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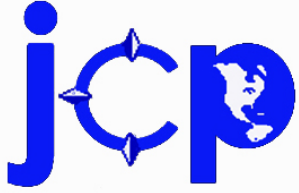https://escholarship.org/uc/item/0rk9w130

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Forecasting exurban development to evaluate the influence of land-use policies on wildland and farmland conservation

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ABSTRACT: Exurbia (rural low-density residential development) is one of the fastest growing types of land-use and can result in habitat fragmentation and loss of farmland. Local zoning restrictions and farmland protection are the most common ways of controlling low-density development in rural areas. While planners have recognized the utility of land-use change models for decision-making, most models do not effectively forecast exurban expansion. To rectify this problem, a spatially explicit model called UPlan that projects exurban development was adapted for Sonoma County California, where an estimated 27% of the people live at low densities (< 1 unit/0.8 ha [2 acres]). The projected pattern and extent of development resulting from three alternate agricultural land protection policies were compared, and the likely impact on natural areas and farmland was assessed. The results reveal that if current farmland is not protected from exurban development, 73% of all Sonoma County's remaining core forest could be comprised of edge habitat (within 500m of development) by 2010, and as much as 12% of existing farmland will be developed. We demonstrate that some farmland protection policies can have unintended consequences for forest conservation due to increases in exurban residential development. This research represents a real-world application of a new model that can assist planners to assess the impact of zoning and subdivision controls on land conservation where exurban expansion is a concern.

Keywords: farmland conservation, geographic information system, habitat fragmentation, land-use change model

INTRODUCTION

The growth rate outside of cities in the United States currently exceeds that of metropolitan areas (Morrill, 1992; Heimlich and Anderson, 2001), in part due to the popularity of countryside living. Davis et al. (1994) estimated that almost 60 million people in the United States lived in exurbia – a type of development that occurs in the rural countryside resulting in an unorganized scattering of homes on large parcels of land (Lamb, 1983). The increased rate of exurban development, along with the larger land area required to support it, means that ten times the amount of land in the United States was converted to exurbia as compared to urban development in 2000 (Theobald, 2002). Estimates based on nighttime satellite imagery suggest that 37% of the U.S. population now lives in exurban areas that account for 14% of the land area. In contrast, purely urban areas account for only 1.7% of the land area and house 55% of the population, and rural areas make up 84% of the land area but only contain 8% of the population (Sutton et al., in press).

The process and consequences of exurban development on rural land formerly dominated by extensive agriculture (e.g. ranching and forestry) in the United States is well documented for Colorado (Riebsame et al., 1996; Maestas et al., 2001), Virginia (Lucy and Philips, 1997), and Arizona (Esparza and Carruthers, 2000). The extent of exurban development also appears to be increasing across much of the world. In South Australia the peri-urban areas, defined as around the edges of a city, had a growth rate of 4 times that of metropolitan Adelaide in 1996 (Fisher 2003). Between 1971 and 2001, Alberta experienced a 32% increase in rural population (Azimer and Stone, 2003). Country homes are common across Europe, and especially in France, where there was an explosion of home building in rural areas starting in the 1970s (Dubost, 1998). The number of rural residents has also increased dramatically in Denmark (Tress and Tress, 2001). In the Netherlands, large estate homes are very popular and attempts are being made to make these "New Rural Lifestyle Estates" pay for restoring agricultural land for conservation purposes (van den Berg and

Wintjes, 2000). What started off as simple country outposts in Russia (Dachas) are now year-round exurban homes outside of Russian cities (Struyk and Angelici, 1996). This type of low-density development on the edge of cities and towns that is poorly planned, land consumptive, auto-dependent, and designed without respect to its surroundings is often referred to as sprawl. We can conclude that no matter what it is called – spawl, peri-urban, or exurban – this type of low-density development is becoming increasingly common in much of the world.

An example of the type of fragmentation that can result from exurban development was well documented for the Sierra foothills of California (Walker and Fortmann, 2003). Here the median size of landholdings in 1957 for Nevada County was 223 hectares and by 2001 it had been reduced to just 3.6 hectares. The impacts of this type of fragmentation on biodiversity are generally unknown and likely to be undervalued (Harte, 2001). Only recently have there been attempts to quantify these impacts. In particular, research examining the response of bird communities to residential development has demonstrated that only certain species tolerate houses and their associated disturbances (Nillon et al. 1995; Clergeau et al., 1998; Merenlender et al., 1998; Fernandez-Juricic, 2001; Reynaud and Thioulouse, 2000; Parsons et al., 2003; Odell et al., 2003).

The fact that exurban development is responsible for loss of farmland has also only recently been appreciated (Bradshaw and Muller 1998; Theobald 2002). The development and fragmentation of agricultural landscapes can present problems for the production of food and fiber. In addition, conflicts between farmers and their rural residential neighbors can arise over noise, chemical applications, and smells that are part of farming (Kay et al. 2003).

