, Montana, North Dakota, Oregon, Washington and Wyoming the burrowing owl is listed as a species of special concern (Martell 1990). The burrowing owl has been on the *Journal of American Birds'* blue list since 1971 (Arbib 1971) which indicates that bird researchers have identified it to be a declining species. The California Department of Fish and Game listed the burrowing owl as a Species of Special Concern in 1979, due to declining populations throughout the state (Remsen 1978). In November 1994, the U. S. Fish and Wildlife Service classified the burrowing owl as a federal Category 2 candidate for listing as threatened or endangered. Additional evidence (DeSante & Ruhlen 1995) has shown that the burrowing owl is, without question, a species at risk throughout California.

In California, distribution of the burrowing owl is not uniform. There are an estimated 9,450 pairs of burrowing owls within the state (DeSante & Ruhlen 1995). Seventy one percent of the breeding pairs of owls can be found in the Imperial Valley, 14% of the breeding pairs are in the southern Central Valley, and the last 14% of the breeding pairs are distributed throughout the San Francisco Bay area, middle and northern Central Valley and southern interior portions of the state. Flat, lowland valleys, basin bottoms, and coastal plains are the habitat of 90% of all breeding burrowing owls in California (DeSante & Ruhlen 1995). These lowland areas, in addition to supporting the greatest number of breeding pairs of burrowing owls, have also been the centers of the greatest human population growth throughout the 1980's and early 1990's, particularly in the San Francisco Bay area and Central Valley locations (DeSante & Ruhlen 1995, Medvitz & Sokolow 1995).

The Institute for Bird Populations (IBP) censused burrowing owls throughout the State of California during the years 1991-1993. Today there are approximately 170 pairs of owls in the area from Alameda to Redwood City. The findings of this study indicate a population decline greater than 50% in the last decade (DeSante & Ruhlen, 1995). Nesting populations of burrowing owls have been extirpated in the past 15 years from adjacent counties including Santa Cruz, Marin and San Francisco and nearly eliminated from several others. Most of the owls in Santa Clara County utilize undeveloped or limited use lands throughout the urban matrix.

Human population growth predictions indicate the population of California will double its current level by the year 2040 (Medvitz & Sokolow 1995). The Imperial Valley and the southern Central Valley are among the fastest growing regions within the state. In the Imperial Valley, the population is increasing by 3.6% per year and San Joaquin Valley's population is increasing by 2.5% per year. These human population increases are directly linked to the loss of agricultural lands. By the year 2040, the predicted loss of agricultural land in California is expected to be 5 million acres, or 17% of today's farmland base. Most of this loss will be linked directly to urban expansion (Medvitz & Sokolow 1995). Urbanization due to human population growth directly impacts burrowing owls because today over 85% of the burrowing owl population in California can be found on agricultural land in the Central Valley (DeSante & Ruhlen, 1995).

Santa Clara County, the focus of this study, was a major agricultural center thirty years ago. Thousands of acres of farmland existed across the valley floor with some of the richest agricultural soil in the world. However, the 1970's brought explosive human population growth to Santa Clara County. Now, over one-half of the valley floor in Santa Clara County is covered with development (Bell et al. 1994). Within the last century, at least 90% of the land which was in agriculture was abandoned and for the most part has been developed (Faye et al. 1985).

The burrowing owl population in Santa Clara County represents a window into the future of the remaining owl habitat throughout California. This small population of owls is surrounded by urbanization with very few options for long-term protection. Urbanization represents a permanent loss of available habitat for the owls. Changes which result in fragmentation of the habitat into patches and a reduction in the total area of available habitat are detrimental to any species (Saunders et al. 1991).

A Geographic Information System (GIS) will spatially link nest locations to current land uses across the entire county creating a landscape perspective for the evaluation of burrowing owl habitat protection. Habitat protection requires all cities within the county to participate equally in the protection of the species. In Santa Clara County the current location of burrowing owls and availability of habitat can not be solved by relying on each city to develop an individual habitat protection plan. Some cities throughout the county have more owls and less available habitat for the future. Other cities have more available habitat but fewer owls. Knowledge of owl locations and habitats that are most likely to be lost to development in the coming years will be critical in the development of mitigation plans which offset the environmental impacts of development. Mitigation plans can include mitigation banks or conservation easements to define best available habitat without the limitation of city boundaries. Successfully protecting burrowing owl habitat in Santa Clara County in the future relies upon understanding where burrowing owls are found, how development will change available habitat in the future, and which lands are most appropriate to protect in the future to ensure a viable population.

OBJECTIVES

This study will quantify the type of habitat used by burrowing owls in Santa Clara County and will explore the extent to which birds are using available habitat. The specific questions addressed in this study are:

1. With respect to the distribution of burrowing owls throughout Santa Clara County from 1991-1994, are there defined groups of owls?

H_0: From 1991-1994, the burrowing owl population was evenly distributed throughout the county.

This null hypothesis can be falsified by geographically displaying the data for each year, 1991-1994 and analyzing the distribution of the locations.

2. Are burrowing owls utilizing all available/potential habitat throughout Santa Clara County?

H_0: All burrowing owl habitat within Santa Clara County is currently occupied.

This null hypothesis is falsified by plotting the locations of the burrowing owl nest sites and reviewing these locations with respect to the locations of dry and irrigated grasslands.

3. Can specific locations, corridors or preserves of unoccupied but available owl habitat be identified that are important to the long-term viability of the population of burrowing owls in Santa Clara County?

H_0: There are no habitat patches or corridors that would maintain the long-term viability of the population in Santa Clara County.

This null hypothesis can be falsified by determining if within the urban areas there exists lands that have limited development potential and would provide a resource for creating a burrowing owl preserve within the County (figure 2).

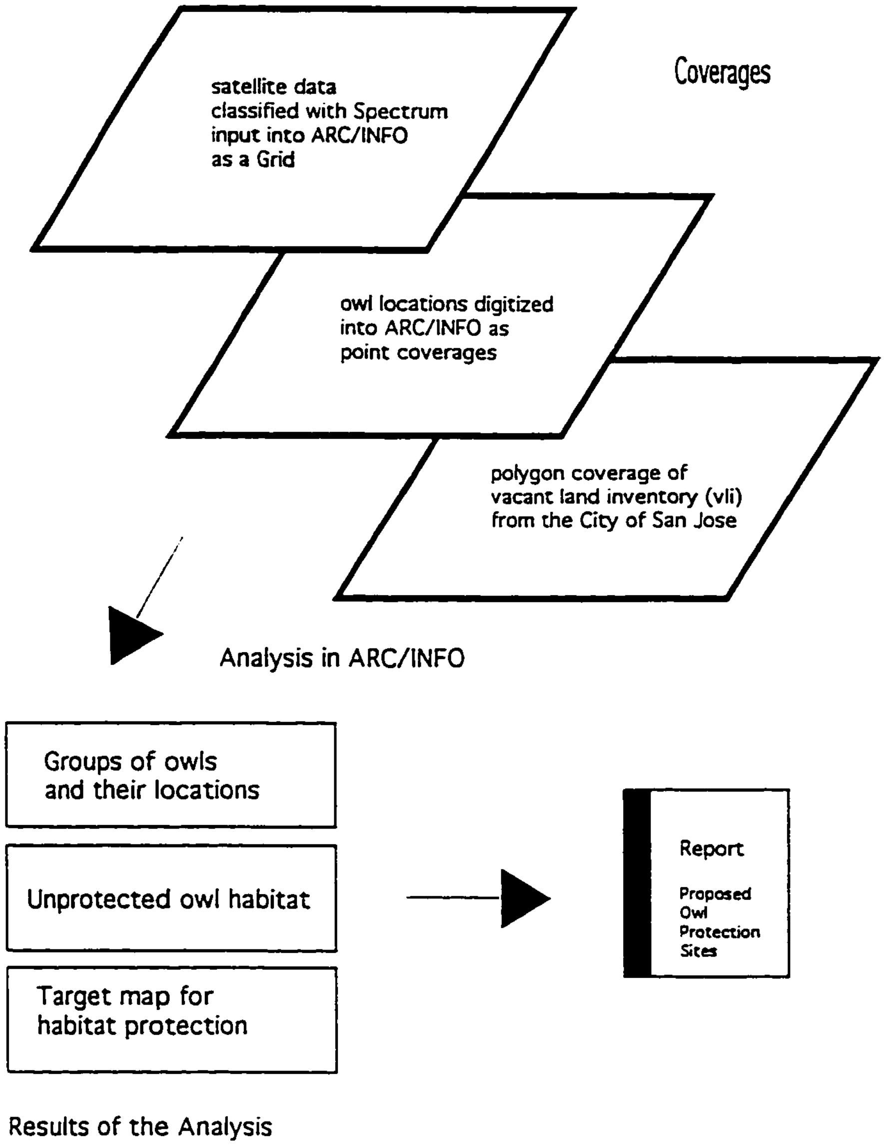


Figure 2. Diagram of study objectives.

RELATED RESEARCH

Research related to this project includes studies defining habitat requirements of the burrowing owl, studies of urban wildlife, population studies including predicted population viability of burrowing owls, and studies using GIS with remote sensing to identify habitat characteristics of different species.

Burrowing Owl Habitat

Burrowing owl habitat is defined as open, sparsely vegetated areas with available burrows. Characteristics of this habitat which have been studied include vegetation parameters, associations with fossorial mammals and burrow suitability and availability.

Vegetation cover and heights that prevent owls from seeing approaching predators put the burrowing owl at a severe disadvantage. Studies of vegetation cover have suggested a range of acceptable coverages. In California, Trulio (1995) found between 44-57% vegetation cover to be optimum and, in the Columbia Basin, Green and Anthony (1989) found 28% cover was optimum. Green and Anthony (1989) also found that owls selected areas with a greater percentage of bare ground. Tall vegetation presents similar disadvantages associated with visibility. In Oklahoma, owls occupied areas where vegetation was 4 inches tall or less (Butts 1973). Similarly, in California occupied burrows were found in areas that had an average vegetation height of 5.6 inches (Trulio 1995).

Burrow availability has long been identified as a limiting factor for burrowing owls in all areas (Coulombe 1971, Green & Anthony 1989, DeSante & Ruhlen 1995). Both natural and unnatural cavities provide suitable burrows.

Natural burrows are built by an associated fossorial mammal such as California ground squirrel (*Spermophilus spp.*), prairie dog (*Cynomys spp.*), marmot (*Marmota spp.*) or badger (*Taxida taxidus*) based on the respective geographic location. Other burrows are found in rock or lava outcroppings (Rich 1986, Gleason & Johnson 1985), limestone (Coulombe 1971), concrete or asphalt (Trulio 1995) or man-made artificial habitat (Collins & Landry 1977). Burrows are different in all areas based on available resources, but the physical dimensions remain consistent.

