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Modeling potential species richness and urban buildout to identify mitigation sites along a California highway

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Abstract

One-foot resolution imagery is used to develop a detailed land cover map for part of Highway 99 in the San Joaquin Valley of California, US. The land cover map is used to model the probability of occurrence of 12 endangered or threatened species and as input to an urban growth model to examine the likelihood of development of every map unit. The combination of the two model predictions permits the categorization of every map unit with a potential endangered species richness index and predicted degree of development. Polygons with high potential endangered species richness were ranked according to the degree of development pressure. This planning approach is computationally intensive, but the input data are relatively easy to assemble, consisting of: a detailed, and fine-scale, land cover map; species presence locations; statewide climate and landcover maps; a parcel ownership map; population growth projections; and a digital map of the county general plan.

Keywords: Regional mitigation planning; Urban growth model; Potential species model; Land cover map

1. Introduction

Maintaining environmental quality while accommodating improved transportation infrastructure is a recognized challenge for transportation departments in the US (Levinson, 2004). The California Department of Transportation (CalTrans) faces numerous environmental planning challenges. Both the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA) require environmental mitigation, where feasible, for major projects. Loss and fragmentation of habitats is an environmental concern (Forman and Sperling, 2003), particularly in California's Central Valley, where many habitat types have been almost entirely converted to agricultural, residential, or urban uses (Olson and Cox, 2001). This study presents planning capabilities of a land cover map created from high-resolution imagery. The land cover map is used as input for two types of models: potential species richness for a select group of species; and potential for urban

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development. The model outputs are combined in a matrix to rank each polygon by potential species richness and development potential. We demonstrate the capacity to assess district-wide mitigation planning, which can save time in project design, environmental review, and project approval; result in better cumulative impacts mitigation; and foster regional environmental planning.

This study along California's Highway 99 transects eight counties. CEQA initial, scoping filings for potentially significant environmentally impacting projects in the study area comprise 14,000 documents, filed for private and public construction projects between 1989–2004 under the California Environmental Quality Act Net (CEQAnet Database, 2004). Of those, 714 projects subsequently required full Environmental Impact Reports (EIRs), all of which concluded the need for one or more mitigation efforts. This stepwise approach to planning, review and mitigation fails to evaluate the negative cumulative impacts of projects on agricultural lands, biodiversity, and wildlife movement corridors (Landis et al., 1996).

CalTrans has more than 150 planned highway construction projects in the region, at a projected cost of $1 billion over the period 2004–2010 (California Transportation Investment System Tool, 2004). CalTrans management is interested in methods that provide better management of cumulative impacts and streamline the permitting process. In 1999 CalTrans convened the US Environmental Protection Agency (EPA) and the Federal Highway Administration in a dialog to identify innovative approaches to planning. The resulting Mare Island Accord committed the agencies to seek methods for cooperative, comprehensive planning, and pledged the partners to a pilot project in Merced County, California, called the Merced Partnership for Integrated Planning. (http://www.mcag.cog.ca.us/projects/pip.htm).

The Merced project used geographical information systems to combine natural resource data with growth modeling scenarios based on alternative transportation solutions, resulting in a regional transportation plan which minimized the land use/transportation impacts on natural resources. With the success of the Merced project, CalTrans initiated a conservation/mitigation study of its programmed projects for the 448-km (280-mile) length of Highway 99 in the San Joaquin Valley. CalTrans seeks a comprehensive picture of the economic and environmental infrastructure within and adjacent to its right-of-way and to understand those assets in relation to regional environmental factors and future growth.

We used CalTrans' high-resolution imagery, originally taken to assess road conditions, to develop a detailed land cover map. This map became the base input for two modeling efforts: to model the potential presence of 12 regional endangered species and to assess the level of urban development expected for each map unit. The biological information was combined into a potential species richness index for the selected species. Combining the two models in matrix form created output useful for regional mitigation planning.

2. Methods

2.1. Land cover map and model development

We developed the land cover map from one-foot, true color, ortho-rectified digital imagery acquired by CalTrans along Highway 99 in 2003, for an eight-county region of the San Joaquin Valley. Map development techniques were similar to other land cover maps for California (e.g. Thorne et al., 2004; Thomas et al., 2004), and used heads up digitizing to delineate polygons from remote sensing images, and a classification of vegetation types based on the Manual of California Vegetation (Sawyer and Keeler-Wolf, 1995), which complies with the National Vegetation Classification Standard (Federal Geographic Data Committee, 1997). The imagery spanned one kilometer on each side of the highway, resulting in a 448-km-long, 2-km-wide highly detailed map. We used a two-county, Madera and Fresno Counties, (Fig. 1), area to test the modeling efforts.

The land cover map was used to rank potential mitigation sites along the Highway 99 corridor. Two components of the landscape were modeled for each polygon: biological importance, as measured by the potential species richness of 12 selected endangered species; and potential urban growth. Since both models used the same base map, graphic and tabular outputs of ranked potential species richness and degree of urban buildout were comparable by polygon, permitting evaluation of the mitigation potential of all polygons.