Attempts to reduce the expansion of exurban development are widespread. By 1998, 19 U.S. states had formally addressed sprawl and open-space issues through task forces or growth-management plans (Staley, 1999). Low-density zoning and subdivision controls are

probably the most common policies used to contain exurban development, along with open-space and farmland preservation programs, which often entail the purchase of partial development rights through conservation easements (Merenlender et al., 2004). In addition, agriculturalists have a long history of trying to protect private land from development in order to ensure the future sustainability of farming (Medvitz, 1999; Sokolow, 1999). These land conservation policies are usually implemented at the local scale of governance through a land-use plan. For example, more than 20,000 local land-use plans were developed in Denmark alone by 1977 (Enemark, 2002). There is much debate in the literature about the effectiveness of various policies, such as low-density zoning, at confining development in and around urban centers (Squires, 2002), and the likely impact of these policies is rarely assessed prior to adoption. However, a very useful framework for how to best evaluate land-use planning activities on biodiversity has been developed (Theobald and Hobbs, 2002).

The framework that Theobald and Hobbs (2002) recommend includes the use of spatial models to examine the consequences of various build-out scenarios. Developing models of future landscape change to assist land-use decision-making is becoming more common (for reviews see Berling-Wolff and Wu 2004 and U.S. EPA, 2000). Some of these models have been applied to examine future rates of habitat fragmentation and deforestation (Turner et al., 2001; Cogan, 1997) and threats to farmland conservation (Bradshaw and Muller, 1998; Berger and Bolte, 2004).

These models focus primarily on urban development because of their reliance on transportation and other socioeconomic factors (Swenson and Franklin, 2000). Another reason is that spatially explicit models based on past land-use transitions often rely on data from remote sensing which, due to the resolution of the data, can not detect more subtle types of development (Ward et al., 2000; Sutton et al., in press). This means that most existing land-use change models can not forecast increases in the extent of low-density residential development.

Given that exurban expansion is a widespread phenomena and can have significant impacts on land-use and conservation, better models are required to explore the pattern and process of exurban development. These models can be used to examine the influence of local land-use policies such as subdivision controls on future patterns of exurban development and the resulting impacts on remaining natural areas and farmland. This paper provides a real-world application of a new model which forecasts exurban development. We use this model to evaluate the likely effects of various policy scenarios on forest and farmland conservation. The results quantify how land-use policies result in tradeoffs between farmland and habitat conservation and increase our understanding of how useful policies commonly found in local land use plans are for habitat and farmland protection.

Study Area

Sonoma County, in the northern San Francisco Bay Area (Figure 1, page 43), has an intermix of low-density housing, vineyards, and wildlands that cover more than half of the County's one million acres (Merenlender 2000), resulting in an increased interface between human-dominated landscapes and wildlands. Throughout this paper we use wildland to mean areas that are not developed and have few roads and widely scattered structures if any. Due to the exceptionally high oak species diversity, Sonoma County's woodlands support a myriad of birds and other wildlife (Pavlik et al. 1991).

Sonoma County's Mediterranean climate and topography help to produce some of the world's best wine grapes. Approximately 22,621 hectares (55,900 acres) of wine grapes are grown in the County, worth approximately $390 million (County of Sonoma, 2000), making farmland conservation paramount for the local economy.

While Sonoma County residents have enacted laws to create urban growth boundaries around the expanding cities, low-density housing development (< 1 unit/0.8 ha