Even in disturbed areas, the presence of fossorial mammals is significant. Associated burrowing mammals provide unquantified attributes to a successful burrowing owl colony, including burrow maintenance between nesting seasons and shared alarm calling behavior (Trulio 1995).

Wesemann and Rowe (1987) studied burrowing owl abundance and distribution in Cape Coral, Florida, identifying specific parameters which made these urban areas suitable burrowing owl habitat. Some very unique findings of this study included the owl's preference for nesting habitat in areas of high residential development, up to 60% developed, over areas that were less developed. The researchers related this to some of the subtle characteristics of these developed areas including enhanced vegetation coverage in landscaped areas due to year-round irrigation which increases the abundance of prey species, ground dwelling insects and vertebrates. However, high levels of development also bring with it other limiting pressures on owl populations, such as an increase in auto fatalities and an increase in vandalism of habitat by people and their pets (Wesemann & Rowe 1987, Wiggins 1988, Dickey 1990, Nauman 1993).

Wesemann and Rowe (1987) consider the habitat the owls were using to be transitional habitat, including dry unirrigated grassland. Land in a pre-development, or fallow stage, could be considered good habitat if the population was considered for only a brief time span. Evaluation of the population over time would reveal the reality that long-term availability of these human-modified habitat areas will always be plagued with economic pressures to develop and continuous human activities detrimental to the owls such as weed abatement (DeSante & Ruhlen 1995, Trulio 1992).

Population Trends

Populations are defined as local breeding units in which all interactions occur, such as reproduction, population regulation and predation (Taylor 1990). A metapopulation is a population of local populations, interdependent over ecological time (Harrison et al. 1988). The interdependency is due to continuous local extinctions and associated recolonizations of habitat patches within the metapopulation (Harrison et al. 1988). The viability of any population relies on a regional persistence, which does not require all available habitat within the spatial extent of the metapopulation be occupied at all times. Instead, regional persistence relies on a balance of occupation of all habitat fragments between a mainland or source for the metapopulation and all habitat patches, similar to the theory of Island Biogeography (Harrison et al. 1988).

The IBP census of burrowing owls revealed a decline in the state-wide population to be approximately 8% per year (DeSante & Ruhlen, 1995). They also have estimated that 50% of the population of burrowing owls in the state has been lost between the years 1985-1995. The burrowing owl is still widespread throughout the state and occupies a variety of habitats, but small local populations like the one in the San Francisco Bay area may have limited long-term viability unless the population is increased and a permanent system of protected areas is established (DeSante & Ruhlen, 1995, Trulio in review).

Deterministic and stochastic factors which influence the persistence of burrowing owls Santa Clara County were evaluated by Trulio (in review) in an effort to develop strategies which can be used in the protection of owls in the future. Her results show that deterministic factors have had the greatest impact on the population to date. Habitat loss to development and habitat degradation due to weed abatement and rodent control were the culprits. Stochastic factors relating to the current small population size made protection of large population patches in the landscape a requirement in order for the population to recover to a more sustainable size. In addition, population viability is dependent upon successful dispersal between patches of the population to reduce the effects of fragmentation and to maintain genetic diversity.

Geographic Information Systems and Remote Sensing

Ecosystem management requires information on the entire system, its components, and their interactions across the landscape, identifiable at a variety of spatial scales. Modeling landscapes and species distribution with GIS and remotely sensed data has relieved researchers of difficult and time consuming processes using traditional cartographic methods. Integration of diverse databases, spatial analysis, and a final map product are all benefits of using a GIS. Utilization of a GIS in ecosystem management makes recording and spatial analysis of the data time efficient while creating the environment for a flexible visualization process to display complex relationships.

A GIS provides a platform for combining data from different sources such as satellite data or species maps. Land use and land cover data often represent a baseline data set for ecosystem analyses. Geographically pertinent land use and land cover data sets can be imported into a GIS study to establish a starting point in the evaluation of habitat use of any animal species. Geospatial evaluation of a specific animal species or biodiversity in a region generally require the integration of diverse data sets. On March 10, 1995, the Environmental Protection Agency committed to a partnership for long-term research on remote-sensing data from space satellites. This partnership is known as the Multi-Resolution Land Characterization Consortium. The resultant land use and land cover databases developed will be available to federal, state and local organizations to aid scientists in monitoring environmental changes, as well as assist in environmental decisions (Ecological Society of America 1995).

The Gap Analysis project, initiated by the Department of the Interior, is a prime example of data integration for the purpose of determining areas of high biodiversity which are unprotected. Gap Analysis, a geographic approach to the study of the biological diversity in America, utilizes existing information on the distribution and status of vegetation and vertebrate species and compares this population distribution information to different land management and land ownership classifications, identifying "gaps" in the protection. The result of GAP analysis is a comprehensive assessment of the status and trends of biodiversity, a useful tool for recommending strategies aimed at protecting areas or species at the greatest risk. This information will help focus areas of interest for impact assessment of future development. The product of Gap Analysis will ultimately bring us one step closer to ecologically sustainable development (Scott et al. 1993).

Species studies using GIS as the spatial tool include habitat evaluation for sage grouse in Utah, black rails in California, sand hill cranes in Michigan and spotted owls throughout California and Oregon. In Utah, researchers used Landsat Thematic Mapper data to model structural and compositional attributes of sage grouse (*Centrocercus urophasianus*) habitat (Homer et al. 1993). A combination of macro-scale remote sensing habitat assessments and fine-scale selection of structural and compositional attributes of habitat were used to delineate habitat classes and sage grouse preferences for particular habitat types. This information was then extrapolated to other unsampled areas to demonstrate the ability of a remote sensing/GIS application predict attributes of useful wildlife habitat over large spatial scales. Such information is beneficial in evaluation of possible impacts on habitat modifications.

In California, black rail (*Laterallus jamaicensis*) habitat use was evaluated using a GIS. Species distribution data was compiled with vegetation type boundaries to determine areas where black rails are more likely to be found. The California black rail is a "category 1" species, indicating that the U.S. Fish and Wildlife Service has compelling reasons to add this species to the federal list of endangered and threatened wildlife (Flores & Eddlemann 1995). Habitat management is crucial to the long term protection of black rails, in this case water levels, as well as wetland area, were the significant habitat parameters which could be modified to enhance areas under-utilized by California black rails. GIS evaluation generated information that led to a more specific modification of habitat protection efforts.

In Michigan, sandhill crane nesting habitat was evaluated from a variety of spatial scales using GIS (Baker et al. 1995). Five different sizes of circular buffers were created around both known nest locations and random points. Habitat variables were evaluated to identify possible patterns of habitat selection. Results from this study imply that as the scale of analysis is increased, relative to a constant study area, the ability to detect and interpret all habitat variables decreases. At a large scale, vegetation, soil moisture, and other detailed land cover characteristics are well represented. However, only at a smaller scale will details about distribution of habitat variables and their adjacency to one another become clear. A comprehensive study of habitat for any species should incorporate both large and small scale evaluations in order to capture specific land cover details, as well as, spatial patterns of habitat characteristics.

Researchers have studied spotted owl (*Strix occidentalis*) metapopulations in the northwest through extensive research on resource and space utilization (Carey & Peeler 1995). Results from these studies have played a valuable role in the development of conservation plans designed to protect the species. Conservation plans identify specific areas which coordinate with other areas to create a landscape matrix conducive to movements and recolonization typical of a spotted owl metapopulation. Design of a reserve has its challenges due to the continuous debate of what actually defines critical habitat characteristics and the debate over private property rights and the public interest (Hunter et al. 1991, Morganti 1994). Congressional legislation mandated that a conservation strategy for the threatened northern spotted owl must employ scientific methods.

In response to this legislation, Murphy and Noon (1992) developed a scientifically defensible planning process for reserve design to protect spotted owl habitat which will be included in the management of public forests in the northwest. Murphy and Noon's planning process included numerous key components, such as the known distribution of the species, and population viability characteristics like the number, size and geographic location of habitat patches. Another key factor was land ownership. Habitat protection on public land is very different from habitat protection on private land (Murphy & Noon 1992).

A GIS was used to develop the reserve design for the northern spotted owl (Murphy & Noon 1992). Four primary map layers which represented spatially explicit information relevant to the species' ecology were developed. The first layer represented species distribution at a scale dependent on species level response to environmental variation and the spatial extent of environmental disturbances. Map layer number two represented the distribution of historical and present locations of suitable habitat including disturbed areas that had the potential of recovery to suitable habitat. The third map layer consisted of survey and census data on the northern spotted owl. The final map layer represented land ownership and use patterns. The combination and intersection of all four map layers became the initial conservation map representing a starting point in the design of a reserve system for the northern spotted owl. Pertinent biological variables were applied to this initial map to create different map patterns. Additional iterations of maps were statistically analyzed in the development of a final map product which represents a scientifically valid approach to the development of a conservation reserve for the northern spotted owl.

The study, for this thesis, follows a methodology similar to Murphy and Noon (1992). Several map layers, including census data, historical data on the population, and land ownership are combined to initiate a plan for protection of burrowing owls and their habitat in Santa Clara County. This study differs from Murphy and Noon (1992) because less is known about burrowing owl demographics and distribution than spotted owls. Thus, this study does not go as far as Murphy and Noon (1992) with the planning process for the future. This study does provide important information on owl distribution in relation to habitat type and land uses. It also indicates areas that burrowing owls might use and which could be sought as owl reserves. This study forms a basis from which burrowing owl conservation plans for the future can be developed.

METHODS

Remote sensing in conjunction with GIS were the tools for this study. Three data sets were used to analyze burrowing owls and their habitat use in Santa Clara County, California. Population data from the Institute of Bird Populations (IBP) and local researchers provided locations of owls within the study area. A Landsat TM image was classified and combined with owl location data to analyze habitat use within the study area. A land use data set from the City of San Jose was overlaid on the classified image with owl locations to identify potential owl habitat areas which can be protected.

Study Site

Santa Clara County is located in northern California, at the southern end of San Francisco Bay. It is a broad, flat valley surrounded by the Santa Cruz Mountains to the west, the Diablo Range to the east, and San Francisco Bay to the north. This study focused on the central portion of Santa Clara County (figure 3), approximately 730 square kilometers of the valley floor. Current land uses within the study area include industrial, residential, commercial, open space and vacant land. Intermixed within all of these land uses is a burrowing owl population of approximately 170 breeding pairs (DeSante & Ruhlen 1995, Trulio in review).

