Protecting Wildlands Beyond the Urban Fringe

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Introduction

Land use change is the primary driver of habitat loss and ecosystem degradation, and greatly intensifies other threats to the environment (Harte 2001). Habitat loss and fragmentation are leading to an unprecedented rate of species extinction, which heightens the importance of conservation planning to protect biodiversity and the need to increase the efficiency of land and water use for a growing population.

Much conservation planning in the United States is focused on the recovery of endangered species. This is because the Endangered Species Act, one of the most powerful environmental laws passed by Congress, makes the "take" of listed species illegal. The planning required for endangered species recovery has led to innovations in protected area planning, and has helped address the gradual loss and fragmentation of wildlands (McCaull 1994). However, endangered species recovery plans are limited to certain areas of the country, and this process is well-described and has been evaluated in existing literature (Kareiva et al. 1999).

In the majority of cases, land use and land conservation decisions are made at the local level. For example, land use policies such as zoning, transfer of development rights, and urban growth limits are used by local governments to minimize loss of natural habitat and agricultural land. Absent compensation, the level of protection that can be expected from local land use regulations is influenced by the extent to which regulations limit the current or future economic returns to private landowners.

The use of incentive-based conservation programs has greatly increased over the past twenty years, in part as a backlash to local land use regulations that limit the use of private lands and their associated resources (Merenlender et al. 2004). Thus, purchasing partial or full interest in land has become a very important tool for protecting private land resources. According to the Trust for Public Land (2005), between 1994 and 2006 voters approved 1,299 land protection initiatives that authorized $31 billion in conservation funding. Such incentive-based land conservation has resulted in an explosion of the land trust movement in the United States and elsewhere. Private trusts and public agencies are involved in these acquisition programs for private land conservation, and have had to invest in conservation planning in order to maximize the returns on their investments.

As a result, these institutions have in some cases been leaders in implementing conservation science for planning purposes (Stoms et al. 2005). The literature on targeting land conservation for private and public organizations involved in acquisition and compensation programs is well-developed (Zbinden and Lee 2005, Newburn et al. 2005, Wilson et al. 2006). Despite the importance of such protected area planning, this essay is not focused entirely on it; though I do discuss the need to improve the way we estimate the relative value of natural areas to include the multiple conservation benefits they may provide. I also avoid dealing explicitly with the general principles of conservation biology that should be extended to planners, such as habitat loss, fragmentation, and restoring connectivity. These, while also still in need of increased understanding, are well-developed in books and journal articles, and have already been translated to the public by earlier efforts (Hilty et al. 2006 (a), Environmental Law Institute 2003).

Instead, I explore several scientific hurdles that need additional research, in order to better advise city and county land use planners who are faced with multiple, and in some cases conflicting, objectives to ensure the protection of social and environmental amenities. These include: 1) addressing multiple environmental benefits that need protection to maintain and restore natural ecosystems and their associated goods and services; 2) quantifying non-linear cumulative impacts of land use change and thresholds beyond which we observe environmental degradation; 3) exploring patterns, processes, and consequences of low-density development; and 4) stressing the importance of outcomes research so we can evaluate the effectiveness and unintended consequences of policies that are currently used by land use planners to control sprawl. My recommendations to local planners are focused on collaborative regional planning to slow the spread of low-density development, which is having an unprecedented impact on wildland fragmentation, and stress the importance of taking a more adaptive approach to land-use planning.

It is very difficult to effectively implement science-based conservation planning, because success is measured by whether people change the way they do business in response to learning about scientific findings. It is much easier for scientists to teach college students and to publish in the scientific literature than it is to change the way planners, land owners, and resource managers do their work, or how decision-makers view an issue and the potential solutions. Based on my experience working with planners at the local level, I propose ways that science-based information might be more effectively integrated into the practice of land-use planning.

What are the major gaps in the conservation biology research agenda that need to be filled to improve land use and conservation planning?

In general, we need to better couple land conservation efforts for biodiversity protection with land-use planning. Below are three areas where research is needed to better inform both land-use and land conservation decision making. These include: increasing our understanding of low-density exurban residential development patterns and their consequences for animal and plant communities; addressing how to prioritize multiple environmental benefits that are in need of protection; and quantifying the cumulative effects of land use to better inform planners about the environmental and social trade-offs of their decisions.

Patterns, processes, and consequences of exurban development

Exurbia, defined as low-density residential development outside of urban services boundaries, is now the fastest-growing type of land use in the United States (Theobald 2001). This development is different than the dense suburban development that commonly occurred in the United States between 1960 and 1990. Exurban development results in an unorganized scattering of homes on large parcels of land (one unit per 4-16 hectare or 10-40 acre parcel). These developments typically rely on private water wells and individual sewage systems, and are located along rural roads without street lights (Theobald 2001). Heimlich and Anderson (2001) estimate that nearly 80 percent of the acreage used for new housing construction in 1994-1997 was on lots larger than one acre, and 57 percent was built on lots ten acres or larger. This type of development now takes up fifteen times the area of higher-density development (Brown et al. 2005). Estimates based on nighttime satellite imagery suggest that 37 percent of the U.S. population now lives in exurban areas that account for 14 percent of the land area. In contrast, urban and suburban development house 55 percent of the population and account for only 1.7 percent of the land area.

A well-documented example of the type of fragmentation that can result from exurban development was the Sierra foothills of California (Walker and Fortmann 2003). Here, the median size of landholdings in 1957 for Nevada County was 223 hectares, but 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) given the comparatively larger amount of research focused on urban ecology.