FIGURE 1 Land considered already developed, and hence unavailable for additional growth, included 2000 Census blocks with housing densities of 1 unit or more per acre and all parcels that are developed at or above the zoned density.
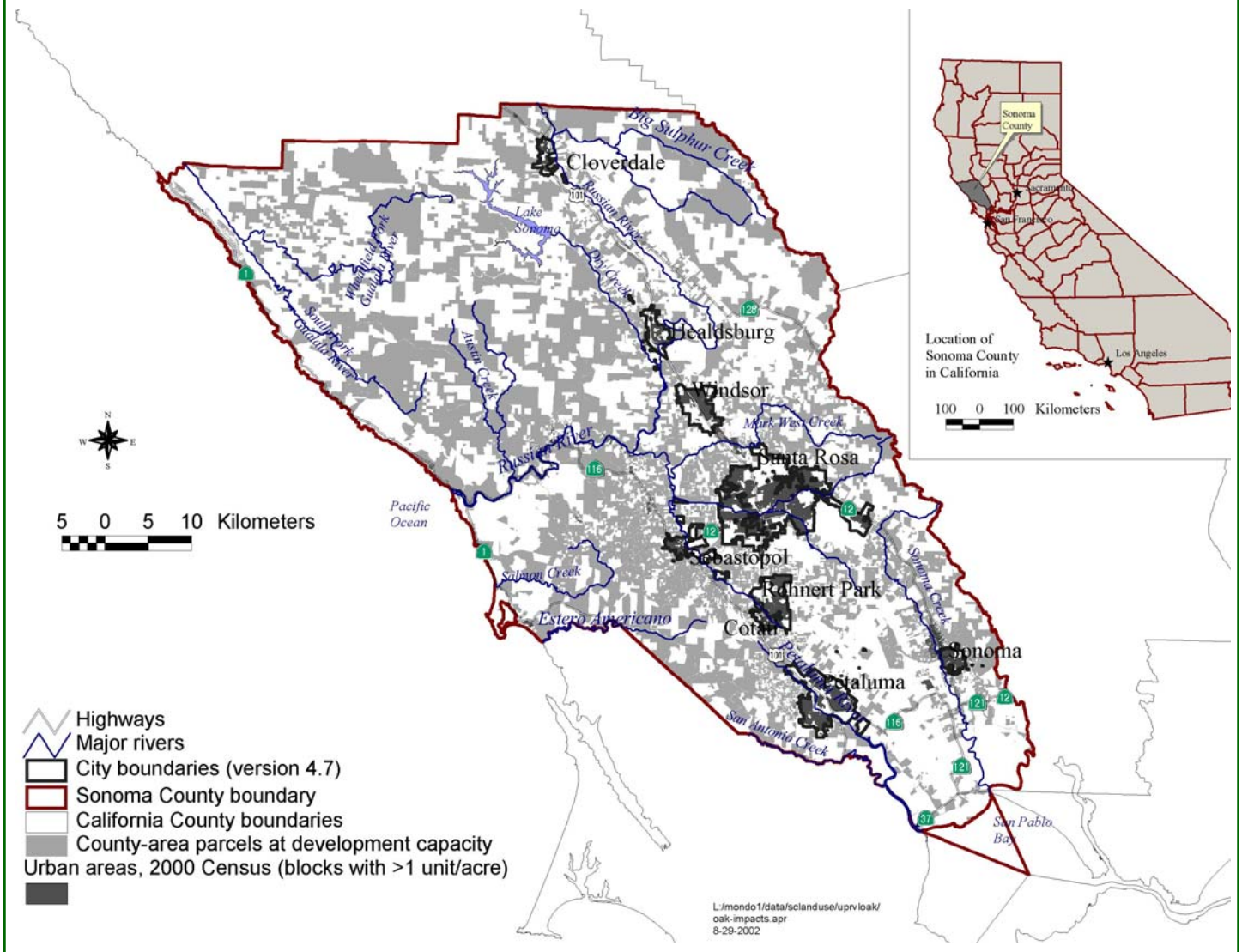
[2 acres]) still consumes large amounts of wildland. This type of development primarily comes from the subdivision of farms and ranches into small parcels (2-16 hectares or 5-40 acres) that are often on high ground with open views (Mitchell et al., 2002), in part, because most exurban residents view the natural environment as an important amenity (Crump, 2003).

UPlan Sonoma

UPlan (Johnston and Shabazian, 2003) is a rule-based model that incorporates land-use categories commonly used in general plans. The general plan is the predominant method of land-use control employed by local governments in California and results in general land-use classes such as commercial, residential, and agricultural. This model also offers an opportunity for users to change the input parameters and examine the results. In addition to using general plans to determine areas that will be developed, UPlan uses population and employment projections, weighted attractants (e.g. highways) and disattractants for development (e.g. slope), and user-defined constraints on development (e.g. floodplains, public land).

UPlan is written in the Avenue programming language to run in ArcView, a Geographic Information System (GIS) program (ESRI, Redlands, CA), and converts user-specified parameters into grids that are then used to form new grids which forecast patterns of future land use. A grid is a geographic data model representing information as an array of equally sized square cells arranged in rows and columns. Each grid cell is referenced by its geographic x,y location. The resulting development grids are based on attraction and exclusion grids, the general plan, and areas of existing urban development. Attraction grids are sites that are preferentially developed (i.e. near to freeway ramps and roads) and exclusion grids are comprised of areas where development is restricted (i.e. parks, waterways etc.). The general plan grid is a composite grid of the general plan land-use maps, and the existing urban grid includes all areas considered already urbanized. The density of projected new development is determined by a fixed grid cell size for each type of development (e.g. commercial, residential) and therefore does not result in the exact densities allowed by the county general plan.

Policy Scenarios

A public policy called the Rural Heritage Initiative was included in the November 2000 local election in Sonoma County. This Initiative was similar to neighboring Napa County's anti-sprawl initiative, Measure J which was passed in 1990. If passed, the Rural Heritage Initiative would have required, with a few exceptions, the passage of a ballot measure approved by a majority of the voters to change the land-use designation or increase the density of land designated as various classes of agriculture in the current Sonoma County General Plan. The Rural Heritage Initiative received 42.6% of the vote and therefore did not pass. However, given the popularity of preventing development on these agricultural lands, we wanted to compare the pattern of future development if all agricultural land is protected from subdivision or if only agricultural land zoned 40 acres or larger is protected. From our discussions with planners, commissioners, and academics there is some consensus that properties zoned at this density or greater are more likely to be developed despite their land-use designation. We compared these two agricultural land protection options with future development if no designated lands were protected from subdivision (i.e. no agricultural land protection). Here three different agricultural land protection scenarios for 2010 are examined for Sonoma County: 1) all agricultural land remains protected from further development; 2) only agricultural land with a designated residential density of 16 hectares (40 acres) or more is not subject to further development, allowing for development in agricultural land designated as 4-16 hectares/unit (10-40 acres/unit); and 3) no agricultural land is protected from development. In all three scenarios agricultural land is defined by the land-use designations found in the county general plan (land intensive agriculture, land extensive agriculture, diverse agriculture).