Potential species richness was modeled using a multiple logistic regression approach (Carroll et al., 1999; Guisan and Zimmermann, 2000). We modeled the distributions of 12 species (selected from State and Federal endangered, threatened, and species of concern lists) for which location records exist in the California Natural

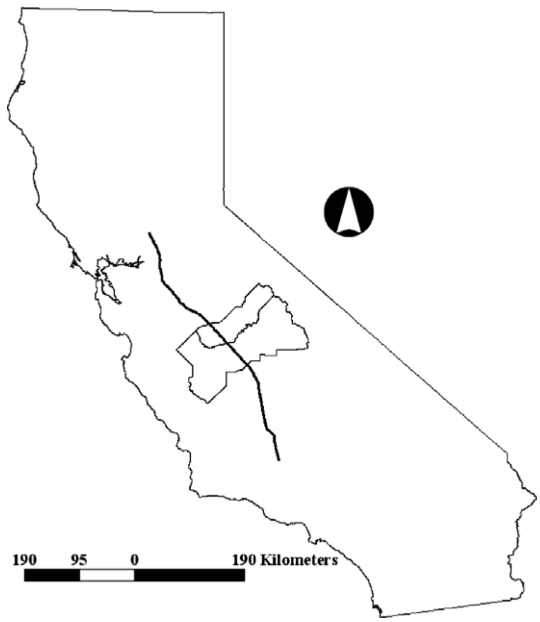

Fig. 1. Study Area.

Diversity Database List (California Department of Fish and Game, 2004). The likelihood of all 12 species for each polygon were summed to create the potential species richness index.

A GIS-based urban growth model, UPlan (Johnston et al., 2003), which uses a series of urban growth attractors and discouragement factors was applied to the study region to model the location of new households and employment according to local land use plans. UPlan is a proximity-type model, where land market demand is represented by proximity to freeway interchanges, highways, arterial streets, and water and sewer services. It is not calibrated to past growth, although past growth rates for households and for employment by zone can be used as attractors. The model is judgmentally calibrated by inspecting the future land use maps and tables of densities, as was done for the Albuquerque region (Hester, 1998).

2.2. Study region

US Highway 99 was the first major north-south interior highway on the West Coast, and once extended from Los Angeles to Seattle. Portions have been incorporated into Interstate highways, but 99 is still connects Sacramento to the major cities in the southern half of California's Central Valley (the San Joaquin Valley). The counties it passes through constitute some of the most valuable and productive farmland in the US. The region is experiencing some of the nation's most rapid population growth, resulting in the overburden of the aging highway. The region's combination of congestion, safety issues and aesthetic issues led to Highway 99's classification as a priority area for many proposed transportation improvement projects. The extent of proposed repair, modification and expansion in the corridor presents an opportunity to look at the corridor's natural resources and projected urban growth holistically. This paper reports on environmental analyses for two counties, Madera and Fresno (Fig. 1). The study area contains six cities, which house the counties' most important industrial and commercial establishments. Initial existing urbanized levels along the highway were high in both counties. The counties as a whole are much more rural and agricultural than the areas adjacent to the highway.

2.3. Highway 99 imagery and classification

The land cover map used CalTrans Digital Highway Information Photography Program (DHIPP) imagery, collected for all State highways. GIS polygon delineation was done manually on screen. Polygon attributes were labeled using a composite of map classification systems: the Manual of California Vegetation (Sawyer and Keeler-Wolf, 1995) for native and natural vegetation types; a wetlands classification (Cowardin et al., 1979) for wetland types; and the Anderson Classification for agriculture and urban types (Anderson et al., 1976). This hybrid classification permitted a more policy-relevant description of land cover than any single classification would have provided. The minimum mapping unit (MMU) used in map production was 0.8 ha (2 acres) for agricultural or developed lands and 0.4 ha (1 acre) for critical habitat types such as wetlands, open water or riparian vegetation. However, the smallest polygons in final map were closer to 0.25 ha (0.6 acres) and identify small areas of important habitats.

2.4. Potential species richness model

Logistic regression-based distribution models for 12 species along the Highway 99 corridor were developed (Fig. 2). The 12 species were a subset of those used in an earlier study (Hollander et al., 2001) of sensitive species in an eight-county region of the San Joaquin Valley. The earlier study identified 70 sensitive species and natural communities from sources including the USFWS recovery plan for upland species in the San Joaquin Valley (US Fish and Wildlife Service, 1997), the California Natural Diversity Database (California Depart-