Due to the extent of this problem, there has been a call for increased focus on ecological principles in land-use planning and for sprawl-limiting policies to address the issues associated with what is sometimes termed the wildland-urban interface (Radeloff et al. 2005). Others have argued for further studies on the impacts to species conservation, and suggest an extinction debt (the time lag between disturbance and when species extinctions are observed) that remains to be paid resulting from the relatively recent expansion of exurban development (Hansen et al. 2005). Because of the severe consequences associated with this expanding type of land-use, much of this essay considers issues surrounding low-density development beyond the urban fringe.

Very little is known about what determines the extent and pattern of exurban development, and this lack of understanding makes it difficult to pose solutions to the problem. The growth in rural residential development comes from factors that “push” residents towards these areas, such as low housing supply and higher costs associated with city dwellings and the urban fringe; as well as “pull” factors, such as attractive scenery and quiet country living (Heimlich and Anderson 2001). In many places exurban residents view the natural environment as an important amenity (Crump 2003). One survey showed that 45 percent of Americans living in medium-to-large cities wanted to live in a rural or small-town setting 30 or more miles from the city (Brown et al. 1997). But the exact attractants for this type of development are relatively undocumented, and the resulting patterns are not sufficiently quantified. This is in part due to the inherent difficulties in mapping and monitoring this type of development remotely – making useful information generally unavailable (but see Sutton 2006).

More information is needed on exurban development patterns to better evaluate the extent to which privately owned wildlands are in fact highly modified by low-density development. Unfortunately, mapping low-density residential development often requires local parcel and assessor’s data that is not always available digitally, and that can be time consuming to acquire over a large area. Furthermore, surveys of people living in exurbia are needed to identify the exact attractants that lure them to live in the countryside as well as factors that may push them toward remote locations. This information will help increase our understanding of the process and pattern of exurban development, which is needed to better address the problem through policies, regulations, and incentive programs.

Conservation biologists are only beginning to address the consequences of low-density development for habitat loss, fragmentation, and biodiversity. Much of the work has focused on the response of bird communities to residential development, and demonstrated that only certain species tolerate houses and their associated disturbances (Nillon et al. 1995, Reynaud and Thioulouse 2000, Parsons et al. 2003, Odell et al. 2003, Manley et al. 2006). In California's oak woodlands, low-density residential development proves as unsuitable for some bird species as are suburban neighborhoods where urban adapted species dominate (Merenlender et al. 1998). Also, Odell and Knight (2001) found that meso-carnivore densities were affected up to 300 meters from residential developments, and that differences in wildlife densities in areas of low and high development density were insignificant. These results are cause for concern, given the increasing amount and large geographic extent of exurban development. More research is needed on wildlife abundance along land use gradients that explicitly include areas of low-density development.

Additional research is also needed on how the distribution of invasive species is associated with the degree of fragmentation and connectivity of the landscape (With 2002). The synergy between spatial patterns of disturbance and the spread of invasives may be especially important in areas of high biodiversity that are undergoing rapid anthropogenic change (Abbitt et al. 2000, Hilty et al. 2006 (b). In particular, the extent and pattern of exurban and other land use modifications influences the probability of exotic species invasions. For example, rural residential development was associated with invasion by exotic plant species around Lake Tahoe, California; and these sites are potentially serving as staging areas for dispersal of those species into less fragmented lower montane forests (Manley et al. 2006). Also, if there exist disturbance thresholds beyond which invasions by non-natives are more likely, then quantifying these could help land-use planners and managers reduce such risks.

Targeting multiple environmental benefits for conservation planning

As discussed earlier, the literature dedicated to protected area planning is well-developed. Research and models designed to help decision-makers prioritize land conservation goals makes up most of what is understood as systematic conservation planning (Margules and Pressey 2000). The most important components of protected-area planning models are the distributions of biological or other conservation benefits, economic costs of the required conservation action, and the probability that the site will be lost if no action is taken. Most recently, experts in the field have advocated for minimizing the future loss of species and habitat by integrating threats from land use into protected-area planning algorithms. It is also important to integrate the cost of removing that threat through full or partial purchase of land iteratively when optimizing private land protection; and both the threat and the cost need to be considered over time in order to prioritize acquisition correctly over the long-term (Wilson et al. 2006, Newburn et al. 2005, Meir et al. 2004, Costello and Polasky 2004).

There are ways to sort through tens of thousands of parcels and consider changing probabilities of each parcel being converted, as well as the relative costs of acquiring each parcel (Newburn et al. 2006) for targeting purposes. The importance of quantifying the relative threat to habitat and its associated natural resources cannot be overstated (see Figure 1 for an example of a parcel-level threat map). This is essential in order to ensure that we are prioritizing land that needs protection rather than what is more commonly done, which is to maximize investors' returns by purchasing full or partial interests in inexpensive land that is often not in need of immediate protection, thereby allowing higher-priority sites to be lost to development or resource extraction. This means that conservation science needs to do a better job at modeling the built environment and transforming these models into decision-support tools for conservation planning.

While more attention is needed to refine our threat and cost models, we also are often missing information on the distribution of ecological benefits that need conservation, and information on how much land, of what types, quality, and patch size is required to effectively protect biological benefits such as endemic species and habitat. This is particularly difficult when multiple conservation objectives, such as several different species, habitat types, and services, are in need of protection. This is a key issue because most incentive-based conservation programs have multiple desired outcomes such as wetland protection, water quality, and endangered species conservation. Thus, one of our greatest challenges is to help ensure that the money spent on these programs optimizes the returns for multiple environmental benefits. Many conservation scientists working with economists have resorted to relating environmental benefits to a common monetary currency, which solves the problem if and only if the benefits can be quantified in financial terms (monetized) – which is often not the case.