METHODS

We customized UPlan for Sonoma County by specifying the appropriate input parameters based on available data for the County. UPlan Sonoma allocates future development based on General Plan land-use, the areas defined as already developed, percentage of the population designated for the different residential density categories, the population projection used, and areas that were masked out from development. Because Sonoma County's General Plan is parcel-based, we used a strict compliance model that does not allow spill over into other land-use classes. There are other necessary input parameters used in the model that can serve as attractants or disattractants for development in cases where the land-use plan is not as detailed as Sonoma County's General Plan. Examples of attractants are major arterials, city sphere of influence (area of future services), freeway ramps, and highways while slope can be used as a constraint to development (Johnston and Shabazian, 2003).

UPlan Sonoma uses a single land-use map layer that was developed by reclassifying the Sonoma County General Plan and nine incorporated city plans into the following classes: residential high (RH) [> 8 units/0.4 ha (1 acre)], residential medium (RM) [8 units/0.4 ha (1 acre) to 0.5 units/0.4 ha (1 acre)], residential low (RL) [1 unit/0.8 ha (2 acres) to 1 unit/2 ha (5 acres)], residential very low (RVL) [< 1 unit/2 ha (5 acres)], agriculture, industry, high-density commercial, low-density commercial, public land, and water. Land considered already developed, and hence unavailable for additional growth, included 2000 Census blocks with housing densities of 1 unit or more per acre and all parcels that are developed at or above the zoned density. The latter information was calculated by dividing the size of each parcel by its designated residential density from the County General Plan land-use layer. This represents an estimated maximum number of lot splits or added residences allowed per parcel. Subtracting the existing number of residential units per parcel from the estimated maximum number yields the potential number of lot splits or added residences per parcel. The existing number of units per parcel was obtained from 2001 County Assessor's data. This method does not account for second units (i.e., mother-in-law units) which were reported to be fewer than 1,000 by Sonoma County planners. The resulting map of areas considered already developed based on this combined data set is shown in Figure 1. The parcels which remain available for further development (areas not colored) represent the remaining land supply. We believe that this is the first time that the remaining land supply has been mapped using these methods. The relative amount of future residential development that was allocated to the four different UPlan residential density classes was based on an estimated distribution of residents currently living in each density class. These current estimates were calculated using parcel data layers for the entire County and largest city, Santa Rosa (this was the only city with digital parcel data available to us), 2000 Census blocks, and the General Plan land-use categories. The resulting proportions for the County were 4% RH, 30% RM, 25% RL, 41% RVL; for the city of Santa Rosa the proportions were 18% RH, 71% RM, 7% RL, and 4% RVL. We then weighted these proportions based on 67% of the population living in cities and 33% in unincorporated areas, reflecting the 2000 urban-rural population breakdown for the County (Association of Bay Area Governments, 2001). The resulting breakdown (14% RH, 59% RM, 12% RL, 15% RVL) was used as input parameters in the model to allocate future residential development. This means that an estimated 27% of people in Sonoma County now live in low density residential areas, so we allocated 12% of the estimated future population to RL and 15% to RVL. The average lot size for these residential classes was calculated by intersecting the County and Santa Rosa parcel data with the county and city general plan layers reclassified as UPlan land-use categories and taking the average of all the parcel sizes identified within in each type. The resulting average lot size in acres for each residential type is 0.06 RH, 0.5 RM, 2.0 RL, and 10.6 RVL. Also, low and very-low residential development requires at least a 200m x 200m grid cell (≈4 ha, ≈10 acres) in UPlan to be available for development in order for this type of land-use to be allocated, as compared to a 50m grid cell (≈

0.25 ha, ≈ 0.6 acres) for all other types of development. These numbers influence the amount of acreage consumed by the model for each type of residential land-use. The required commercial development is based on employment parameters determined by the local government (e.g. persons per household, employees per household).

We set the starting population at 458,614 as reported in the 2000 Census data for Sonoma County (U.S. Census Bureau 2000). The population projection for 2010 of 527,200 from Association of Bay Area Governments was used to calculate demand for future development (Association of Bay Area Governments, 2001). Areas masked out from development included rivers and lakes and areas within 100m surrounding these features, public land, properties with conservation easements, and land mapped as already developed. The three policy scenarios discussed above were then run using UPlan Sonoma.

Each model run results in a map of the amount and distribution of estimated future development, called the "allocation" in the UPlan Avenue program. It also estimates the amount of land needed for development, as well as the amount of land developed in a given run of the model, and any unallocated demand for land (i.e., deficit) that may exist due to a lack of capacity for development given the input parameters of each run.

To distinguish the loss, degradation, and fragmentation of large forested areas that provide essential habitat for wildlife, as compared to the conversion of isolated small stands of native vegetation that can result from development, we focused our analysis on core habitat patches. To do so, we adapted the "core.aml" habitat analysis program, originally written by Shawn Saving of the California Department of Forestry's Fire and Resource Assessment Program. Core habitat areas were defined as 100 ha or more of continuous forested habitat that existed in 1990 based on a classified satellite imagery vegetation map (25m, 82ft resolution) of Sonoma County provided by California Department of Forestry and Fire Protection (Pacific Meridian Resources, 1994).

Individual habitat patches were separated by at least two 25m pixels. To eliminate edge habitat, all cells within 25m from the edge were removed around each identified core habitat patch. These distances were arbitrarily fixed to remove very small forest fragments from the analysis because these areas are not the focus of conservation efforts.