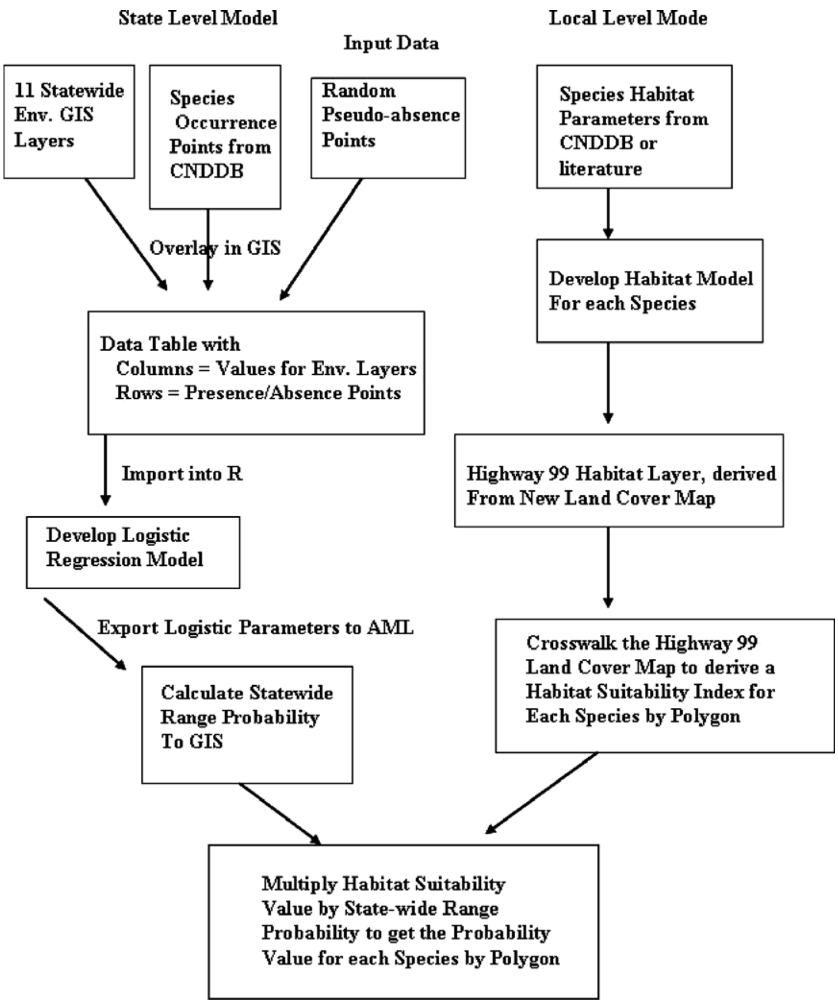

Fig. 2. The steps used to build the potential species richness model for 12 threatened and endangered species.

ment of Fish and Game, 2004), Partners in Flight/Riparian Habitat Joint Venture (2004) list of priority bird species, and suggestions of biologists, Peter Stine (US Forest Service), and Ron Jurek, Ron Schlorff, and Marc Hoshovsky (California Department of Fish and Game). Twelve species were chosen to represent six different taxonomic categories and four major habitat categories (alkali scrub, grasslands, riparian areas, and vernal pools), as follows: two amphibians; the western spadefoot toad (*Spea hammondii*) and the California tiger salamander (*Ambystoma californiense*), two reptiles; the giant garter snake (*Thamnophis gigas*) and the blunt-nosed leopard lizard (*Crotaphytus wislizeni silus*), two birds; the burrowing owl (*Speotyto cunicularia*) and the Swainson's hawk (*Buteo swainsoni*), two mammals; the San Joaquin kit fox (*Vulpes macrotis mutica*) and the Tipton kangaroo rat (*Dipodomys nitratoides nitratoides*), two plant species; Colusa grass (*Neostapfia colusana*) and heartscale (*Atriplex cordulata*), and two invertebrate species; the vernal pool fairy shrimp (*Branchinecta lynchii*) and the valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*).

All species had at least 20 geo-referenced occurrences in the California Department of Fish and Game (2004). The CNNDB data provided statewide records of the distribution of threatened species, but lacked the spatial resolution and intensity of sampling needed to predict occurrences within the Highway 99 land cover map, necessitating statistical modeling to estimate each species' occurrence probability by polygon.

Species modeling was carried out in two stages. First, we developed statewide range models for each species, using the CNDDB occurrence points together with a raster stack of environmental data layers to model potential species occurrence at a coarse geographic scale with a probability index ranging from 0 to 1. To produce the statewide range maps, we overlaid the known species occurrences on a set of environmental data layers, and extracted the environmental values at each occurrence point. Multiple logistic regression was then used to produce a model of the environmental associations for each species across its range. Each model was in turn applied across the environmental data layers in a GIS to extrapolate species distribution maps. This statistical summary is best done by running a classifier that distinguishes between known presences and known absences. Since we lacked documented species absence points (i.e., a biologist had searched for the species in that location, and had not found it), we created a surrogate for absence points with a set of statewide, randomly placed points. Use of randomly selected points was valid because we modeled rare and narrowly distributed species, not likely present at our selected absence locations.