Three examples of theoretical benefit functions are shown in Figure 2; the shape of these curves determines how much land is needed to secure a sufficient proportion of a particular conservation benefit. Since the actual shape of these functions is rarely known, it is difficult to determine the precise extent of land protection needed. This challenge is compounded by the fact that the pattern and configuration of a protected area network influences benefit functions in ways we rarely understand. Based on basic principles of conservation biology, we know that the benefits from one site depend on the type and protection status of neighboring sites, and that nonlinear increases in benefits can result from increased protection of adjacent land – complicating matters greatly. Therefore more work is needed on the value of connectivity among protected areas.

Biological resources are often not fungible (countable and interchangeable), and therefore it may be impossible to evaluate the tradeoff between conserving one type of habitat and another, just as we can't compare apples and oranges (Williams and Araujo 2002). These problems are illustrated when we think about trying to conserve mature forests for spotted owl habitat along with open wetlands that support their prey. We don't necessarily understand the amount of mature forest required to support the owls and maintain resistance to invasion of competing barn owls; mature forests generally do not overlap with open wetlands; and prey availability varies dramatically due to fluctuations in rodent population sizes, making the amount of prey habitat required difficult to predict.

In practice, protected-area plans are typically determined by regional goals and *ad hoc* scoring procedures, and site ranking depends on the choice of relative weights within and between benefit types. Setting regional conservation targets such as a certain percent of habitat, which is commonly done to meet international conservation goals, is another way of weighting and comparing habitat types. In this approach, the relative measure of irreplaceability or complementarity depends on the differing extent of remnant habitat and how this compares with stated targets, usually based on estimates of historic vegetation coverage. For example, if only a small percentage of historic levels of wetland or tropical forest exist today, then recovering enough to meet a target of 10% of the former extent will weight this rarer habitat type over a less impacted habitat type.

The sensitivity of ranking which sites ultimately get selected for conservation will depend fundamentally on the correlation and relative variation among the benefit functions. Positive correlation signifies co-occurrence of the priority species or habitats, whereas negative correlation indicates that the two distributions rarely overlap. If the biological benefit function were redefined to differentially weight one type in comparison to another – thus increasing the ratio of weights between the two distinct habitat types -- the resulting set of priority sites would include more parcels from one habitat type at the expense of the other. This substitution effect of site selection increases with the strength of negative correlation among multiple distributions of benefit types. This may result in a see-saw effect, where site rankings shift primarily as a function of the relative weights, which are usually defined with very little objective scientific basis (Newburn et al. 2005).

To avoid this, multiple benefits must be decoupled in the prioritization process when they are uncorrelated in space. In other words, apples and oranges should not be pooled together and given a relative weight prior to selecting which lands to protect; rather sites should be selected to ensure the protection of one and then the other independently. Or example, in Sonoma County, California, natural resources such as oak woodlands, conifer-dominated forestlands, and greenbelts are not correlated in space, and therefore parcels supporting these resources had to be prioritized separately for acquisition by the Sonoma County Agricultural Preservation and Open Space District (Figure 3). Unfortunately, although this solution avoids erroneous results, it does not allow for the most efficient targeting of multiple benefits that will minimize the costs of protecting the many natural resources in need of protection.

We need to recognize that even with the best available data, the benefit functions assumed and their relative weightings are products of their particular social, economic, and political contexts (Newburn et al. 2005). A planner or decision-maker unfamiliar with the optimization algorithms may not clearly see how differences among spatial data on benefit distributions and relative weights of model inputs can dramatically influence the optimal solutions produced. It is critical that conservation scientists and economists continue to address how best to combine the values of multiple environmental benefits in order to set thresholds and prioritize land conservation.

Cumulative impacts, non-linear thresholds, and marginal gains

Planners work toward protecting environmental quality through the construction of sustainable development plans, and by overseeing environmental review of specific development projects. In California and at least eighteen other states, individual projects are reviewed under state environmental quality laws and policies that hinge primarily on an environmental impact report. Environmental review usually takes place at the project or regional scale in order to balance protection of the environment and quality of life with the need for economic growth. As part of this process, the cumulative effects of the project in relation to past, present, and foreseeable future projects in the surrounding area must be assessed. Understandably, then, land use planners are requesting research to identify cumulative effects and the thresholds beyond which they might occur to justify restrictions on development (Environmental Law Institute 2003, Huggett 2005).

Predicting how ecosystems will respond to proposed current and future development requires an understanding of ecosystem resilience -- the amount of disturbance that an ecosystem can withstand without changing its self-organizing processes and the variables that control its structures (Holling and Gunderson 2002). There is mounting evidence that resilience is reduced in response to human-induced disturbance that results in reducing biological diversity, removing assemblages of species or entire trophic levels, changing the climate, polluting the ecosystems, and altering the frequencies and duration of disturbance (Folke et al. 2004). In response to these changes, ecosystems can become brittle, and suddenly shift to undesirable states that reduce their capacity to provide desired goods and services (Scheffer et al. 2001).

A well-known example of this is Wisconsin's Lake Mendota, which had received a steady influx of nutrients from surrounding farms and developed areas for years without any dramatic change. Then suddenly, following a large rain event in 1993, Lake Mendota displayed a large increase in algal growth and became eutrophic. It turns out that phosphorus buildup in the mud for years prior to this storm event had decreased the lake's resilience, and ultimately resulted in a sudden ecosystem state change that greatly impacted water quality and the fishery (Bennett et al. 1999). It is highly desirable to prevent these sometimes disastrous transitions and, where possible, attempt to restore ecosystems so that they can continue to function. To encourage planners to maintain resilience, we need to better understand the interactions between human and natural systems, and how disturbance influences ecosystem resilience and biodiversity conservation.