Burrowing Owl Location Data

When the IBP censused burrowing owls in California during the years 1991-1993 all potential habitat was included in their census except the Great Basin and desert areas in southern California. IBP broke the state up into 1835

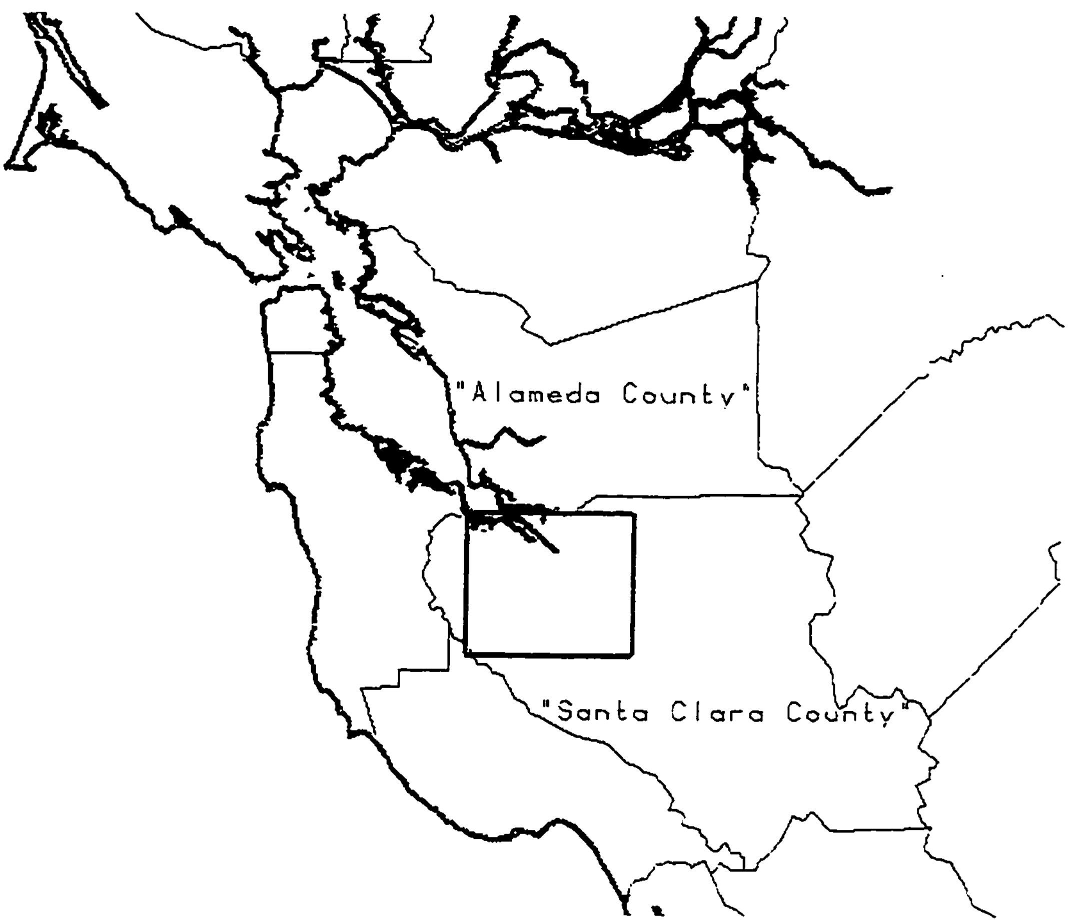


Figure 3. Map of San Francisco Bay Area counties. The study site is outlined in red.

census blocks which were 5 km x 5 km. Each block extracted from a 7.5 minute topographic map became the data sheet where volunteer census takers recorded owl locations, during the burrowing owl nesting season, May 15 to July 15.

In preparation for the census, IBP gathered together historical locations of burrowing owls for the years 1986-1990, from breeding bird surveys, Christmas bird counts and mitigation studies.

In addition to the historical and census data from IBP, this study utilized owl location information from local researchers. These researchers included Dr. L. Trulio, P. Delevoryas, Biosystems Analysis Incorporated, and myself. We censused burrowing owls in Santa Clara County in 1994.

An owl location is where one or more owls are observed at a burrow. All geographic locations of burrowing owls in Santa Clara County, historical records for the years 1986-1990, census records from IBP for the years 1991-1993 and local census information for the year 1994, were digitized using ARC/INFO Geographic Information System (GIS) software, v. 7.0 (ESRI 1994). Five georeferenced point coverages, representing four years (1991-1994) of owl locations throughout Santa Clara County and historical locations (pre-1991) of owls in the County, were generated. Each point in the coverages was attributed with the year in which it was referenced, the map sheet number, and a specific location number recorded in the census for that location.

Habitat Classification

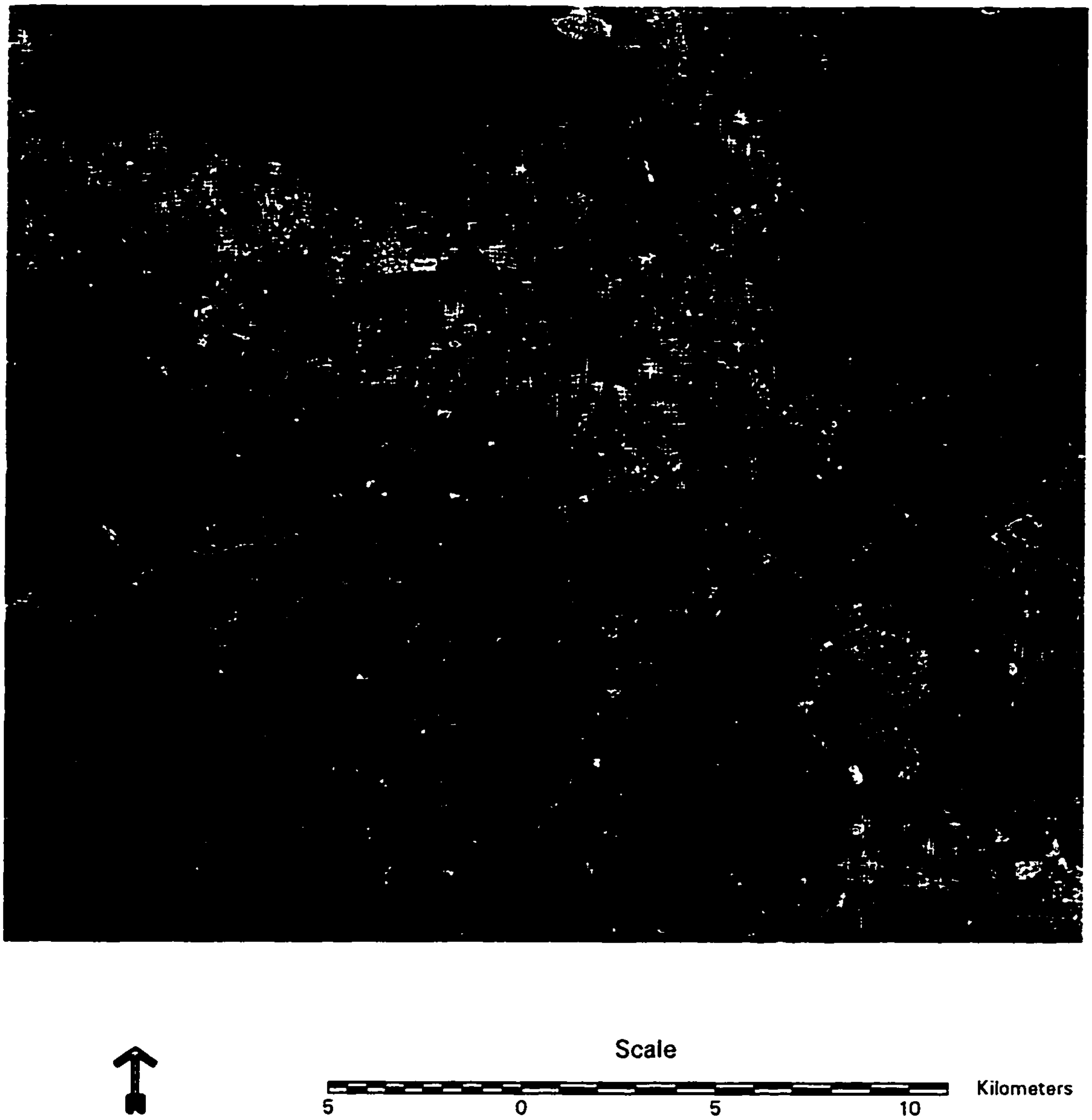
A June 20, 1990, Landsat TM scene (path 44, row 34, ID 52302-18061) which includes the San Francisco Bay Area, was used to characterize six categories of land cover. The image, in its raw data format, was registered to a

30 meter Universal Transverse Mercator (UTM) grid using corner and center coordinates supplied by EOSAT (C. Bell, NASA/Ames 1993). A subset of the full Landsat scene, which included over 95% of the known owl locations in Santa Clara County, both past and present, was made by excluding land above 250 feet in elevation (figure 4). Lands over 250 feet in elevation were eliminated based on information gathered by the IBP which showed that 98% of the burrowing owls in Santa Clara County occupied sites below 200 feet in elevation. The southern-end of the Santa Clara County, including the towns of Morgan Hill and Gilroy, had very few reported sightings of burrowing owls, and was not included in the study.

The software program "Spectrum" was used to classify the six band spectral image containing the section of Santa Clara County under 250 feet in elevation. Spectrum, developed by Los Alamos National Laboratory, pre-processes the data using clustering and vector quantization by taking advantage of intrinsic properties of the digital data. The raw spectral data from the Landsat TM scene was grouped using a nearest neighbor algorithm into 240 clusters, creating a smaller more compressed data set, while retaining the integrity of the original spectral data. Each pixel in the multi-band image was assigned to one of these clusters. The output was a single-band image, called a clustered image.

Classification of the clustered image included on-screen interpretation of visible land cover and physical features, with the aid of aerial photography and knowledge of the area. When a pixel, or group of pixels, is selected and put into a designated land cover category, Spectrum automatically selects all other pixels within the image that have the same electromagnetic reflectance

Figure 4. Landsat TM image of the study area displayed as an infrared image with owl locations shown in yellow.


Scale
5 0 5 10
Kilometers

value and places them into the same land cover category. This eliminates the need to individually classify each pixel.

The six land cover categories used were water, developed land, irrigated grassland, trees/shrubs/wetlands, dry grassland and bare soil. The water category included the San Francisco Bay, salt ponds, water retention ponds and creeks and rivers. The "developed land" category included areas covered by concrete, asphalt, buildings and other human-made structures. The "irrigated grassland" category included parks, golf courses, athletic fields and lawns. The "trees/shrubs/wetlands" category was a big category which included all vegetation other than grassland. The "dry grassland" category included vacant, unimproved lands, airport runways and fallow non-irrigated farmland with grass and small herbaceous plants. The "bare soil" category included land such as farmland, development sites and some vacant unimproved land that has been cleared of vegetation. These land use categories were chosen because they represent the dominant land uses and the types of habitats that burrowing owls prefer especially, dry grass, irrigated grass and areas of bare soil (DeSante & Ruhlen 1995) (figure 5).