We used 11 environmental predictor variables, each expressed as statewide raster maps at a 100 m resolution: five climate layers (annual precipitation, January minimum temperature, July maximum temperature, July precipitation, and summer relative humidity) derived from the PRISM climate data set (The Climate Source, 2000); five soils layers derived from the STATSGO (US Department of Agriculture, 1994) soils dataset for California (soils pH, soil organic matter content, and indices for loam, sand, and clay content); and a 100 m digital elevation model. These environmental data layers were sampled using an ArcInfo Arc Macro Language (AML) (Environmental Systems Research Institute (ESRI), 2004) to overlay the occurrence points together with a like number of surrogate absence points across the study region.

The logistic regression was run in R, open-source statistical software (R Development Core Team, 2004), and used a step heuristic to reduce the number of independent variables in the classifier. A script in R transformed the logistic regression model to a GIS probability of occurrence map for each species, derived from the stack of 11 environmental data layers. An AML script was created for each species and executed in ArcInfo GRID to produce a statewide raster range map at a 100 m grid resolution.

In the second stage, we used the land cover map and a California Wildlife Habitat Relationships model (California Department of Fish and Game, 2002) for each species to derive a map showing suitable habitat polygons within the Highway 99 corridor. This habitat suitability map was multiplied by each statewide range map to derive the relative likelihood of each species' presence in each polygon.

We derived the habitat suitability map for each species by assigning numeric suitability values to each polygon of the land cover map. For the eight vertebrate species, we used the California Department of Fish and Game (2002) models as the source for the habitat model. For the invertebrates and plants, we devised from the literature (US Fish and Wildlife Service, 2003a,b; Collinge et al., 2001; Hickman, 1993) a set of habitat relationship models equivalent to the CWHR vertebrate models. Habitat suitability was expressed as four classes from 0 (unsuitable habitat) to 1 (optimal habitat). By cross-walking the land cover map vegetation classes to the CWHR habitat classification we transformed the land cover map to a numeric habitat suitability map for each species.

Finally, a fine-scale species probability map was produced by multiplying the statewide range probability value by the habitat suitability value for each polygon of the Highway 99 land cover map. We wrote a Python script (Python Software Foundation, 2004) to perform this calculation. Output of this script was a table for each land cover polygon giving the probability values of occurrence for each species.

2.5. Urban development model

UPlan is a rule-based urban growth model that spatially allocates projected growth into various land use categories, based on projected population increases, local land use plans, existing cities, and existing and projected roads. A flowchart (Fig. 3) shows the progression of the model. For this study, we used year 2000 for initial conditions, and projected growth according to projected population increases for the year 2050 (California Department of Finance, 2004).

The first rule is that urban growth will take place according to city and county land use plans. California state planning law requires each county and city to adopt a general plan as the blueprint for development (California Government Code, sec. 65300; Fulton, 1999). Once a general plan is adopted, it is usually maintained for over 10 years, without significant change. All zoning and permitting must conform to these land use plans. Therefore, the existing land use pattern is the consequence of implementation of past local plans, and new development patterns will be shaped by the currently effective plans. The UPlan model uses general plans

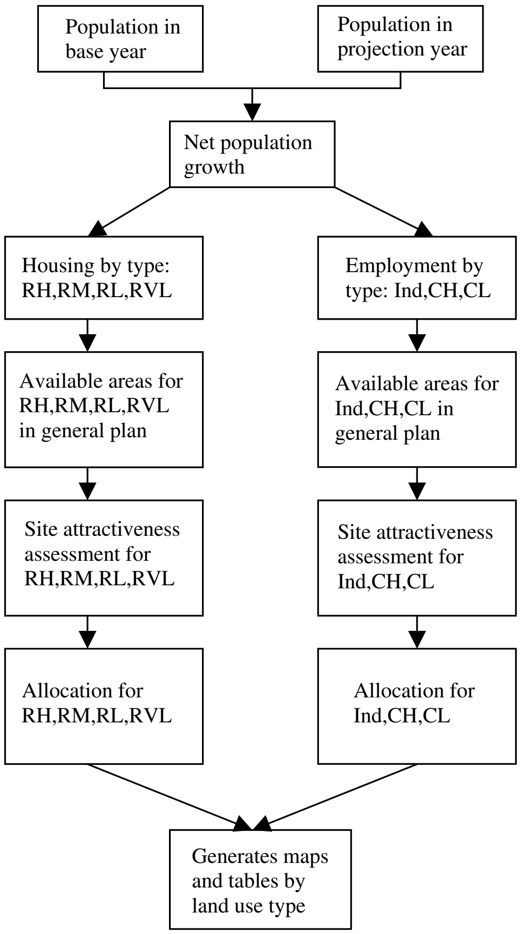

Fig. 3. The steps used in the UPlan model.

as the basis for allocating growth. We started with digital maps of current land use and zoning from the Fresno and Madera County general plans.

We identified seven classes of land use: industrial, high-density commercial, low-density commercial, high-density residential, medium density residential, low-density residential and very low density residential to represent the industrial, commercial and residential uses in the general plans. We modified definitions for low and very low density residential areas to differentiate between commercial farmland and rural residences situated on large lots not primarily managed for agriculture based on Census 2000 block data for population (US Census Bureau, 2000). No model growth was permitted on public land explicitly designated as open space in county general plans.