There is mounting evidence of threshold effects resulting from human perturbations to ecosystems (Muradian 2001). For managers and planners, there is a strong desire to know at what particular point the level of disturbance crosses a threshold -- leading the organizing processes of the system to change from one state to an alternative, potentially more degraded state (Carpenter et al. 2001). Ecosystems often display non-linear responses to stressors (Donohue et al. 2006, Phillips 2006), which means that changes between one environmental state and a more degraded state may happen suddenly, rather than as a gradual response to increased disturbance. To predict the response of ecosystems to disturbance thus often requires the use of non-linear models and extensive data on the response variable across time and space. The importance of dealing with non-linear dynamics of ecological systems and existing thresholds is widely recognized (Muradian 2001).

The use of non-linear statistical modeling to examine potential thresholds is on the rise but linear models still prevail in ecological literature, making it more difficult to define breakpoints or thresholds. Non-linear thresholds beyond which land use change will result in the degradation of ecosystems are rarely quantified. It is even more rare for researchers to take the additional step of forecasting the foreseeable expected changes to the landscape and assessing their effects. We also need an understanding of how the environment responds under different initial conditions, in order to maximize marginal gains (greatest response per increment of change) that may result from proposed changes to future land use and restoration.

For example, recovery of coastal salmon populations along the coast of California involves many small watersheds and upland tributaries, some of which have extensive land use and water demand by residents and agriculture that has led to degraded habitat; others are relatively undeveloped and support good salmonid spawning habitat. Restoration of the most disturbed watersheds may be too costly and difficult to expect any marginal gains. On the other hand, there is little opportunity for salmon recovery in relatively undisturbed watersheds. However, efforts in areas with moderate amounts of urban and agricultural development could result in more substantial marginal gains and ultimately lead to crossing a threshold required for salmon recovery – making these watersheds the most cost-effective places to begin restoration efforts.

While the state trajectories of certain ecological systems such as lakes have been extremely useful in increasing our understanding of ecosystem resilience (Carpenter et al. 1997 and 2001), many coupled human and natural systems remain unstudied, making it difficult to provide planners and managers with guidelines on how to manage for resilience. The impacts and thresholds associated with exurban development for woodlands and forestlands across the United States is a good example where almost nothing is known with respect to thresholds.

We recently completed a study on land use and its impacts on salmon spawning grounds in 87 watersheds throughout the Russian River in Sonoma County, California. Here the highest-quality spawning grounds are gravel beds, but fine sediment from erosion in the uplands may silt these gravel beds, making them unusable for salmon. We found that the urban and vineyard land uses had non-linear, negative relationships with salmon spawning substrate quality (Lohse et al. in prep), consistent with our previous work using linear models on lower resolution data (Opperman et al. 2005) and other studies (Wang et al. 2001, Pess et al. 2002, Morse et al. 2003).

Unlike previous studies, we were also able to examine the non-linear effects of exurban land use, and found that this land use category was a significant predictor of the distribution of fine sediments. Increases in the percent of total exurban development in a watershed significantly reduced the odds of observing high-quality habitat. Although urban development had the largest marginal effects, exurban development will affect a much larger land area. The land use change model that we developed for this research predicted that over the next decade, ten times as much land will become developed in exurban as in urban areas. Further, future urban development will tend to be clustered in areas that already have high levels of urban development, and thus already had little high-quality spawning habitat. Exurban development, however, is predicted to occur in watersheds that range from the least developed to the most developed, and will affect reaches that currently have small to moderate amounts of land use. Thus, exurban development will likely have a much greater overall impact than urban development on spawning conditions in Russian River basin streams over the next decade. Given the very low population densities of exurban development, the per-person effect on the environment of this type of development is large.

More studies using this approach are needed to examine the non-linear response of different types of land use change on measures of environmental condition, so we can better inform planners about the potential impacts of land use on multiple environmental benefits. These studies should also attempt to forecast how future development scenarios can influence the environment in order to provide decision-support systems.

Unfortunately, the complexities and non-linear behavior inherent in ecological systems mean there is a great deal of uncertainty in predicting the extent and nature of changes in natural systems from human perturbations, which vary widely in their type and impact.

Policy outcomes and tradeoffs

It is hard to disagree that monitoring is essential for adaptive management, and we must view private land-conservation tools similarly and monitor their outcomes in order to better adapt our methods in the future. This is true for commonly employed incentive-based tools, such as conservation easements, as well as for regulatory tools such as zoning and urban growth limits. For example, little is known about the ecological outcomes of conservation easements at the local or landscape scale, despite the increasing acreage and public investment in this approach (Merenlender et al. 2004). It is even more difficult to determine how the regulatory tools change future development patterns. Sewer and water services may be the most important determinant of urban and suburban development; however this infrastructure does not constrain exurban development, which by definition is not dependent on such services (Newburn and Berck 2006). So policies that may curtail urban sprawl may not be the same as those needed for reducing exurban expansion trends. For example, urban growth boundaries are a recent popular tool for limiting sprawl (Quigley and Raphael 2004), but they can have the perverse effect of pushing development beyond the cities, and probably have little effect on exurban development. The complex trade-offs that are made when land use policies such as growth limits and zoning are enacted need to be examined further through an integrated modeling approach.

Current policy options are being adopted with little attention to the actual outcomes of these policies for curtailing the loss of open space. Transportation and urban economic models have explored lower land costs, and we know that inexpensive transportation costs can influence development distance from the central business district (Fujita 1999). But we still need spatially explicit models that integrate policy and economics with landscape ecology to explore how policy tools such as urban growth boundaries influence the pattern of development, including low density development; Newburn and Bercks' (2006) empirical model provides fertile ground for these ideas. Planning for development across urban and rural areas involves complicated landscapes and economies, which is why most policies are likely to have unintended consequences (Nechyba and Walsh 2004). It is critical that we work across disciplines, including land economics, landscape ecology, and land use planning, to see how policies have influenced development patterns and land conservation as well as other concerns, such as air pollution, associated with sprawl. We also need to examine the inherent trade-offs associated with various policy options so we can inform local decision-makers of these trade-offs and offer better tools for private land conservation. This is an important new direction for land use planning, however, a simple set of policy recommendations are unlikely to arise.