An accuracy assessment of the classification was performed using Erdas IMAGINE software, v. 8.0 (1994). An equalized random selection of 245 5x5 pixel blocks were selected with 35 locations chosen within each class for the assessment. Photography dated June-July 1990 and multi-spectral Landsat TM data were used to identify the actual land use of the selected pixel clusters. A good working knowledge of this area was an asset in the creation of a good classification due to definitive knowledge of the landscape (Lillesand & Kiefer 1994).

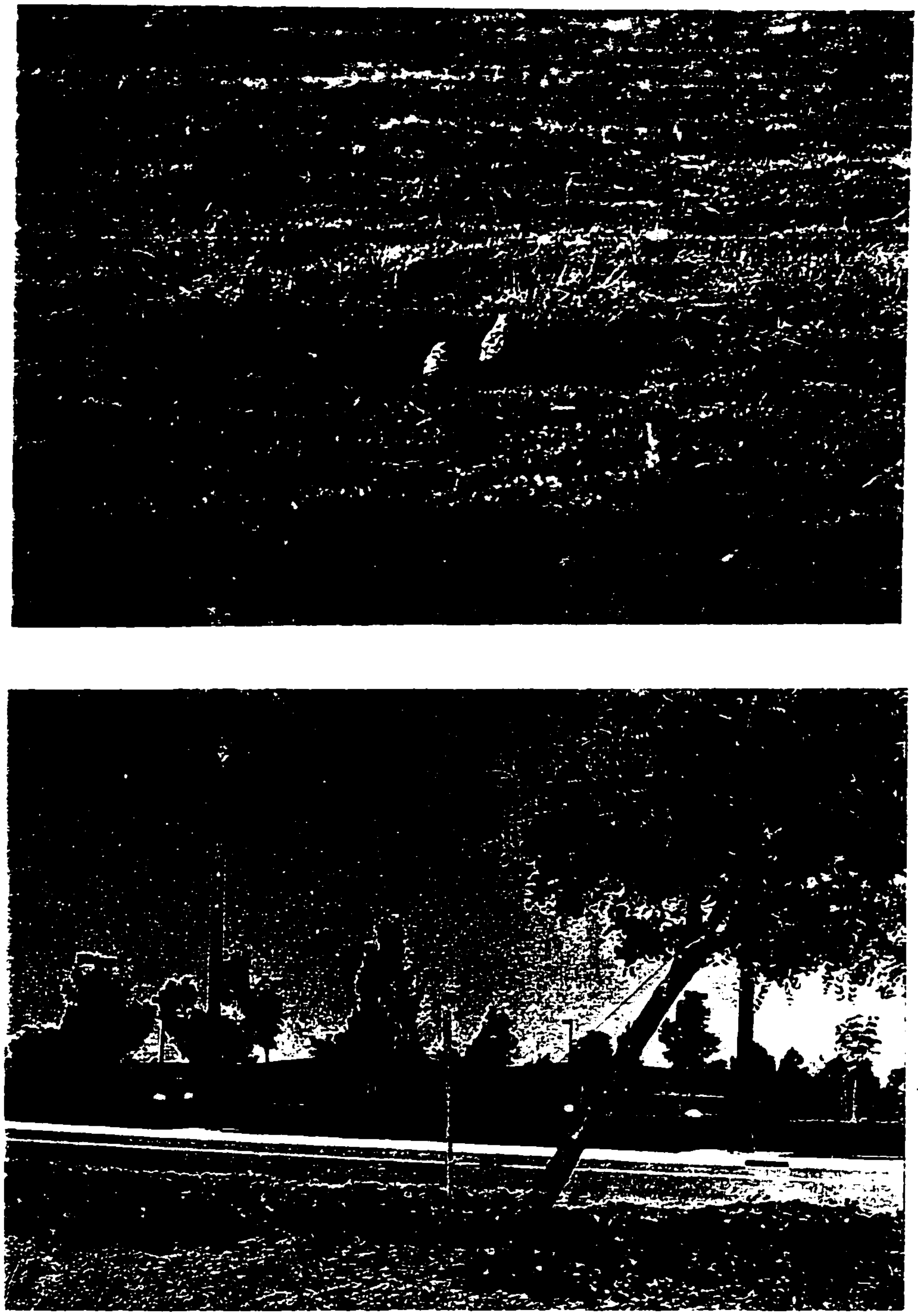


Figure 5.

Top: Dry grass habitat, spring green conditions

Bottom: Irrigated grass habitat, a golf course in Santa Clara

Photos by J.T. Buchanan.

Geographic Information System

GIS was used to combine the data sets described above: burrowing owl locations, the classified Landsat image, the city limit for Santa Clara, and the vacant land inventory (VLI) from the City of San Jose. Spatial relationships between owl locations were evaluated, land cover was quantified by category, habitat at each owl location and within regions around owl locations was identified, and owl locations with respect to current and projected land uses were evaluated to determine protection status of owls in the study area.

Spatial Analysis of Burrowing Owl Locations

A spatial analysis of the owl locations included interpretation of distribution patterns over time. Five GIS coverages, one for each year (pre-1991, 1991-1994), which consisted of a point for each owl location were plotted and visually compared to one another. Polygons were drawn around groups of owls based on criteria from studies done by DeSante and Ruhlen (1995) and Trulio (in review). Groups of 5 or more locations in a single habitat area have a much lower chance of extinction and the need to protect all current large colonies to avoid stochastic factors which can eliminate a small population (DeSante & Ruhlen 1995, Trulio in review).

Burrowing Owl Habitat Analysis

An analysis to determine the type of habitat used by owls was done by overlaying a raster version of the point data from years 1991-1994, 90 meter buffer data and polygons onto the classified image in GRID v. 7.0 (ESRI 1994). The amount of area within each land cover category was calculated.

The amount of dry and irrigated grassland habitat was calculated for each owl location between the years 1991-1994. The amount of dry and irrigated grass habitat within a buffer of 90 meters around each location was calculated. The 90 meter buffer was chosen because it is an approximation of the territory around an owl location (Thomsen, 1971). The amount of dry and irrigated grass habitat was also calculated within the polygons which represented groups of five or more owl locations.

Future Land Use

An analysis of potential future habitat or reserves for the burrowing owl in parts of Santa Clara County was conducted by evaluating the location of owls with respect to potential habitat and future development throughout the cities of San Jose and Santa Clara. Visual inspection, in conjunction with information about land ownership, was used to evaluate whether the known owl locations within the City of Santa Clara were protected from habitat loss in the future. Future habitat in the City of San Jose was also evaluated. This was done by overlaying the vacant lands inventory generated by the City of San Jose which showed projected land uses for currently vacant and agricultural lands. Projections were made about how habitat for burrowing owls could be increased in the northern portions of San Jose by mitigating development of open or agriculture land with burrowing owl habitat. The expected development throughout the entire study area was considered with respect to the impacts on burrowing owls in the future.

RESULTS

Spatial Analysis of Owl Locations

Visual inspection of owl locations for each of the years, 1991-1994 and pre-1991, revealed distribution trends. The pre-1991 owl locations were fairly evenly distributed across the study area, illustrating that owls were previously found throughout the urban matrix of Santa Clara County. During the years 1991-1994 the distribution became clumped. Most of the owl locations for the years 1991-1994 fall into 9 groups in the study area (figure 6). Red polygons are drawn around the groups which represent habitat areas with 5 or more owl locations which are important to the long term viability of owls throughout Santa Clara County.

Land Cover

The entire study area was 730 square kilometers. The amount of land in each of the land cover categories is listed in table 1. The least abundant land cover category was irrigated grass habitat and the most abundant was developed land (figure 7).

Table 1. Land area within each land cover category

category	area in square kilometers
water	42.8
developed land	340.2
irrigated grass	11.8
dry grass	34.2
trees/wetlands/shrubs	143.1
bare soil	61.8
land above 250 feet in elevation	95.7

Figure 6. The spatial distribution of burrowing owls throughout the study area using the five data sets: pre-1991, 1991, 1992, 1993, and 1994. Red polygons represent a continuous habitat area with at least five owl locations.