The second UPlan rule is that net population growth by county drives urban growth in the form of needs for housing and employment. Conversion between net population growth and areas needed for future employment and housing is done through formulae built into UPlan and input parameters available via a user interface (Table 1). Future employment is projected into industrial, high-density commercial and low-density commercial classes. Housing growth is assigned to the four types of residential depending on the average dwelling units per acre, based on census data. The UPlan model assumes all the new growth will go to new development. Redevelopment of employment and housing in existing urbanized cells are not taken into account, but there is little redevelopment in these fast-growing counties.

The third UPlan rule is that areas closer to existing urban infrastructure are more attractive to developers, and will be developed prior to more remote areas. Each grid cell gets a numerical attractiveness value through buffering and weighting a set of attractors, discouragement factors and masks. Each land use type has separate attractors and discouragements. Areas that are not available for development for political, economic or legal reasons are masked from selection by the program. Attractors to development include: cities, freeway ramps, highways, major arterials, minor arterials, and census blocks with net population growth between 1990 and 2000. Discouragements to development include vernal pools (a protected environmental feature) and flood plains. Areas excluded from growth projections include existing urban, public lands, and water bodies. Any planning elements represented in GIS format can be used as attractors, discouragements or masks.

Once each cell's value is determined, UPlan allocates land use by type to the grid cell with the highest attractiveness value on down through the ranks of cells until all acres needed are allocated. If the area zoned

Table 1
The formulas that convert population growth into land area allocations in UPlan

Population increment = 2050 population–2000 population
Total household increment = population increment/persons per household
Total employment increment = total household increment* employees per household
Industry employment = total employment increment* (percent employment ratio in industry/100)
Acres for industry = industry employment* (sq. ft. per employee in industry/industry FAR)/43560
High-density commercial employment = total employment increment* (percent employment ratio in high-density commercial /100)
Acres for high-density commercial = high-density commercial employment* (sq. ft. per employee in high-density commercial/high-density commercial FAR)/43560
Low-density commercial employment = total employment increment* (percent employment ratio in low density commercial /100)
Acres for low density commercial = low density commercial employment* (sq. ft. per employee in low density commercial/low density commercial FAR)/43560
Households in high-density residential = total households* (percent households in high-density residential/100)
Households in medium density residential = total households* (percent households in medium density residential/100)
Households in low density residential = total households* (percent households in low density residential/100)
Households in very low density residential = total households* (percent households in very low density residential/100)
Acres for high-density residential = number of households in high-density residential* average lot size per household in high-density residential
Acres for medium density residential = number of households in medium density residential* average lot size per household in medium density residential
Acres for low density residential = number of households in low density residential* average lot size per household in low density residential
Acres for very low density residential = number of households in very low density residential* average lot size per household in very low density residential

for a land use type in the general plan is smaller than the area needed, UPlan stops allocating that land use type after all available areas are filled out, and produces a report tallying unallocated area by land use category. When more growth is projected than zoned area is available, the user can accept the allocation and report, select a shorter time period to identify how soon growth will fill available land, or modify the land use plans to allow for more growth.

UPlan model outputs include a set of tables and grid maps, and a record of all inputs. Growth allocation maps by land use type show the area and location of development, and can be used in spatial or statistical analysis. We ran UPlan for Fresno and Madera Counties. For the non-Highway 99 land cover map parts of the counties, we used parcel data and air photo-derived land cover data from the State Department of Water Resources to represent existing urban land uses. Where available, the Highway 99 land cover map was used for existing urban because these data were more spatially detailed.

Table 2
The 38 land cover classes mapped along the Highway 99 corridor in the San Joaquin Valley, California

Land cover code	Land cover title	Total area in land cover map,ha.	Total area in land cover two-county study area, ha
1100	Residential	6770.9	1615.0
1200	Commercial and services	2886.4	664.6
1300	Industrial	3283.3	1093.1
1400	Transportation, communications and utilities	876.3	219.8
1410	Highway 99	3930.6	1315.8
1500	Industrial and commercial complexes	9.1	9.1
1700	Other urban and built-up land	571.6	149.7
2100	Cropland and pasture	12666.9	1925.0
2160	Irrigated cropland	0	0
2200	Orchards, groves, vineyards, nurseries, and ornamental horticultural	9345.8	2873.4
2210	Nurseries and ornamental horticulture	3.8	0
2220	Deciduous orchard	1039.3	0
2230	Evergreen orchard	37.8	0
2240	Vineyard	827.3	0
2300	Confined feeding operations	326.0	13.4
2400	Other agricultural land	353.0	86.2
3110	California annual grasslands	3840.9	1150.0
3120	Ruderal forbs and grasses	191.3	83.8
3200	Shrub and brush rangeland	0.5	0.5
4110	Valley oak forest and woodland	40.8	1.4
4210	Eucalyptus naturalized forest	209.9	68.4
4220	Coast live oak alliance	2.1	0
5100	Streams and canals	91.9	7.6
5200	Lakes, reservoirs and ponds	58.4	6.6
5300	Canals	425.8	68.3
6110	Fremont cottonwood riparian forest	112.4	19.3
6120	Mixed willow riparian forest and woodland	35.7	0.5
6130	California sycamore riparian forest	5.4	4.7
6200	Non-forested wetlands	23.6	0.6
6210	Seasonally flooded grasslands and forbes (vernal pools)	0.1	0
6220	Cattail wetlands	2.3	0.3
6230	Narrow-leaf willow riparian scrub	21.7	6.7
6240	Giant cane	1.4	1.5
6250	Temporarily flooded vernal pools	2.2	0
7500	Strip mines, quarries, and gravel pits	3.4	0
7600	Transitional areas	1342.7	361.3
8010	Roadside planted vegetation	179.4	87.3
8020	Roadside planted vegetation	50.4	17.2