The three resulting UPlan development maps were intersected with the core habitat layer for Sonoma County, and areas of overlap were quantified to compare the affect of each scenario on core forestlands. In addition to calculating the amount of core forestland consumed by future development for each scenario, we also calculated the amount that fell within fixed distances from each resulting development grid to measure potential edge effects.

The resulting three development grids were also intersected with existing farmland types designated as prime, unique, and of statewide or local importance by the California 2000 Farmland Mapping and Monitoring Program data for Sonoma County. This provided us with an independent source of data to measure how much farmland was consumed by development under each scenario.

RESULTS

The results of these models are based on all of the land-use and growth parameters outlined in the Methods section, with only the type of agricultural land protected varying among the three scenarios. Because the Sonoma plan specificity dictates the precise location of each type of development, the weighting of the various attractants and constraints to development that are in the model had little influence on the outcome. We believe that this effort has produced the most realistic picture to date of future development patterns that are likely to occur in Sonoma County given the current planning policies and population projections. It is clear that if all land designated as agriculture is restricted from development then the density of development increases (Figure 2, page 47) in

FIGURE 2 UPlan results when land designated as agricultural in the 1989 County General Plan is protected from development.

the non-agricultural areas of the County. Under this scenario the model was not able to fully allocate the calculated demand for low- and very-low-density residential development (Table 1). When development is prohibited only on agricultural lands zoned for parcels of 16 hectares (40 acres) or more (Figure 3, page 49) then the development footprint is more extensive and less dense in some areas and more development could be accommodated (Table 1). The most extreme example of sprawl can be observed if all agricultural land is opened up to residential development as is depicted in Figure 4, page 50. This last scenario comes closest to accommodating the demand for very-low-density residential development (Table 1).

The greatest amount of core forested habitat is affected when no agricultural land is protected (7,565 ha) because most core habitat is designated as Agricultural in the County General Plan. However, less intuitive is the finding that more core forestland is developed if all agricultural land is protected (5,813 ha) than if only agricultural lands zoned for 16 hectare (40 acre) or larger parcels is protected from development (4,599 ha). This is because in the latter case the future development is spread across current agricultural lands with small parcels, most of which is on relatively flat lands containing no core forest land, reducing the development pressure in hilly rural residential lands that contain core oak woodlands. The core forested areas that are lost to development under scenario two (only agricultural land designated as 16 hectare (40 acre) parcels or larger is protected from development) are shown in Figure 5, page 51. Here we see that the core

TABLE 1 Number of Hectares that Each Model (a = all agricultural land protected, b = agricultural land zoned larger than 40 acres/unit protected, c = no agricultural land protected) Calculated Would be Needed, Available, and Developed, and any Remaining Deficit

Note that when the model develops the final grids, the resulting development acreage closely matches the calculated demand and, in some cases, the model could not fully allocate the needed acreage so a deficit is reported.

Table 1 a.

Land-Use type	Ha needed	Ha available	Ha developed	Deficit if any
Industrial	229	2144	233	—
Commercial High	32	361	32	—
Residential High	81	152	82	—
Commercial Low	558	1492	558	—
Residential Medium	3,026	6,096	3,027	—
Residential Low	2,713	4,573	677	—
Residential Very Low	17,697	16,066	12,042	5,655

Table 1 b.

Land-Use type	Ha needed	Ha available	Ha developed	Deficit if any
Industrial	229	2185	231	—
Commercial High	32	363	32	—
Residential High	81	154	81	—
Commercial Low	558	1,550	558	—
Residential Medium	3,026	6,174	3,026	—
Residential Low	2,713	4,726	682	—
Residential Very Low	17,697	38,855	17,252	445

Table 1 c.

Land-Use type	Ha needed	Ha available	Ha developed	Deficit if any
Industrial	229	2185	233	—
Commercial High	32	363	32	—
Residential High	81	154	81	—
Commercial Low	558	1,551	558	—
Residential Medium	3,026	6,174	3,030	—
Residential Low	2,713	4,727	717	—
Residential Very Low	17,697	16,959	17,668	29