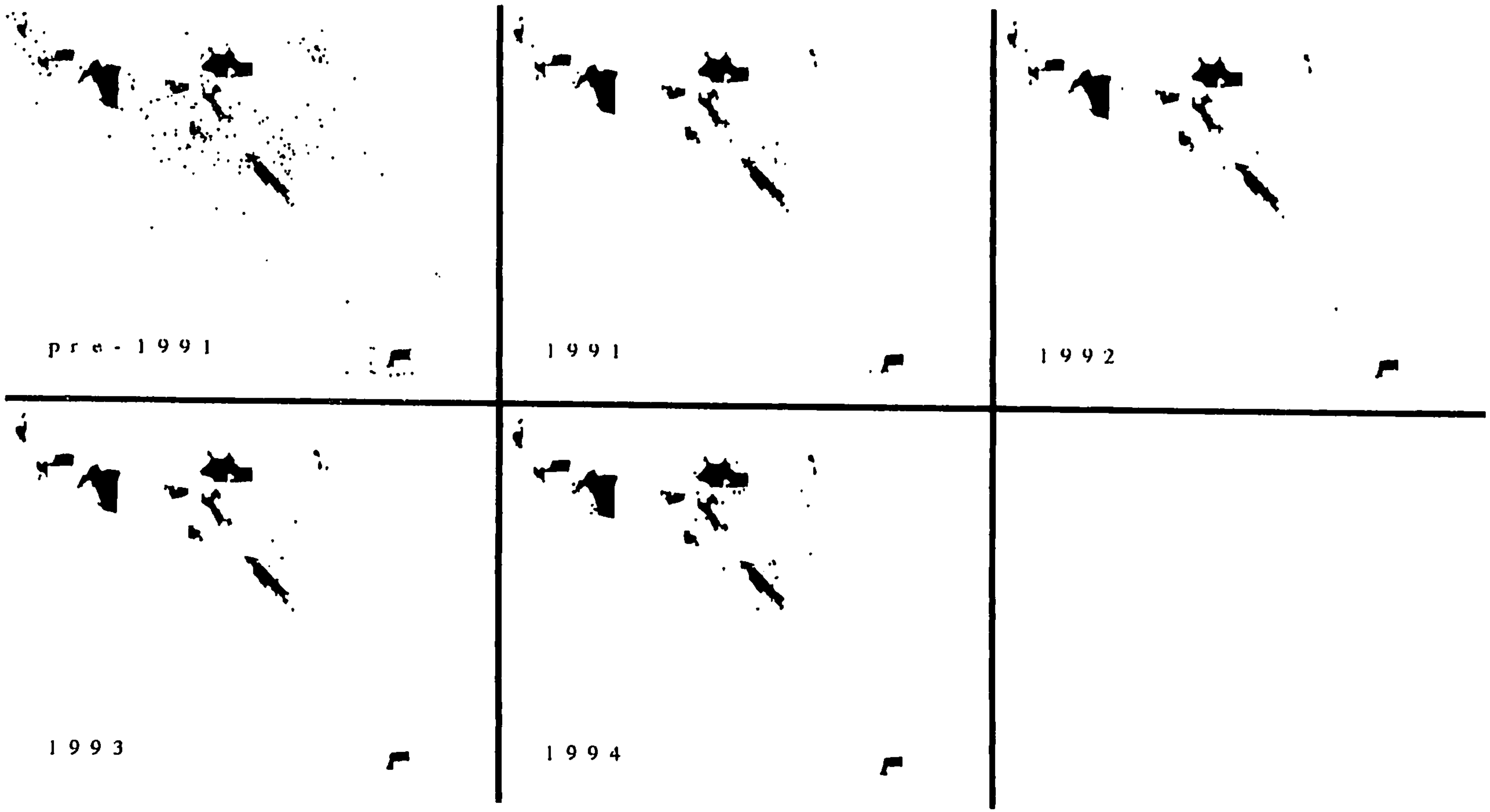
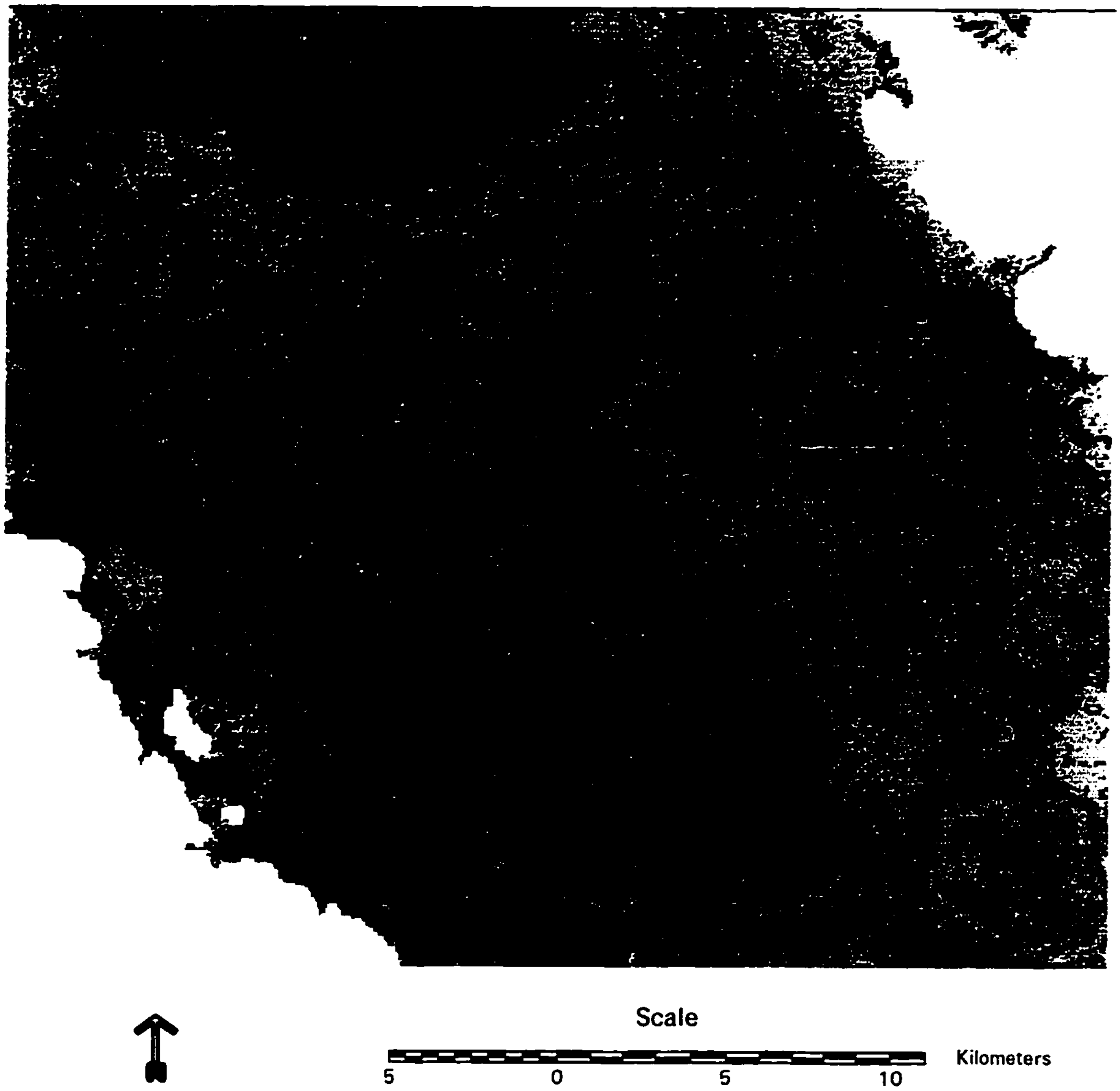

pre-1991
1991
1992
1993
1994

Figure 7. Classified image.

Legend

land cover category	color
water	blue
developed land	dark pink
irrigated grass	light green
dry grass	tan
trees/wetlands/shrubs	dark green
bare soil	light pink
land above 250'	white


Scale
5
0
5
10
Kilometers

Dry and Irrigated Grass Habitat

Within the study area 5% of the land was dry grassland habitat and 2% was irrigated grass habitat. The amount of both dry grass habitat and irrigated grass habitat at owl locations (29m pixel/location), within 90 meter buffer areas around each owl location and within the polygons representing groupings of 5 owl locations or more, was quantified (table 2). The 90 meter buffer was chosen because it is an approximation of the territory around an owl location (Thomsen 1971). Using the location of owls, identified by a single pixel (29 m^2), for each of the years 1991-1994, an average of 26% of the owl locations were found in dry grassland and 6% were found in irrigated grassland. Within circular buffers of 90 meters around each owl location, on average, 18.5% of the habitat was dry grass and 5% irrigated grass habitat. Within the polygons drawn to represent the groupings of 5 owl locations or more there was 21% dry grassland habitat and 9% irrigated grassland habitat. Figure 8 shows the spatial relationship between the owl groups and dry and irrigated grass habitats.

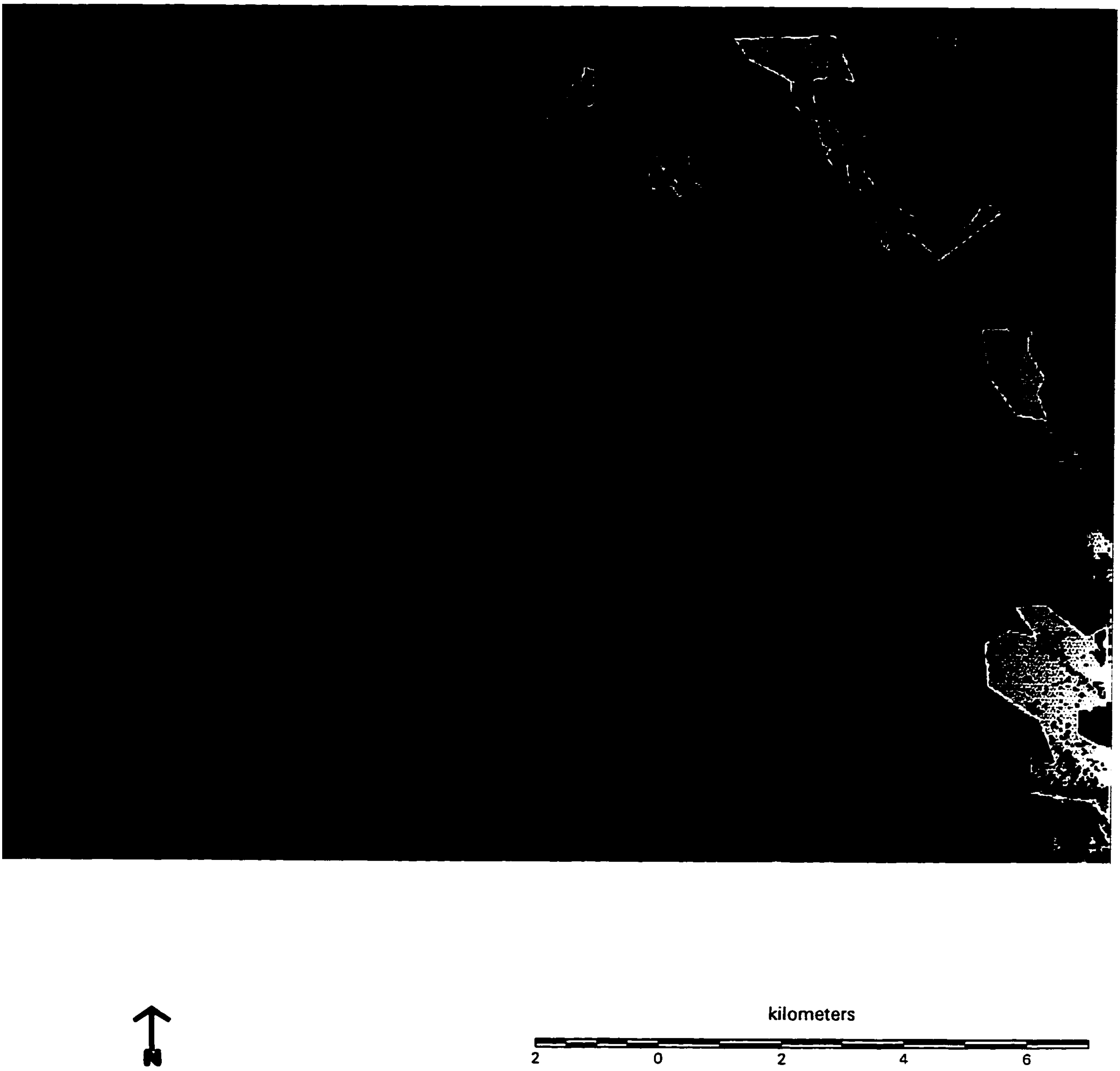
Table 2. Dry and Irrigated Grass within the study area, owl locations, 90 meter buffers, and polygons.