2.6. Combination of model outputs and analysis

We analyzed the correspondence between areas of high potential for the selected species and areas with high development potential. First, the probabilities for the 12 modeled species were summed to derive an index of potential (endangered) species richness for each Highway 99 land cover polygon. Then, the percentage of each polygon predicted to be developed by UPlan in 2050 was calculated. Finally, potential species richness to the buildout fraction was compared for each polygon.

3. Results

3.1. Land cover map

The final Highway 99 land cover map contains 38 land cover classes on 6683 polygons, covering 896 km^2 across eight counties (Table 2). Fig. 4 illustrates a sample of what the map looks like on top of the original DHIPP imagery. The study area used for the following analyses covered 113 km^2.

3.2. Species distribution modeling

State-wide species range models, e.g. Fig. 5, contained areas of high occurrence probability that corresponded to the distribution of the actual occurrence points. The models tended to over-predict species distributions: particularly in Death Valley and the Salton Sea, which were often modeled as biogeographically

Fig. 4. Details that can be extracted from 1-foot black and white imagery used by the California Department of Transportation.

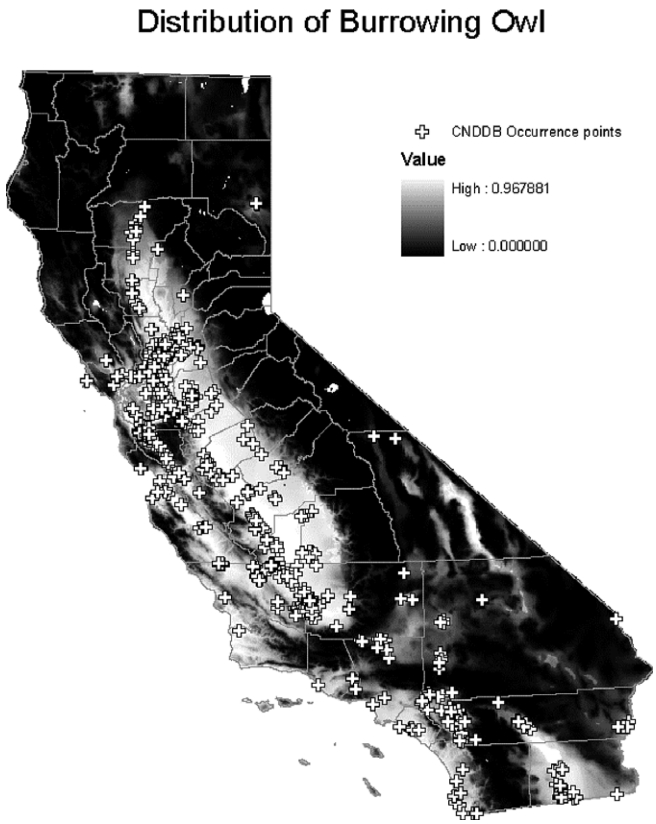

Fig. 5. State-wide species range map, used to identify the species likelihood weightings for the land cover classes found in the Highway 99 land cover map.

similar to the Central Valley. Mostly, there was little difference in the range model values along the Highway 99 corridor, and accordingly statewide range modeling had little impact on the species predictions for the polygons of the Highway 99 vegetation map.

The second step applied the statewide range map habitat probabilities to the numeric habitat suitability derived from the Highway 99 land cover map, producing the areas potentially occupied by each species (Table 3). Two bird species (Swainson's hawk and the burrowing owl), occupy the most potential Highway 99 corridor habitat, followed by western spadefoot toad. In contrast, vernal pool species occupy an extremely small fraction (less than 0.005%) of the map. California annual grassland was the most important habitat type for the species, followed by cropland and pasture. Aside from grasslands, California sycamore riparian forest was important habitat for valley elderberry longhorn beetle, and vernal pools were essential for two species on the list.