FIGURE 3 UPlan results when agricultural land designated as 40 acre parcels or smaller is not protected from development.
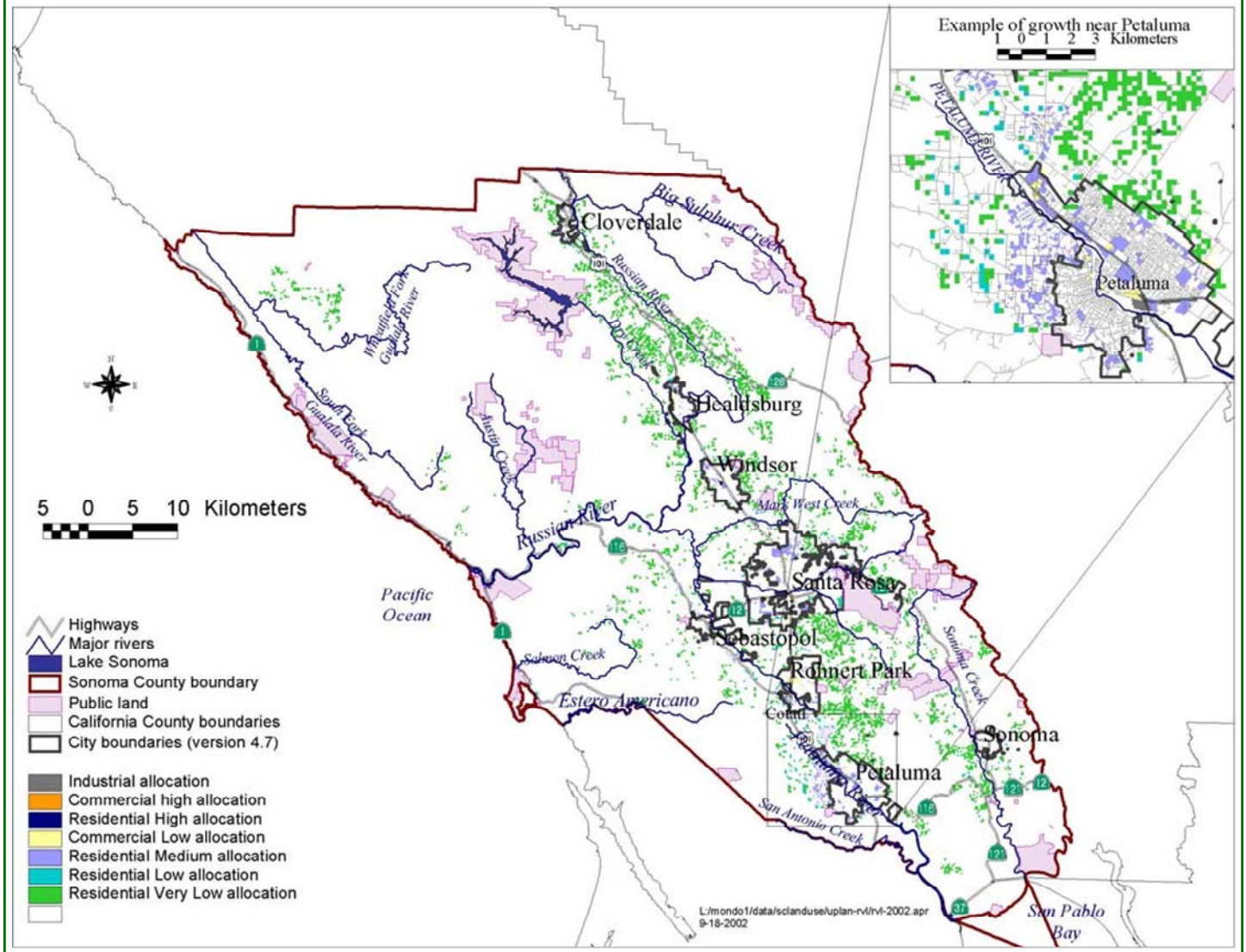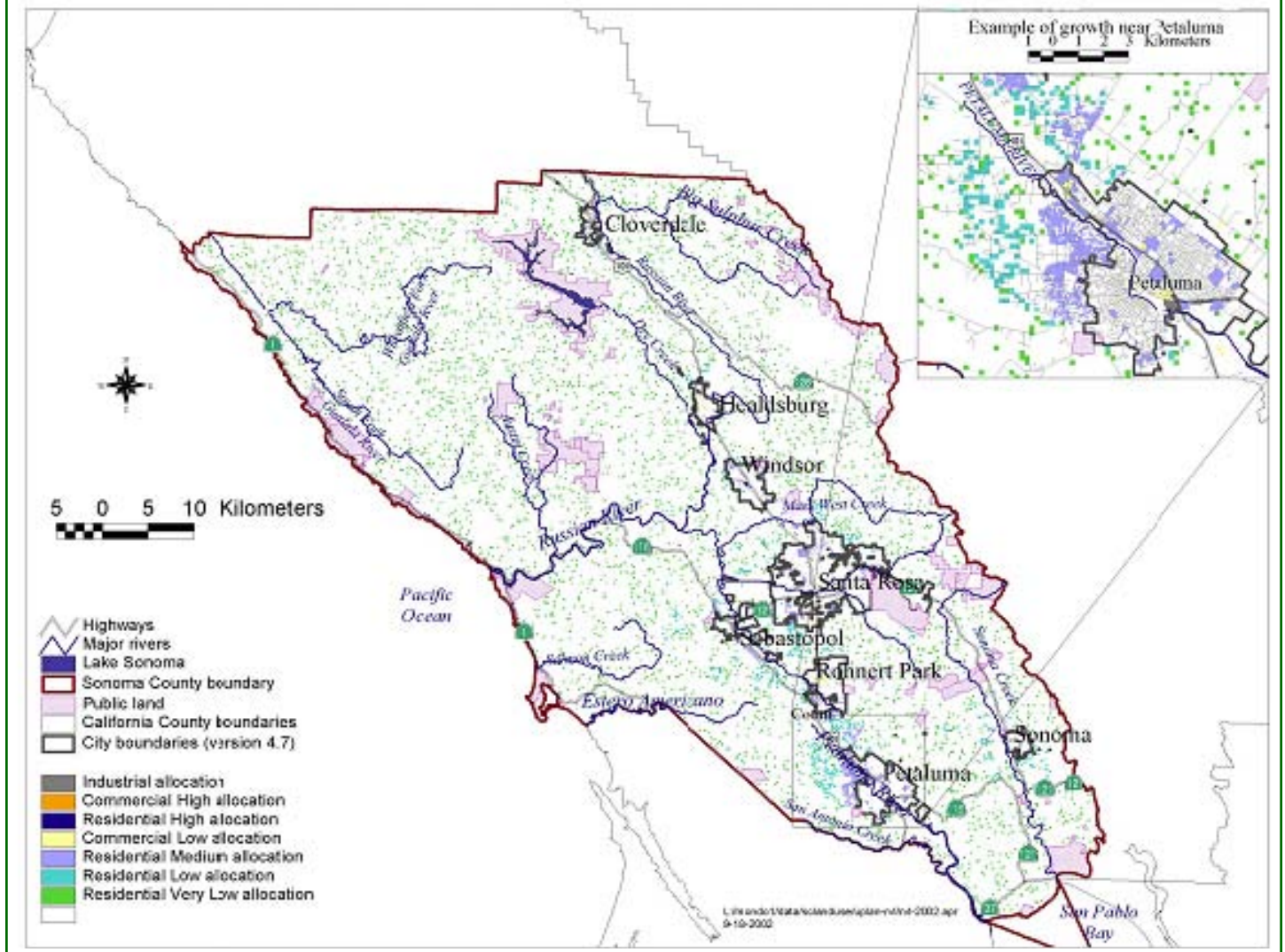
FIGURE 4 UPlan results with no agricultural land protected from development.