Take-home points

- Increasing our understanding of land use patterns and processes, particularly with respect to the drivers and consequences of exurban development, is critical in order to stave off what has become the largest growing source of habitat fragmentation on privately owned open space in the United States.

- Exploring the consequences of combining correlated and uncorrelated environmental benefits across real landscapes for prioritizing land acquisition will greatly improve our ability to help public and private organizations optimize their investments in land conservation.
- Quantifying the causal relationships between land use and environmental responses, using improved non-linear analysis methods to explore thresholds and their sensitivity to other environmental variables, is critical if we are going to advise planners how to avoid crossing these thresholds to maintain ecosystem process and function. Also, measuring the trajectory that degraded ecosystems take following restoration treatments or other alterations is essential to plan for ecosystem recovery.
- We must monitor outcomes from the existing land use planning and incentive-based conservation tools used to protect privately owned open space. Also, spatially explicit models should be developed that incorporate land use dynamics, economics, and landscape ecology to explore the tradeoffs inherent in policies designed to curtail urban sprawl and exurban expansion.

What can land use planners and regulators do that would help lead to the conservation and recovery of biodiversity?

There has been widespread recognition that having local governments be responsible for their own land use planning in a vacuum has been disastrous for regional development patterns, since policies adopted in one city or county affect neighboring jurisdictions. Coordinated regional planning is on the rise. However, in many places counties are dealing with sprawl because cities are not absorbing additional growth through increasing development density and providing attractive high-density development. Coordinated regional planning across multiple jurisdictions is essential to address the problem of exurban development that is operating at a larger scale than single local jurisdictions. One excellent study of the benefits and necessary elements for successful regional planning, “Regional planning in Michigan: Challenges and opportunities of intergovernmental cooperation” (Center for Local, State, and Urban policy 2005), reveals that most successful regional efforts get going to save on costs. And if competing goals and turf issues can be avoided, trusting relationships can be built and regional planning efforts sustained over time to improve cross-jurisdiction communication, increase information sharing, and reduce costs.

Another method for facilitating regional planning is the programmatic environmental impact report, which addresses environmental review for multiple pending and possible future projects within a particular region. This type of comprehensive review often results in a regional plan that allows development in designated areas to proceed without further environmental review. This is an incentive-based approach, because in the end developers save time and money by not having to do further environmental review as each individual project rolls out in the area covered by the programmatic review. Unfortunately, most governments and developers wait too long before they use this tool. This is because “business as usual” is not too costly or time-consuming until natural resources are taxed to the point of needing protection, which can then hold up development – as in the case of endangered species recovery. At that point, the options and costs for land protection are extremely limited.

For example, in the Laguna de Santa Rosa plain, where an endangered California Tiger Salamander population was preventing further development, a 2:1 mitigation ratio is now required as part of a conservation plan. With land costs as high as $300,000 an acre, this will result in roughly $30,000 being tacked on to the purchase price of each additional housing unit. We need to convince local governments that are not yet faced with these crises to levy fees early on that allow for conservation of land and associated natural resources while the options for retaining habitat connectivity at a larger scale remains, which in most cases is less expensive than when development has crossed a threshold that results in limited habitat and rare and endangered species. These plans often require complex ecological and economic analysis; therefore, a science panel, similar to those required by California's Natural Communities Conservation Planning process, should be required for all regional plans and programmatic EIRs to address tradeoffs between development and the environment.

Local government institutions need to be better integrated to address both pull factors that foster higher-density development, through financial incentives for lower-income housing with amenities such as security, parks, and good schools; as well as the usual push factors used for conserving open spaces, through tools such as zoning or incentives like trading development rights or purchasing easements. All too often, conservation planning tools only provide push factors that limit development on farms and wildlands. Protecting land from development may prevent habitat conversion locally, but these restrictions on land supply may not be an effective way to shape future regional growth patterns. The regional demand for land remains despite land protections, and growth will shift to other unprotected locations.

Unfortunately the drivers that create demand for rural residential development do not go away, and therefore this type of development is pushed to other areas not currently protected. This is why open-space protection on private land must coordinate policies that both push development away from sensitive areas where environmental impact thresholds may be crossed, and pull development inside service boundaries – which, as discussed above, may require coordinated planning between cities and counties. Irwin et al. (2003) demonstrate that extending public sewer and water infrastructure may guide urban growth to designated target areas more effectively than placing easements on existing farmland, demonstrating that public infrastructure projects are necessary to redirect and concentrate regional development, and hence to serve conservation objectives.

It is important that we encourage local governments to invoke fees and taxes to pay for enacting these pull and push factors (Brueckner 2000), and again these efforts can work best if they are coordinated as a single policy initiative to generate widespread support. Special open-space and urban housing districts can be established to acquire land and facilitate desired development. Another method of funding these desired outcomes is to enact policy that allows mitigation of project impacts to be accomplished through fees paid to government agencies, such as open-space districts or resource agencies that have a land acquisition program. This will increase the chances that off-site mitigation efforts will be enacted through a coordinated conservation planning effort.

For example, in 2001 California passed legislation that facilitates off-site mitigation of habitat loss by offering an option to donate funds to the California Oak Woodlands Conservation Program. This program is focused on the purchase of conservation easements to protect California's privately owned oak woodlands. The California Wildlife Conservation Board is authorized to purchase oak woodland conservation easements and to provide grants for land improvements and restoration efforts. While the Program is coordinated at a statewide level, it provides opportunities to address oak woodland issues on a regional priority basis. This approach can be useful for conserving habitat types that are widespread, and hence more conservation benefit can be gained from off-site mitigation rather than traditional mitigation approaches such as moving and planting trees. However, these off-site mitigation solutions should always complement stringent requirements to minimize environmental degradation on the project site. Providing funds for regional land conservation from mitigation funds may not work well if the proposed development project affects habitats with extremely restricted distributions, since these habitats may not be able to withstand any further development or may require very local mitigation solutions.