3.3. Buildout results from the UPlan model run

Growth was calculated using county total areas of: 1,558,514 ha for Fresno and 557,672 ha for Madera. Starting urban areas in 2000 comprised 88,181 ha in Fresno County and 30,896 ha in Madera County. Population by 2050 was projected to increase in Fresno County from a base of 803,401 to 1,658,281 and in Madera County from 124,372 to 302,859 (California Department of Finance, 2004). Growth projections were made using these starting conditions, population growth predicted by the US Census, and the growth rules listed in Table 1.

Growth allocated to different areas by the UPlan model (Table 4) was the same as projected growth by land use type, indicating the model allocated the correct amount of land to each land use category. Both existing county plans had enough lands in various zoning categories to accommodate all projected growth.

Table 3
Extent of modeled species ranges

Species name	Percent of study region area at 10% probability	Percent of study region area at 50% probability	Area at 10% probability (sq km)	Area at 50% probability (sq km)	Primary land cover class code	Secondary land cover class code
Plants						
Atriplex cordulata heartscale	0.004	0.004	0.005	0.005	3200	3120
Neostapfia colusana colusa grass	0	0	0	0	3120	2100
Reptiles						
Crotaphytus wislizeni silus blunt-nosed leopard lizard	10.67	0	12.38	0	3110	3120
Thamnophis gigas giant garter snake	0.16	0	0.19	0	3110	5300
Amphibians						
Ambystoma californiense California tiger salamander	11.37	7.23	13.20	8.4	3110	3120
Spea hammondii western spadefoot toad	53.89	10.42	62.54	12.10	3110	2200
Birds						
Buteo swainsoni Swainson's hawk	27.77	16.37	32.23	19.0	2100	3110
Speotyto cunicularia burrowing owl	29.12	28.52	33.79	33.1	2100	3110
Mammals						
Dipodomys nitratoides nitratoides Tipton kangaroo rat	0	0	0	0	3110	2100
Vulpes macrotis mutica San Joaquin kit fox	10.92	10.64	12.67	12.35	3110	3120
Invertebrates						
Branchinecta lynchii vernal pool fairy shrimp	0	0	0	0	3120	2100
Desmocerus californicus dimorphus valley elderberry longhorn beetle	0.22	0.22	0.26	0.26	6110	6130

Table 4
Spatial extent of modeled development for Fresno and Madera Counties, in hectares

Madera County	County-wide land use projection	County-wide land use allocation	Project growth within the highway 99 land cover map	Percentage of county-wide growth allocated to the highway 99 land cover map
Industrial	258	258	120	46.5
High-density commercial	19	19	19	100
Low-density commercial	168	168	38	22.6
High-density residential	881	881	259	29.4
Medium density residential	4417	4417	581	13.2
Low density residential	6709	6709	31	0.5
Very low density residential	4473	4473	60	1.3
Total	16,925	16,925	1108	
Fresno County				
Industrial	861	861	150	17.4
High-density commercial	157	157	96	61.2
Low density commercial	1009	1009	215	21.3
High-density residential	3656	3656	202	5.5
Medium density residential	13,447	13,447	419	3.1
Low density residential	3539	3539	4	0.1
Very low density residential	3539	3539	12	0.2
Total	26,208	26,208	1098	

The area of the new Highway 99 land cover map in Fresno County is 5859 ha, and existing urban occupied 3248 ha. Projected land use growth in Fresno County is 26,208 ha, of which 1089 ha will be along Highway 99. The built out area within the land cover map is expected to reach 4346 ha. In Madera County, the area of the Highway 99 land cover map covers 5436 ha. Existing urban within the Highway 99 land cover map in 2000 was 1276 ha. Madera County projected land use growth from 2000 to 2050 is 16,925 ha, countywide, with 1108 ha along Highway 99. In 2050, the expected total urban area within the Highway 99 landcover map will be 2384 ha.

3.4. Combination of models

We summed each species' probabilities to develop a potential species richness index (for rare and endangered species) for every polygon along the Highway 99 study area (Fig. 6). The highest potential species richness value was 3.969, found on 474 m^2. There are 1293 polygons with low potential species richness value

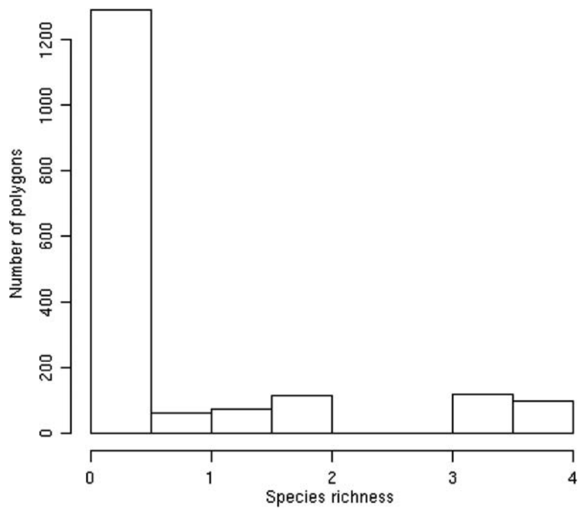

Fig. 6. Potential species richness by polygon.