Location	% Dry Grass	% Irrigated Grass	Total Area (km^2)
Total Study area	5	2	730
Owl Locations (n)[1]			
1991 (62)	2	8	
1992 (75)	25	2	
1993 (47)	32	4	
1994 (83)	19	10	
average %	26	6	
90 meter buffers[2]			
1991	22	6	1.5
1992	18	6	1.8
1993	20	3	1.1
1994	14	6	2.1
average %	18.5	5	
owl colonies[3]	21	9	16.3

1. This represents the land use with the pixel (30m x 30m) where each owl location was found.
2. This represents the land use within a circular buffer around each owl location, approximately square meters with each buffer.
3. This represents the land use with the polygons drawn around habitat areas that had 5 or more owl locations adjacent to one another.

Visual inspection of owl locations with respect to dry and irrigated grass habitat shows that several large areas of these habitat types are not occupied by burrowing owls. Three areas, the hills between 50-250 feet in elevation surrounding the valley, the south-eastern region of San Jose, and the northern reaches of San Jose, including parts of Alviso (south-end of the Bay), have significant dry grass habitat and no recorded owl locations. Owls are not utilizing all dry and irrigated grass habitats in the study area. Figure 8 illustrates these areas outlined in white.

Figure 8. Dry and irrigated grass habitat within the study area based on results of classification. Irrigated grass is green, dry grass is tan and owl colonies are outlined in red. Areas outlined in white represent dry grass habitat not utilized by burrowing owls.


N
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2 0 2 4 6

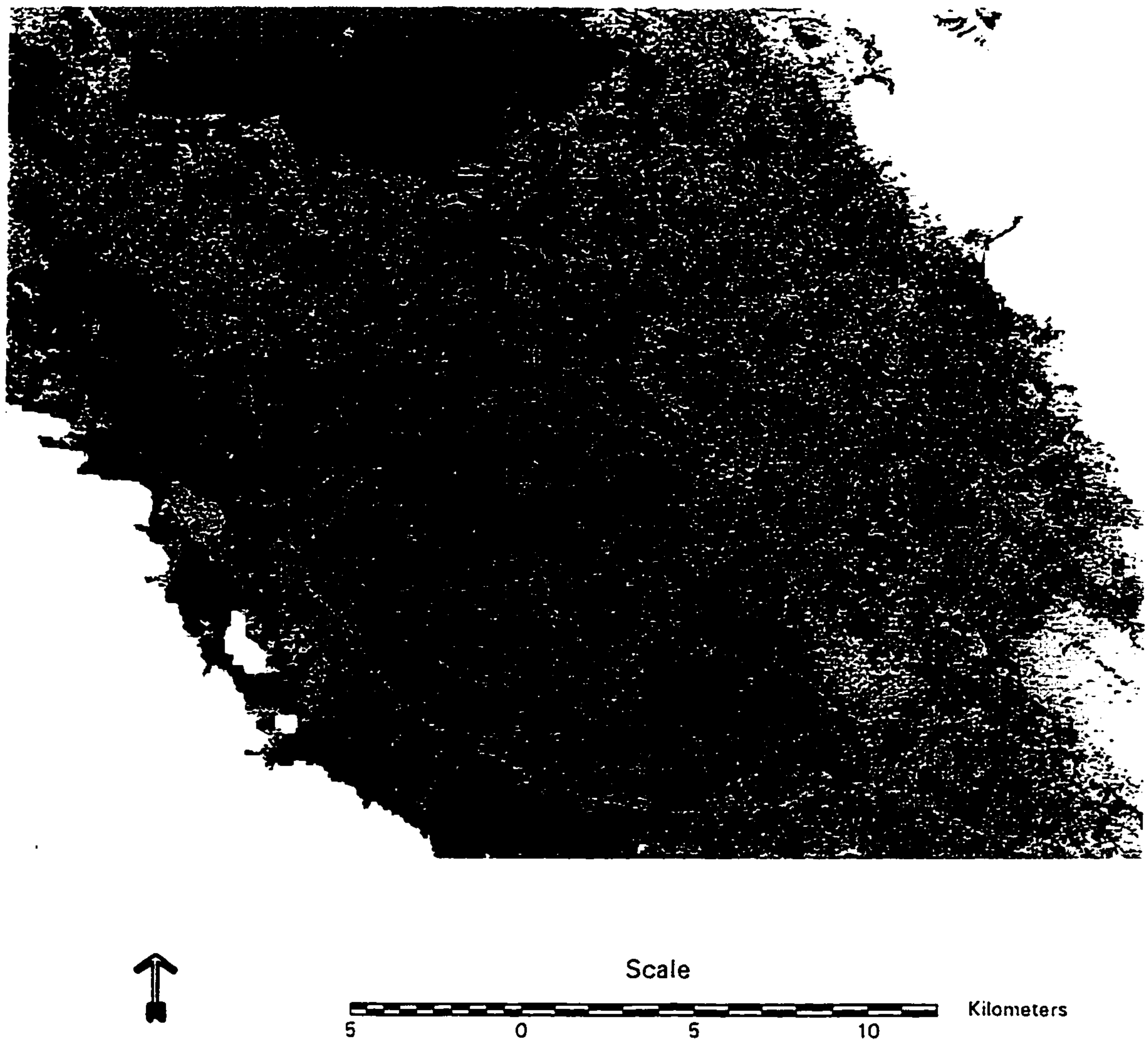
Burrowing owls within the City of Santa Clara

Within the city of Santa Clara there were 19 owl locations in 1991, 18 in 1992, 9 in 1993 and, 25 in 1994. There were 50 owl locations within the city between the years 1986-1990, as seen from pre-1991 data.

There are two owl colonies in the city. The number of owl locations within the Mission College colony remained consistent during the four census years 1991-1994 (6, 11, 11, and 10 respectively). The other large group of owls within the City of Santa Clara, along Lafayette Road with 6, 5, 0, and 8 owl locations, respectively, for the years 1991-1994.

In the City of Santa Clara, over the years 1991-1994, an average of 43% of the birds were located on protected lands. The other 57% were located on private land slated for development in the near future (figure 9).

Figure 9. Classified image of the study site with the City of Santa Clara shown outlined by a black polygon. Yellow polygons represent groups of 5 or more owl locations within a continuous habitat area. Black dots represent owl locations for the years 1991-1994.


Scale
5 0 5 10
Kilometers

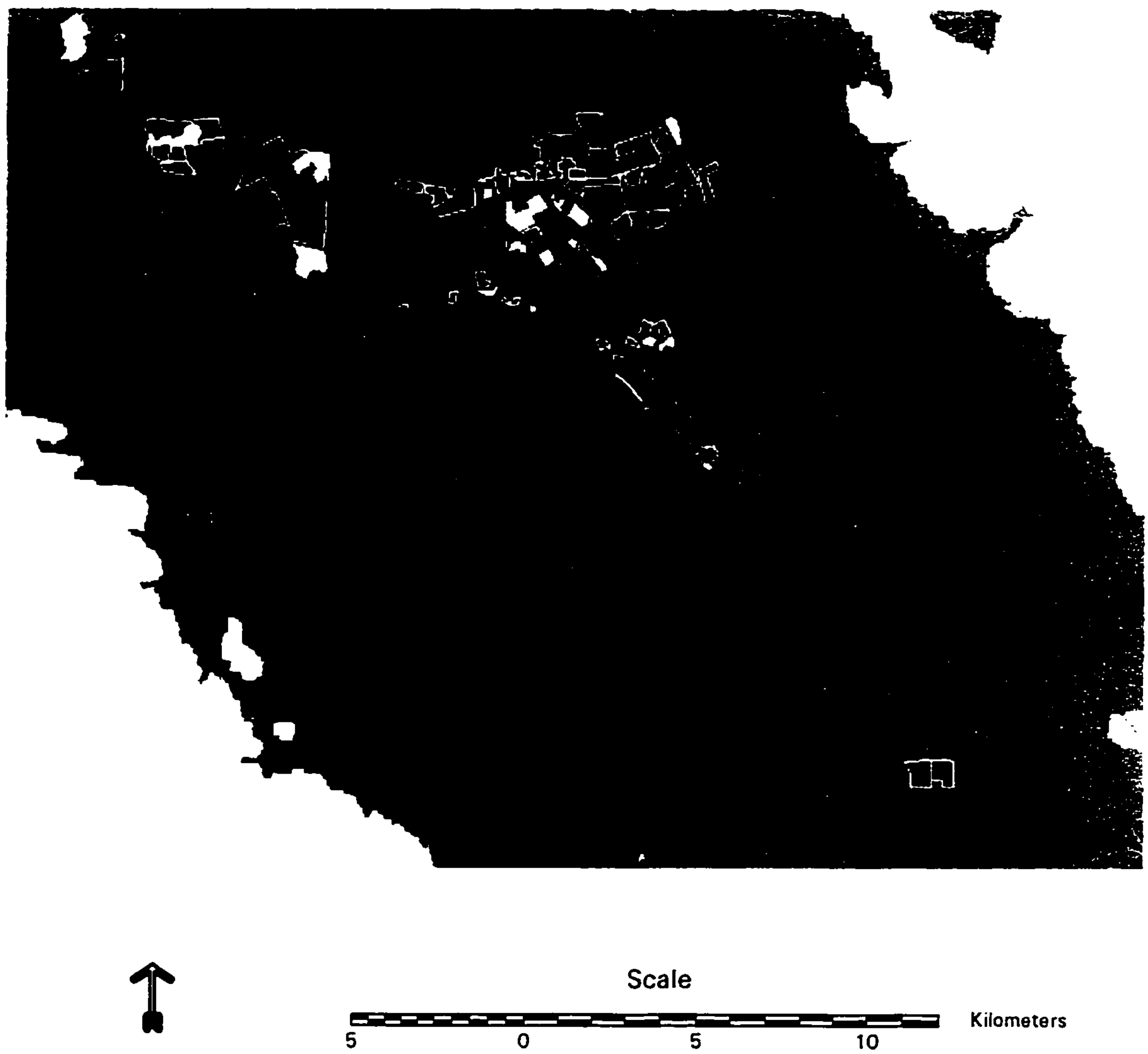
Burrowing Owl habitat and Land Use

The vacant lands inventory for the City of San Jose which identifies projected land use within city boundaries for all vacant, undeveloped lands was used in conjunction with knowledge of the area to develop a land use map. In Figure 10, the polygons are color coded based on ownership and level of burrowing owl habitat protection. Green polygons are areas of public land which have varying levels of protection including parks and designated open space regions. Red polygons represent private land which is likely to be developed before the end of the century. White polygons are areas that have been developed since the date of the satellite image (July 1990). Blue polygons are designated as public/quasi-public land and have varying levels of protection. Yellow polygons are golf courses where conservation easements can be established in order to protect owl nesting locations around the perimeter of the golf course.

Figure 10. Classified image with polygons indicating levels of protection for burrowing owl habitat.