One of the most common ways to prevent further subdivision of large privately owned land parcels without changing the zoning is through trading development rights, which involves the sale of development rights, usually from areas prezoned as "sending," and allows for more development than currently zoned for in designated "receiving" areas. Trading development rights programs have been in place for some time for agricultural land protection, as in New Jersey and Maryland. In these voluntary programs, landowners can sell "development credits" to developers in exchange for removing subdivision rights from their property title. Due to the voluntary nature of many of these programs, they often do not have clear restrictions on sending and receiving zones, but more commonly follow planning guidelines such as restrictions on slope (Johnston and Madison 1997). In many cases the credits allow for increased development density in certain areas, and sometimes can lead to a reduction of environmental standards for a particular project. In this way TDR credits serve as a type of mitigation for environmental impacts. This is the case in Lake Tahoe, California, where the building envelope can be enlarged beyond regulation size if another property's building coverage area in the same watershed is retired.

For conservation of natural resources, it is best if these programs carefully designate sending areas so as to maximize the environmental benefits. Receiving areas should ideally be within the service boundaries, already zoned at a relatively high density (e.g. 1-5 acres), and/or within unincorporated towns to substantially increase development densities and reduce economic, social, and environmental costs. Also, if it is important to protect the land adjacent to the sending zone, these areas should have some form of protection in perpetuity, either through the TDR program or another tool; otherwise these areas will be highly susceptible to growth after the receiving areas have been fully built out. However, the opportunity to sell and buy rights can increase the opportunity costs of both sending and receiving sites, and can accelerate growth and increase property values due to speculation on increased growth opportunities. These programs work best when they are well-planned and executed at a time when options for receiving zones are plentiful, rather than waiting until options for zoning are highly constrained.

The most important zoning objective for preventing habitat fragmentation on private lands and protecting biodiversity should be to discourage and remove areas zoned for medium-sized lots less than 100-200 acres and greater than 2 acres. As discussed above, this can be done through TDR programs. But perhaps more desirable would be for local government to set maximum lot sizes for development of 1-5 acres, and only use minimum parcel size for large agricultural and natural areas over 160 acres/parcel or more. This approach is intended to address habitat loss, degradation, and fragmentation associated with the low-density rural residential development described as exurbia above.

Leaving all the complexities of land use planning to local government is highly problematic, given that most local governments in the United States are under-funded and often cannot afford the necessary staffing levels and expertise required for the job. To improve habitat conservation through better land use planning, applied science needs to interface with planners to assess critically whether or not current policies to conserve open space and stave off sprawl actually produce the desired effect, as discussed in the research section above. This means professional planners need to see their work as adaptive by nature, and be willing to expend some resources on monitoring and evaluation despite the daily pressure they are under to address more pressing issues.

Take-home points

- City, county, and regional planning must be tightly coordinated in order to improve large-scale habitat conservation and contain sprawl.
- Regional plans that incorporate programmatic EIRs should be encouraged as early as possible, to reduce costs that increase dramatically when options for conserving critical habitat for endangered species are constrained by future build-out. The development of these should require a science panel during the planning phase similar to the NCCP process.
- It is critical that conservation and land use planners better integrate both incentives that push development away from priority natural areas, and those that pull development toward areas that are already developed and have service infrastructure.
- Fees and taxes should be levied to pay for open-space acquisition that will prevent habitat fragmentation and protect farmland, and to subsidize amenities that can be attractants for infill, such as parks, city landscaping, recreation centers, low-cost housing, better schools, and safe streets.
- Options for mitigation of habitat loss should include funding off-site land acquisition to maximize environmental benefits from the money spent on mitigating environmental impacts, and these funds should be managed by regional or statewide public agencies with public oversight and conservation plans in place.
- Programs designed to take advantage of trading development rights should be well-planned, including making sure that sending zones will result in protection of large continuous ownerships for habitat protection while receiving zones result in high-density development and not additional exurban development. Increased property values and rates of development should be expected in certain areas as a result of these programs.

- Removing and preventing rural residential parcel sizes from approximately 5-75 acres should be a very high planning priority, possibly by zoning for maximum lot sizes of approximately 2 acres for residential development rather than setting minimum densities for residential areas. Minimum parcel sizes should only be used for agricultural and rural lands that support environmental services and require large, less-fragmented landscapes.
- A more adaptive process that involves monitoring the impacts of local decision-making on resulting patterns of land use and conservation should be adopted by local planners. This approach requires outcomes research that quantifies the effectiveness of commonly applied land use and conservation policies intended to prevent sprawl and protect open space.

What practices would help convey science-based information to land use planners?

I regularly attempt to extend scientific information, research results, and decision support systems to planners and other people working in local and state government, as well as to board members responsible for decision-making. My insights on the process and how it may be improved are based on my own personal experience in northern California, rather than on extensive scholarly research. Also, I am forced to make some broad generalizations about planners for the sake of this essay that of course do not hold true for all planners in all settings. It has been my experience that scientists can not build a decision-support system or provide any other source of information and simply expect that those it would best serve will simply use it. If applied scientists want to influence the local planning process, they must become involved in jointly developing programs that will ultimately be adopted and help planners and representative decision-makers.