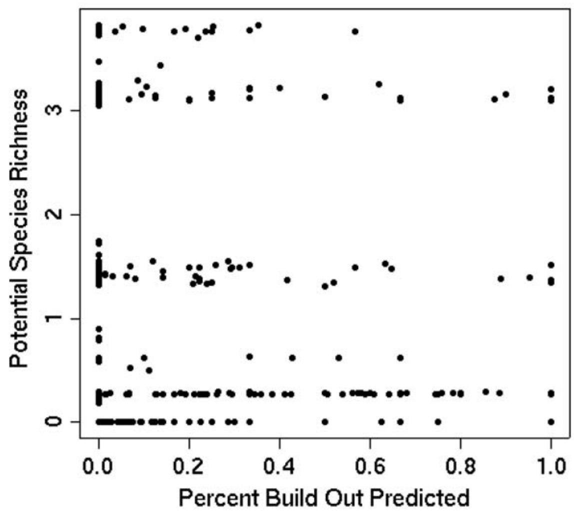

Fig. 7. Potential species richness verses development fraction for each Highway 99 land cover map polygon.

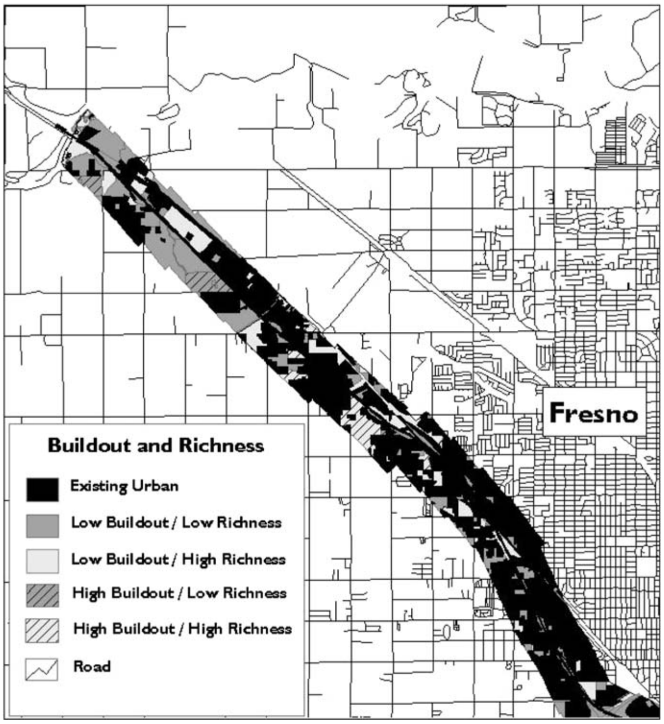

Fig. 8. Area with both high buildout and high potential species richness polygons.

(0–0.5), 118 polygons have a score of 3.0–3.5, and 100 rank from 3.5–4.0. Potential species richness value by polygon was ranked against the fraction per polygon predicted to be developed (Fig. 7). These polygon rankings can be transformed to a map (e.g. Fig. 8, a stretch in the study area near the city of Fresno) that shades polygons according to potential species richness, potential buildout fractions, and combinations of the two.

4. Conclusions

This study integrated two predictive models to create decision support information for regional species mitigation planning, using polygons from the California land cover map as input, and allowing each model's output to be compared on per polygon basis. The new land cover map increased the capacity of the models because of its finer spatial and taxonomic resolution that was particularly useful for representing existing urban land use classes used to parameterize UPlan. Comparison of the model outputs permitted a compact graphical view of which polygons have high biological potential and which are likely to get developed. This contextual information can be useful for planners. The informative results here suggest that the extent of the land cover map should be extended to include entire counties or ecoregions.

Selected modeled species were not intended to include all species considered in environmental impact analysis or mitigation planning for the region. The 12 species selected, however, are all endangered or threatened, and currently influence planning in the San Joaquin Valley. The selected species varied habitats-alkali soils, vernal pools, grasslands, and riparian vegetation, and they can represent the habitat needs of other species that use those particular habitats. For a broader effort, such as modeling an entire county or region, selection of focal species would need to be carefully done—in addition to a full compliment of listed threatened and endangered species, consideration of keystone species, species that require un-degraded habitats, and umbrella species (Thorne et al., 2006) should be considered. Such a potential endangered species richness index could identify sites of maximum potential species richness, but would not necessarily address rare habitat types such as vernal pools. However, in combination with a list of the locations of the rarest species and habitats, potential endangered species richness is a good approach for comprehensive mitigation assessment.

The approach is complementary to the call for greater understanding of how surrounding natural lands and urban growth patterns interact with transportation infrastructure (Badoe and Miller, 2000). It provides a way to permit planners to assess impacts to surrounding lands from various highway infrastructure growth scenarios. This approach supports recent legislative requirements in California for increasing the lead role of transportation agencies in environmental analysis and streamlining the review and delivery of highway projects in a manner consistent with federal, state and local environmental laws.

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