Legend

polygon color	protection level
red	none, expected development
blue	moderate, public/quasi-public
yellow	potential, golf courses
green	high, public lands
white	none, developed since 1990


Scale
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Kilometers

Accuracy Assessment of the Classification

An accuracy assessment of the classification process was performed using aerial photography dated June-July 1990 and Landsat TM data displayed as a color infrared image for reference. A total of 245 assessment sites, 35 random points selected from each of the six land cover categories, were chosen, of which 208 were correctly classified based on the reference data (table 3).

Table 3. Results of the accuracy assessment, Erdas IMAGINE software, v. 8.0 (1994). Reference sources: 1990 aerial photography and Landsat TM data displayed as a color infrared image

Class Name	Producer Accuracy	User Accuracy	Kappa
water	97.14%	97.14%	0.9667
developed land	55.93%	94.29%	0.9247
irrigated grass	100.00%	85.71%	0.8372
trees/shrub/wet.	86.21%	71.43%	0.6759
dry grass	91.89%	97.14%	0.9663
bare soil	85.00%	48.57%	0.4400
245 reference points (35/class)			
overall classification accuracy	84.90%		
overall Kappa statistics	0.8238		

DISCUSSION

The goal of the image classification was to identify the types of lands used by burrowing owls in Santa Clara County and to identify lands which may serve as long term owl habitat. Since correct classification of lands by the program is critical to this analysis, an accuracy assessment was performed to examine how well the classification achieved this goal. Congalton (1991) recommends 50 accuracy assessment sites per land use category in the classification, based on the relative importance of each category. Congalton made this recommendation for very large study areas, often complete Landsat TM scenes, which are approximately 32,400 square kilometers. This study was only a fraction of that size, 730 sq. km., therefore, 35 accuracy assessment sites per land use category was considered adequate.

The type of error found in classifications include omission error (exclusion) and commission error (inclusion). Omission error, also called producer's accuracy is the number of pixels that should have been classified but were omitted. Commission error, also called user's accuracy is the number of pixels improperly included in a category. The Kappa coefficient for each class represents a third error, one a completely random classification would generate. The percentage of correct values which reflect "chance" agreement versus "true" agreement is interpreted by the Kappa coefficient. Even a classification based purely on random assignment of pixels has a percentage of correct values inherent in its development, creating the appearance of a good classification. Overall, good accuracy assessment is a factor of the quality of the information used to determine "true" land cover classes, as well as, avoidance of errors from spatial misregistration, photo interpretation, and data entry (Lillesand & Kiefer 1994).

An overall 85% accuracy rating is an acceptable level of error for a classification of remotely sensed data (Lillesand & Kiefer 1994). Individual categories within the classification will often have better accuracy than others. In this study, both the omission error and commission error of dry and irrigated grassland was 15% or less, indicating that these two categories adequately identified dry and irrigated grass areas throughout the study site. Within the classification, the greatest amount of error occurred in the differentiation between the developed and bare soil categories. User accuracy for bare soil was only 49% and producer accuracy for developed land was 56%. Spectral curves and scatter plot representations of bare soil and developed spectral classes have considerable overlap, and confusion between the two categories is difficult to avoid. The other two categories, water and trees/wetlands/shrubs had acceptable accuracy ratings (table 3).

The census of owls conducted by the IBP revealed a sharp decline in the number of burrowing owls in Santa Clara County over the past decade. Spatial analysis of the distribution change over the time of the study showed not only a decrease in the number of owls, but also a clumping of the remaining owl locations. Nearly all of the burrowing owls currently residing in the study area can be found within a thin band around the south end of San Francisco Bay and in a ribbon of habitat running south, from the bay through the San Jose airport. Moreover, owls are concentrated in habitat patches. The decline in owls and their habitat was confirmed by a ground inspection of all pre-1991 locations by Trulio and Buchanan in 1995. This inspection revealed that over 60% of the pre-1991 locations have been replaced by development. Conversion of dry grass land into developed land is the main reason for the

60% population decline throughout the cities of San Jose, Santa Clara, Sunnyvale, Milpitas, and Mountain View.

This study identified two areas not currently used by owls which appear to be potential habitat. First, there are large tracts of dry grass habitat throughout the Diablo Range located on the eastern side of Santa Clara Valley. There are few recorded owl locations throughout this region. Owls do not appear to accept this area as suitable habitat for reasons which are currently unknown. One possibility may be the difference in the predators or prey found in the foothills (pers. observ.). Adequate studies of this region have not been performed to determine if it represents potential habitat for the future.

Currently, the City of San Jose, in conjunction with the County of Santa Clara, is working on protecting thousands of acres of hillside and flat agriculture land from development in the future. An urban growth boundary around the City of San Jose was initiated in May 1996 by the Mayor of San Jose, Susan Hammer, and a working plan is currently being developed (Greenbelt Alliance 1996). Regional cooperation of this type to curb urban sprawl is commendable. A problem with this plan from the standpoint of the burrowing owl population is that it will increase efforts to infill lands within the urban boundary which are undeveloped. Some of these locations are currently burrowing owl habitat. It is necessary to determine whether the hillside areas can support an owl population before all burrowing owl habitat on the valley floor is developed.

The second potential owl habitat area exists throughout north San Jose and Alviso, on the valley floor. There are several areas of dry and irrigated grass habitat which do not have recorded owl locations. Land management practices which create unsuitable habitat, such as disking for weed abatement or farming may be the reason owls have not been recorded in these locations. It is also possible that the census data were not adequate. These locations represent potentially good owl habitat because they are near other colonies, within 2 miles, a distance which should allow dispersal between colonies (Trulio in review) The applicability of these areas as habitat in the future should be studied further.

It is worth noting that the trend of increasing burrowing owl use of transitional lands is well documented in Florida. Transitional lands are lands which were in agriculture but have been left fallow in anticipation of future development. By 1980, 46% of all wetlands in Florida had been drained, filled, or excavated. Agricultural development caused 2/3 of these losses, mostly in south Florida. With a continuous increase in human population throughout Florida, many of the these agricultural lands are now being developed. Studies also show that burrowing owls in Florida utilize transitional habitat until over 60% of the land area becomes developed (Wesemann & Rowe 1987).

Transitional lands exist in Santa Clara County where agricultural practices have ceased and development is anticipated in the near future. Development would eliminate burrowing owl habitat permanently and most of these lands are privately owned. The trend throughout the study area when transitional lands are developed is to relocate any owls residing on the property which is to be developed off to some other location. There is little record of how these relocated birds have succeeded in their new locations, however the total number of owls in the areas continues to decline.

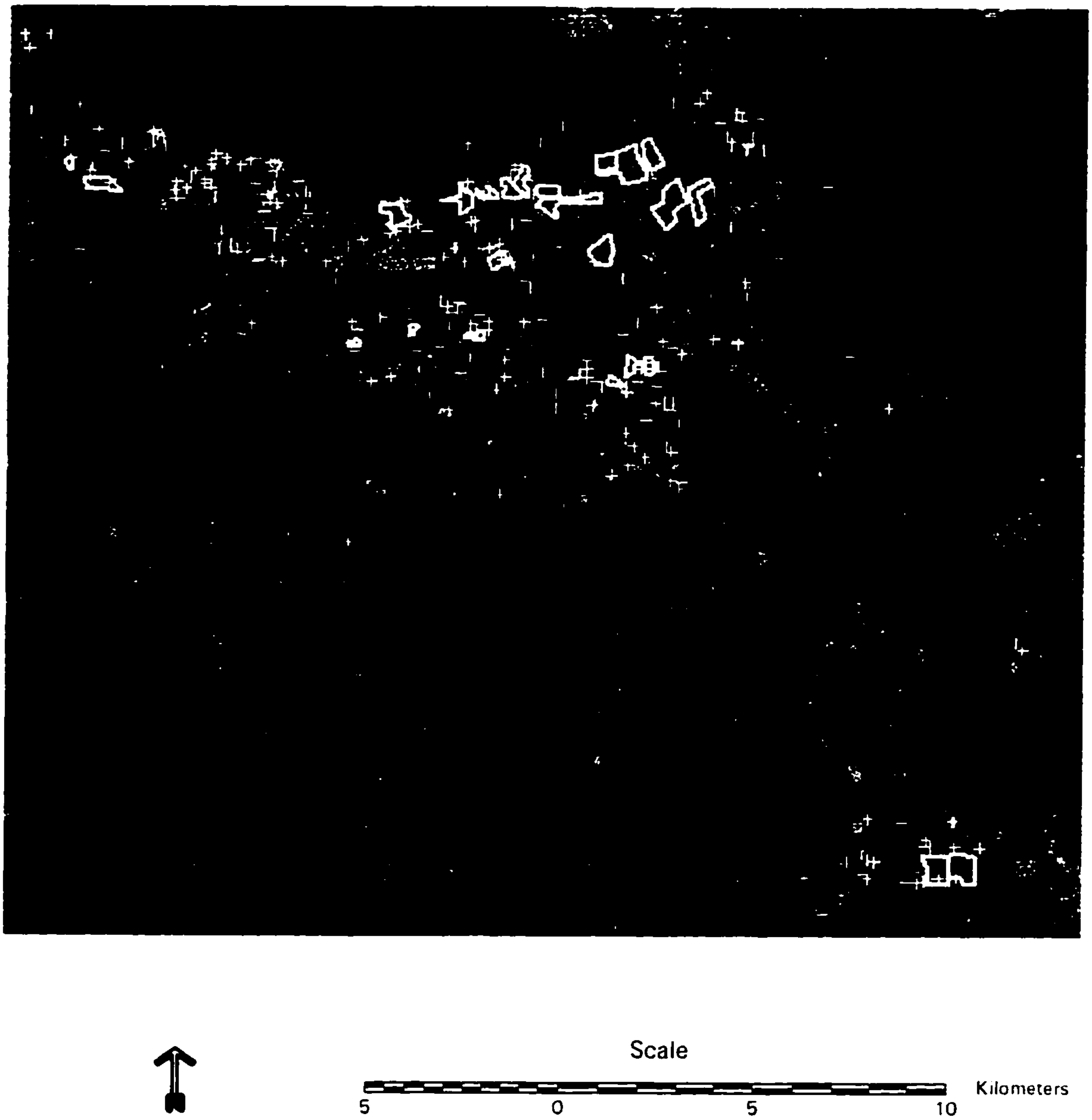
Northern San Jose appears to be an excellent area for burrowing owl habitat preservation because there is still a significant number of undeveloped parcels (figure 11). The vacant land inventory database for the city of San Jose and its future land use projections indicate that much of this open land will be converted to housing or industrial parks. Once this land is converted to urban uses, dry grassland habitat will be nonexistent and the extent of the irrigated grass habitat may not provide adequate habitat for the owls. This study shows that owls utilize dry grass habitats in preference to irrigated habitats. Alviso, located adjacent to the south end of San Francisco Bay and a suburb of San Jose, currently has the most contiguous open areas suitable for owls. The land in Alviso is not as economically viable for development as areas within the urban matrix of San Jose, Milpitas, Sunnyvale, Mountain View, and Santa Clara. However, as open lands become scarce, development in Alviso is expected to occur.