FIGURE 5 The amount of core forestland that falls from 0-2,500m away from the newly developed areas. The difference between the two agricultural protection scenarios is small enough that the two lines entirely overlap at this scale.

forestlands are mostly distant from the main development corridor along Highway 101 and the premium agricultural valleys that run along the major rivers.

To quantify the extent to which core forestland is influenced by edge effects in the three different scenarios we plot the amount of core forestland that falls from 0-2,500m away from the resulting new development grids (Figure 5). We find that 73% of the core forestland would be only 500m or closer to future development if agricultural land is not protected (scenario 3) as compared to 54% if all agricultural land (scenario 1) or only agricultural land designated as 16 hectare (40 acre) parcels or larger is protected (scenario 2).

Various amounts of the future development projected by these models would occur in farmland, designated as prime, unique, and of statewide or local importance by the Farmland Mapping and Monitoring Program (FMMP) [California Department of Conservation, 1994]. This program designates farmland based on existing agricultural activities and soils and does not correspond to the County General Plan farmland land-use designations, providing us with an independent measure of farmland likely to be developed. In the case where agricultural land is entirely protected, 2,164 hectares of farmland would be developed. A total of 8,250 hectares would be developed if land zoned for parcels smaller than 16 hectares (40 acres) were open for development (scenario 2). The UPlan results based on this scenario are mapped with vineyard blocks (mapped by Circuit Rider Productions, Inc through 1997) and designated FMMP-designated farmland in Figure 6, page 53. Without agricultural land protection at all, 3,976 hectares of farmland is consumed for development. As we expected, the amount of agricultural land lost to development increases when 16 hectares (40 acres) and smaller parcels (zoned agriculture) are opened for development. However, less intuitive is the fact that if the agricultural land designated in the General Plan is not protected, the amount of recognized agricultural land by the FMMP that would be subject to development decreases because more development occurs on extensive land (grazing land), relieving the development

pressure on lands under intensive agriculture (prime, unique, statewide and local importance).

DISCUSSION

Model Limitations

The universal importance of general plans for forecasting future development can be debated, as regions that have experienced an overwhelming demand for development have experienced rapid urbanization never accounted for in early general plan documents. However, the advantage of working with County planners and decision-makers on a model that incorporates general plans, their primary decision-making tool, and produces results that they have some confidence in far outweighs other modeling approaches that do not facilitate this type of collaboration. By working with Sonoma County planners we gained great insight into how to best estimate the necessary input parameters and what types of development scenarios are realistic to consider. In particular, Sonoma County has a parcel-specific land-use plan (County of Sonoma 1989) that is the basis for most land-use decision-making; therefore, for a development model to be credible and used by Sonoma County staff, elected officials, and the public, general plan land-use categories had to be incorporated. Also, given that we are interested in relatively short-term growth, we are confident that Sonoma County's General Plan will have the greatest influence over the development pattern of Sonoma County through 2010.

The results of this model should be used to identify regional trends in development risk and not to assume that the portrayed density will be exactly reflected by future growth or that any individual parcel is necessarily going to be developed. For example, Figure 2 shows that some areas, such as the Sonoma Mountain area, are likely to be developed even under the most stringent agricultural land protection policies because of the amount of non-agricultural land designated.

FIGURE 6 UPlan results (in black) from scenario two over vineyards (mapped through 1997 by Circuit Rider Productions Inc.) and farmland types (prime, unique, statewide and local importance) designated by the 2000 Farmland Mapping and Monitoring Program.