I have found that the best approach is to engage intended users of the information in the development of the project by having them invest financially, if at all possible, since that will make them very interested in the outcomes and motivated to use the resulting information. All too often, local governments pay private planning consultants who rarely provide real leadership by challenging government institutions and their staff to explore the most fruitful directions and solutions to the problem. There is a critical need for academics to become more involved in real-world planning in order for science to influence policy.

It is also my experience that planners work with a very local network of contacts from whom they seek information, which rarely goes beyond county staff resources and familiar consulting firms. This means that the best way to increase the role of science in the process is to increase the number of scientists involved in county government and the science literacy of planning and other staff working for local government. A good example is University County Cooperative Extension, where land-grant university academics work in county government to provide expertise on agricultural, human, and natural resources. These expert advisors are linked to research-based institutions while receiving support from local government, and are viewed as “in-house” by local government employees.

This institutional relationship, established with the land-grant colleges, is under-supported and under-utilized. County advisors or agents regularly present to supervisors and city council members, and maintain good relationships with state legislatures.

Environmental scientists should take more advantage of University Cooperative Extension, which exists in almost all states and counties. This is especially true now, when many of the issues that even the most traditional production agricultural advisors face are environmental in nature. Other local government departments that are often interested in implementing science-based decision-making include those who are in charge of information technology (geographic information systems and data repository); special districts for open space, which often run semi-autonomously; and resource conservation districts, which often have their own, more focused planning staff.

Another important criterion that must be adhered to is to ensure that all science-based information is presented in context and clearly relevant to the problems that planners and other government staff are experiencing. Local government is under-staffed and under-supported, and these people do not have time to worry about issues that are not immediately pressing. This means that to serve them best, a two-way street of communication must exist so that applied research is directly informed by the issues that are most critical to planners. Academics, and even scientists working for state agencies and non-governmental organizations, can be far too removed from the world of local planning to take stock of what is really needed on the ground. Again, this is where having "in-house" academics in place can help identify emerging environmental issues where targeted research could help.

It would be nice to think that training local planners is an attractive approach; unfortunately I am often reminded that even leaving the office for a one-day workshop can be next to impossible given some planners' work loads. However, we must try to augment planners' information by finding support for them to attend training opportunities and lobbying for better support for the natural resource experts on whom they rely, such as University Cooperative Extension. Once again, any training or literature must be focused on their most pressing issues in order to justify the time required to participate or to read the material.

Another reason generic decision-support systems don't work is that planners have an inherent distrust of models, and to convince them of their utility requires regular interactions on model development and the use of very high resolution data (e.g. parcel level). It is absolutely critical that the rules they follow and local data be integrated into any analysis and decision-support tools (Newburn et al. 2005, Merenlender et al. 2005). They do need help integrating local data into their decision-making process, but this requires large amounts of time on behalf of the investigator, and planners who have sufficient time to address conservation issues.

While scientists often use technology and the world-wide web to make science information available to the public, we need to do a much better job of marketing these sources of information and using the web to survey planners about pressing issues and how best to provide them with environmental information. Similar to the questions addressed in the first part of this essay, we need to evaluate which types of extension work best to increase the extent to which conservation science can influence land use planning, by studying what works and what does not. This requires outcomes research following all projects that are designed to improve conservation planning at the local level. For example, follow-up studies and surveys could determine to what extent decision-support tools, such as Vista developed by Nature Serve, and education materials provided to planners are actually used. This is fortunately being done by the

Environmental Law Institute to determine the utility of their recent outreach materials for planners on conservation thresholds (Environmental Law Institute 2003).

Effective conservation planning needs to involve the public as well as planning professionals. Planners and local government decision-makers serve the public and are greatly influenced by what they perceive the public to be willing to accept. Thus, the public also needs education in scientific literacy and conservation of natural resources. This is often accomplished through a collaborative conservation process that is based on public participation. In an attempt to define a common language for this approach to decision-making and to share lessons learned from case studies, the Sonoran Institute published a very useful report titled “Beyond the Hundredth Meeting: A Field Guide to Collaborative Conservation on the West’s Public Lands” (Cestero 1999). This investigation offers helpful guidelines for improving the success of public processes that are a necessary part of conservation planning.

Clearly there is no quick fix for informing planners about conservation science. Hopefully the following conclusions will add to our collective understanding of how we can improve the integration of conservation science into the planning process at the local level.

Take-home points

- Applied scientists must work with planners on developing decision-support tools to increase the chances that the information developed will be used.
- Planners, along with the county natural resource advisors on whom they rely, require more support to take advantage of training, which should be focused on emerging issues in order to attract participation.
- Planners and the public are often skeptical of models and their outputs, so high-resolution data should be used to improve model accuracy. In order to be used, models must be developed in close collaboration with planners and extended to the public to increase their acceptance.
- Web sites and other sources of information require better marketing to planners, including soliciting their opinions to influence what information needs to be extended and how best to provide the information to them.
- Studies need to be conducted on the relative effectiveness of the various methods for improving the use of conservation science among land use planners.
- Collaborative conservation efforts that involve the public are critical for success.

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Figure 1.
Example of a parcel-level threat model for low-density residential development outside the city of Cloverdale and Healdsburg, Sonoma County, California (see Newburn and Berck 2006 for modeling details).