Unlike San Jose, burrowing owls located within the City of Santa Clara have few protected habitats because most of the land is privately owned and subject to development. In addition, there is little vacant land left within city limits. However, corridor connections between colonies are possible, utilizing utility rights-of-way. Another approach to protecting the regional population would be for the City of Santa Clara to collaborate with the City of San Jose to identify and preserve undeveloped lands that could be contributed to a mitigation bank.

Efforts must be made now to preserve some land for owl habitat. Planning which integrates burrowing owls should be a high priority throughout the County. According to Trulio (in review), in order for the population of owls in Santa Clara County to be viable in the future, available owl habitat must increase.

Areas in which the larger groups of owls are located can be considered protected habitat based solely on land management practices. For example, burrowing owls which reside on San Jose International Airport property, located mostly in San Jose, or Moffett Field in Mountain View (the property includes an airfield), have a much greater chance of long-term survival because land use on these properties is not expected to change significantly in the future. The dry grass habitat at these locations is mowed several times per year, creating an environment which is conducive to a large number of burrowing owls (figure 12). Management of the airport maintains nesting habitat away from runways, protecting both owls and public safety.

Figure 11. Current undeveloped lands are outlined in white. Alviso is located at the very southern end of the San Francisco Bay. North San Jose is located between San Jose International Airport and the south end of the Bay.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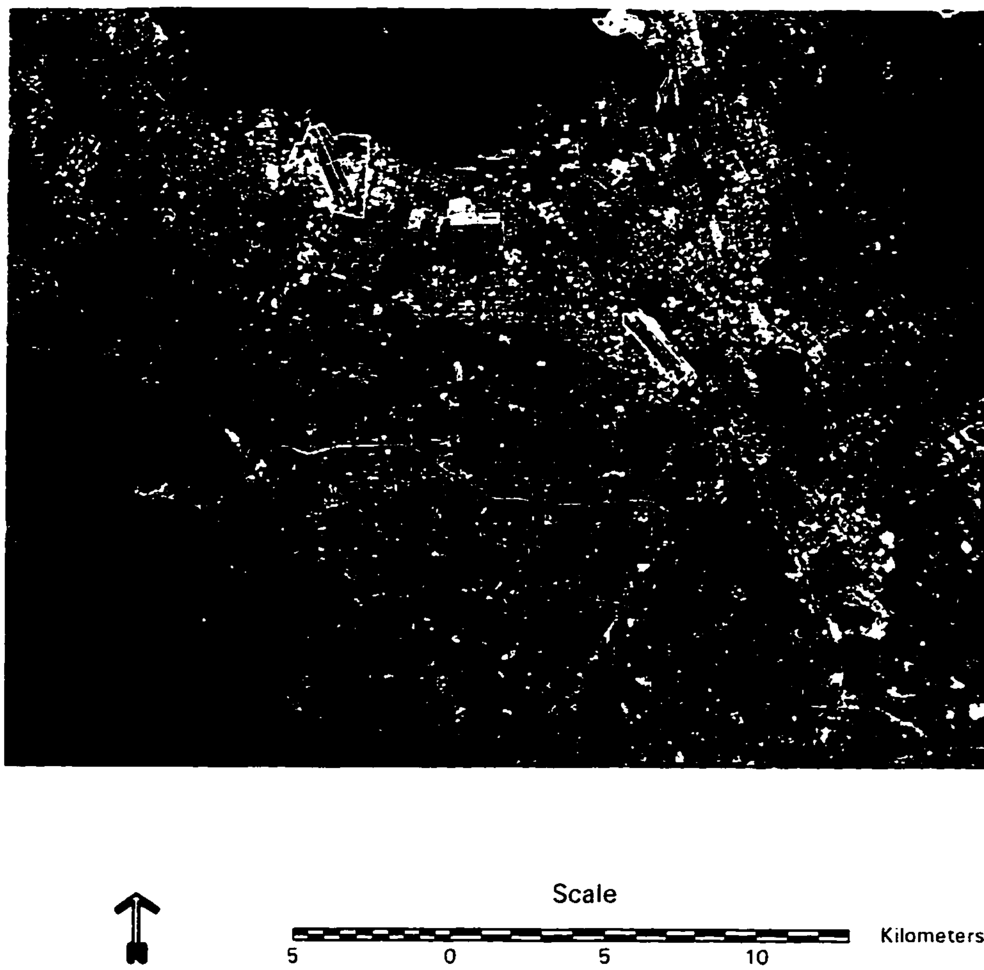
Kilometers

Figure 12. TM image of the study area. The two major airfields in the South Bay are outlined in white. The northern one is Moffett Field and the southern one is San Jose International Airport. Owl locations for the years 1991-1994 are shown in yellow.


Scale
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Kilometers

Owls located on public land are more likely to survive in the future, such as owls at Sunnyvale Baylands Park and Shoreline, where burrowing owl habitat, both nesting and foraging, is actively protected.

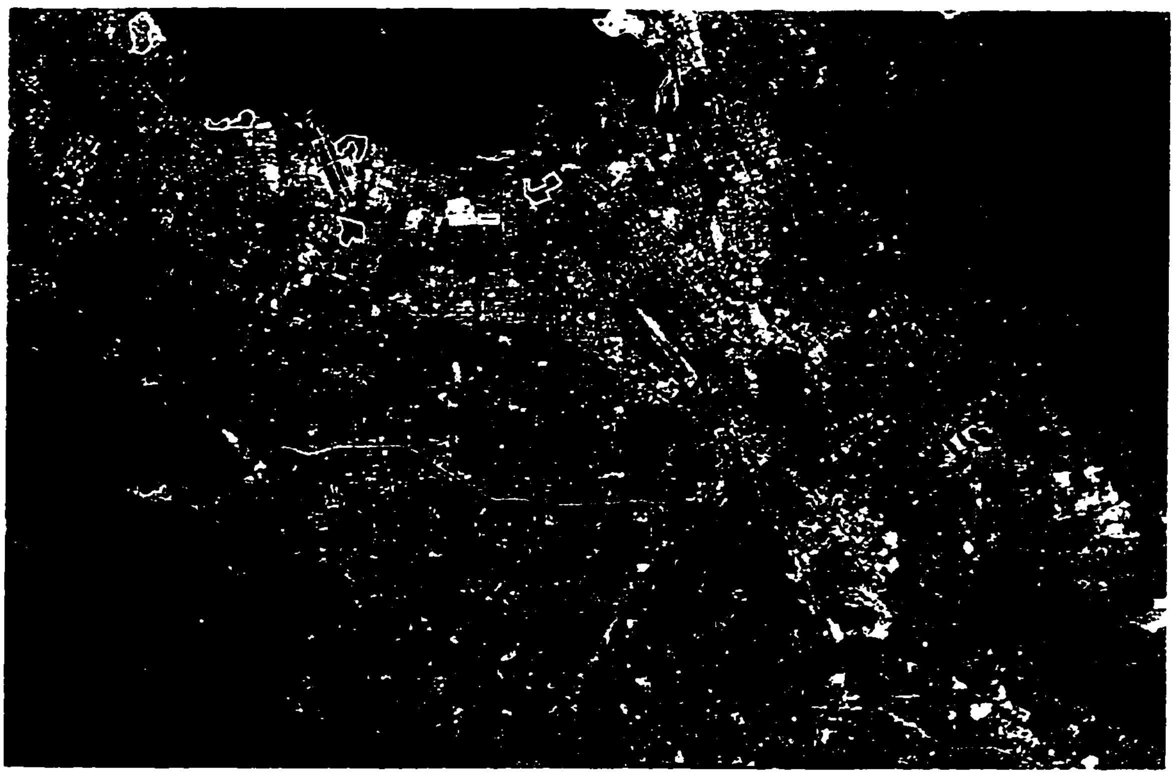
RECOMMENDATIONS

The fact that burrowing owls are found on private land throughout San Jose, Santa Clara, Milpitas, Mountain View, and Sunnyvale creates the need to act in a collective manner which will protect the entire population of burrowing owls in this area. There is no one single development project that will decimate the population, but incremental losses of habitat have a cumulative impact on the number of owls and will eventually result in too small a population for survival (Trulio in review). Over the past decade, owls have been eliminated from the areas throughout the center of the urban matrix and restricted to lands near the edge of the Bay. As these last open lands are developed, the owls will be extirpated from Santa Clara County as has occurred in so many other counties around the Bay (DeSante & Ruhlen 1995).

In light of the findings of this study, the following actions are recommended for protecting burrowing owls and their habitat in Santa Clara County:

1. Identify lands in Alviso, the largest region of contiguous open land, and other north San Jose areas which can be either protected or managed as burrowing owl habitat in the future.
2. Identify golf courses located between the large owl groups that have the potential of protecting burrowing owl habitat (figure 13). Establish a conservation easement with each golf course which incorporates protection of owl nesting locations into the regular management plans for the course.

Figure 13. Golf courses are outlined in white.



Scale

5 0 5 10 Kilometers

3. Establish conservation easements on electrical, transportation, and water utility corridors, to form "habitat corridors" between the larger groups of owls in Alviso, Santa Clara, San Jose, Sunnyvale, Mountain View, and Milpitas.

4. Establish conservation easements or protection agreements with airports in the area to ensure protection of burrowing owls in the future.

5. The lower undeveloped foothills of the Diablo Range which are adjacent to the valley floor should be studied to determine if this region could be habitat in the future. The Greenbelt Alliance in conjunction with the City of San Jose and the City of Morgan Hill are working toward a greenbelt buffer surrounding their cities which could include this potential owl habitat.

Research indicates that this population is teetering on the edge of extinction (Trulio in review). No loss of burrowing owls or their habitat should be tolerated in the future in Santa Clara County. Development which impacts burrowing owls even incrementally needs to be viewed with respect to the whole picture of available habitat in Santa Clara County. All municipalities should pool together ideas of how to secure adequate burrowing owl habitat in this area for the future.

This study examined only a small population of burrowing owls within California. A state-wide planning effort is needed at this time because populations of owls throughout the state continue to decline. Urbanization is a significant threat to burrowing owls and the areas in California with the highest burrowing owl populations are being developed at an unprecedented rate, specifically Imperial Valley and the southern San Joaquin Valley

(Medvitz & Sokolow 1995). This study identifies ways to understand local populations and methods to protect habitat in highly urbanized areas. The methods used in this study should be expanded to a state-wide level.

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