It is worth mentioning again that low-density residential development could only be allocated to cells larger than 4 hectares (≈10 acres), which restricts the amount of this type of development that the model will allocate and, in turn, influences the deficit numbers reported in Table 1. Given the many constraints to development that are not incorporated into this model, water availability being the main one, using a larger grid cell is one way to restrict the amount of this type of development. Also, since UPlan does not directly allocate development into exactly the density categories dictated by zoning, the density of development in the resulting projection grids is only representative in the aggregate of demand for that type of development.

Policy Tradeoffs

This comparative exercise shows that local agricultural land policies and subdivision controls can greatly influence the pattern, extent, and density of development on wildlands. If agricultural land is entirely protected, then the demand on the remaining areas zoned for residential development is greater and the few available areas will most likely be severely affected. However, if agricultural land is not protected, then development sprawls over a larger extent resulting in increased fragmentation of natural habitat due to housing, roads, and recreational development (Standiford et al., 1987). This can be seen in the scenario that allows some agricultural land to be developed (Figure 3) and in the extreme case where no land is protected (Figure 4).

This approach also allows for a visual inspection of where core forestlands and other mapped resources may be lost to development, and so is a useful tool for local planners. The relative impact across the landscape can be seen by the difference in the amount of core forestland that will be adjacent to future development sites, depending on the various agricultural land protection scenarios. The edge effects associated with development in wildlands will increase with sprawling development as compared to compact development (Figure 5). Vegetation composition often is different at the edge than within the interior of a

forest, and altered vegetation can be detected up to 500m into the forest (Laurance, 1995). Under scenario three, 73% of the forestland would be within 500m of development, making most of the remaining forest influenced by edge effects. Hence, the differences in development patterns seen between the three protected land scenarios could influence species-loss rates (Seabloom et al., 2002).

The large amount of overlap between populated areas and agricultural activities in Sonoma County is demonstrated by the proportion of land consumed for development that is classified as farmland. The greatest amount of farmland (excluding grazing land) will be consumed if properties zoned at densities greater than 1 unit/16 hectares (40 acres) are developed. However, if farmland is not protected at all, the rural land in Sonoma County will be entirely intermixed with low-density residential development. Given the demand for additional low-density housing in Sonoma County, the agricultural-residential interface is most likely going to increase, causing additional conflicts between rural residents and farmers (Figure 6).

Even with the most stringent agricultural land protection policies, other conservation tools will be needed to protect Sonoma County's open space. Protecting land from development through agricultural zoning and local ordinances does not necessarily protect habitat for biodiversity conservation. Intensive agriculture and other permitted land-use activities can result in habitat conversion, modification, and fragmentation. However, we examined how agricultural protection would influence development patterns in core habitat in Sonoma County because this is the most likely method of preventing development that may be implemented in the near future. Other tools are needed to prevent deforestation and to protect valuable habitat that is slated for development.

Broader Impacts

The primary goal of many development models is that they be useful to communities who want to examine the implications of growth by projecting the outcomes of various planning options, and so ultimately help to manage growth in a more informed way. Based on our experience, local decision-makers who are involved in producing land-use plans prefer development models that build out the existing land-use plan and allow for different development scenarios based on possible changes to the plan. In general, we find that local decision-makers prefer rule-based models as compared to complex statistical models with fixed results. This may be because they do not understand complex statistical analysis and therefore are not comfortable relying on the results. The United States Environmental Protection Agency recommends such build-out analysis because it allows a community to test out its existing regulations – to glimpse at its possible future when all land is developed to the maximum extent allowed under law (Lacy, 1990). However, it is important to remember that rule-based models require a strong understanding of the system being modeled so that the rules accurately represent the current situation.

This research demonstrates the utility of a rule-based model that forecasts the pattern of future development based on a local land-use plan. By applying this model we were able to quantify an increased level of habitat fragmentation and forest edge effects that would result under a farmland protection scenario. This research quantifies the unintended environmental consequences of agricultural land subdivision controls. This same problem is likely to occur in other countries where wildlands adjacent to agricultural areas will become fragmented for rural residential or peri-agriculture purposes at a greater rate if prime farmland is protected from such development.

With no subdivision controls enacted then scattered development throughout the region is likely to influence forested areas primarily because of the increased amount of edge habitat that will arise from overly dispersed development patterns. This demonstrates the need for clustered development in order to prevent anthropogenic disturbance throughout the remaining natural areas in all developed countries where exurban development is increasing.

CONCLUSION

UPlan can help decision-makers protect important open space by allowing them to consider the consequences of land-use planning on natural habitats and agricultural lands. However, while farmland protection policies can achieve this in part, they are not the entire solution to reducing the impacts of exurban expansion. In fact, restrictions on subdividing lots for high and medium density residential development may result in increased pressure to develop existing large parcels that are not yet developed to their maximum density according to the General Plan. Reducing densities and securing conservation easements are other important planning tools that could be used. Fortunately, Sonoma County does have an Agricultural Preservation and Open Space District that is funded by a sales tax to acquire high priority agricultural, natural, and open space resources through purchasing full or partial interest in land. We are working with the District to apply UPlan scenarios as a method of assessing the risk of wildland and farmland conversion to help prioritize acquisition. The combination of spatially explicit planning tools such as UPlan with a variety of policy options, including incentive based conservation, should improve our ability to stave off continued low-density development and avoid the associated costs to wildland and farmland conservation.

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