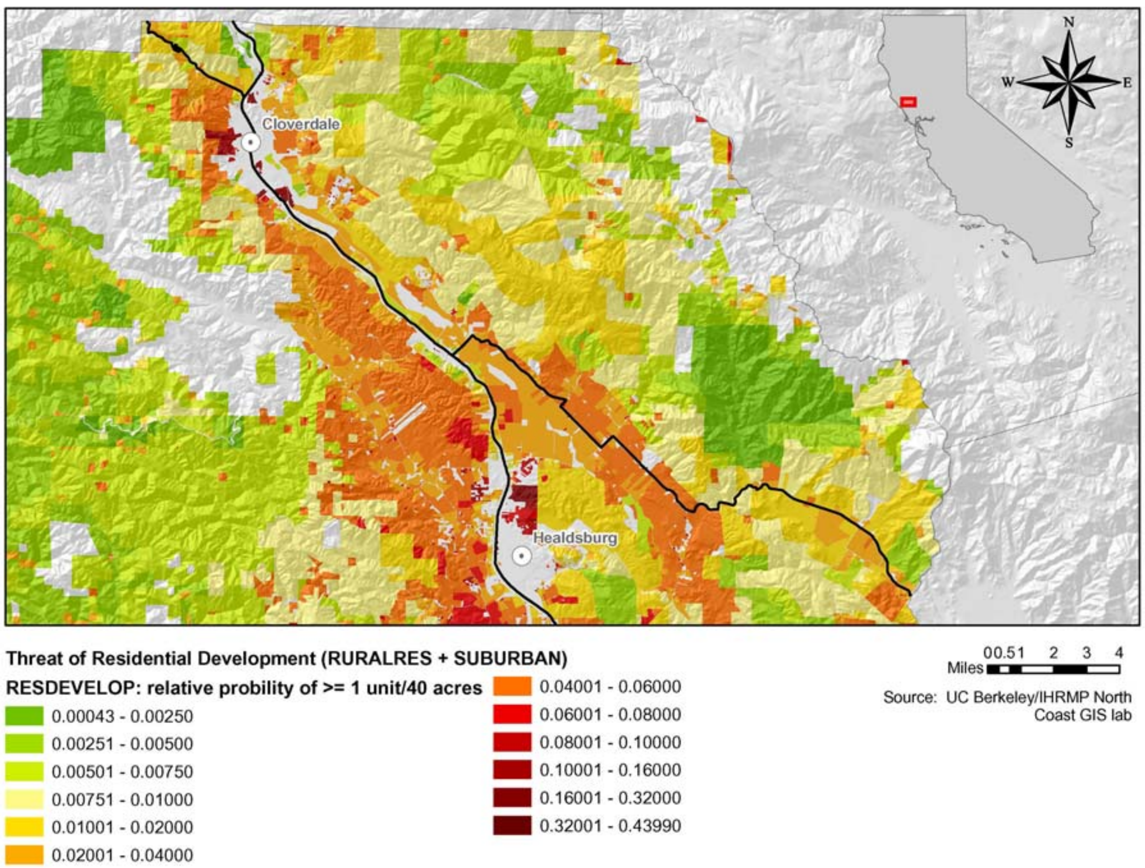

Figure 2. The top line is a theoretical representation of a conservation benefit (e.g. species, habitat or open-space element) that is secured with very little land protected, the straight line represents a resource whose protection is incrementally improved at the same rate with each added amount of land protected, and the s-shaped curve demonstrates a threshold effect, beyond which a certain amount of land secures the entire resource with little benefit of additional acquisition past the threshold point. Examples of the first could be a small vernal pool of endemic fairy shrimp; California's coastal salmon populations may behave more like the straight line; and a greenbelt or community separator would behave like the s-shaped curve.

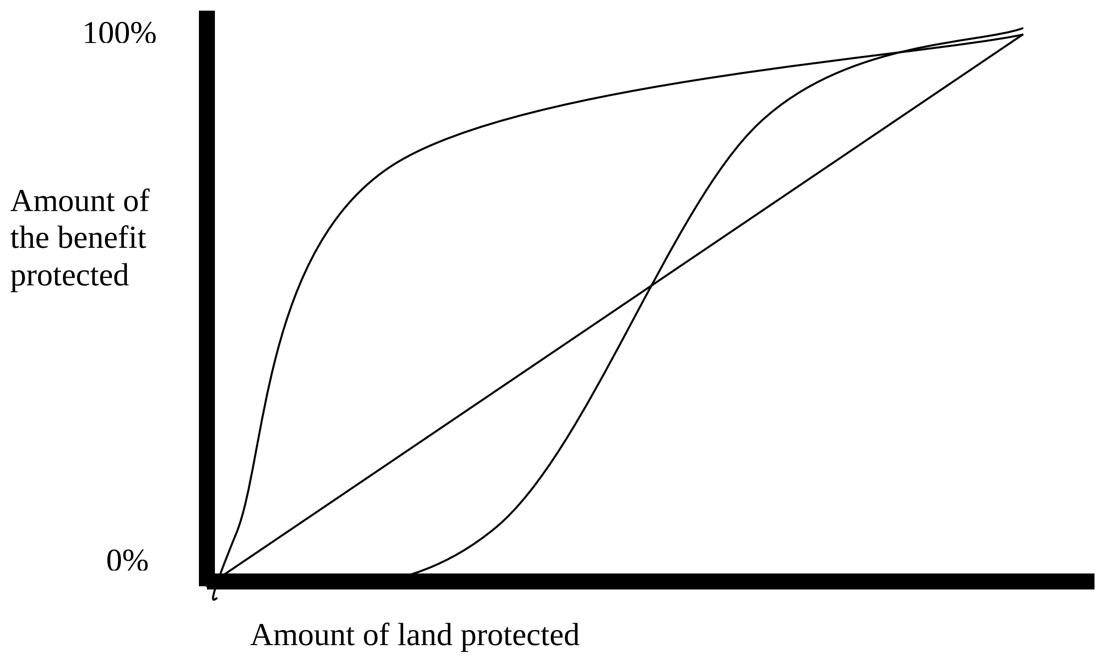

Figure 3. This map demonstrates very little spatial overlap in the priority conservation benefits identified by the Sonoma County Agricultural Preservation and Open Space District. So targeting at the parcel level is done separately for each resource listed in the legend, rather than weighting or summing uncorrelated resources together.