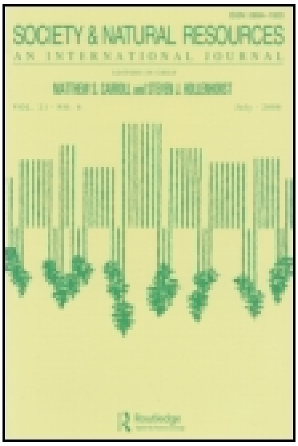

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Mapping Uncertainty in Conservation Assessment as a Means Toward Improved Conservation Planning and Implementation

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Mapping Uncertainty in Conservation Assessment as a Means Toward Improved Conservation Planning and Implementation

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Collaborative and community-based approaches to conservation and natural resource management often utilize maps that designate particular areas as being high priorities for conservation. These maps are used in stakeholder workshops and/or public discourse, but have often been highly contentious and counterproductive. We propose that quantifying and visualizing some of the uncertainty involved in making such maps could decrease their potential for causing conflict, thereby facilitating discourse and eventually, conservation action. We propose that an extra bonus could be attained by mapping the effects of missing or sparse input data regarding landowner "willingness to conserve" (given fair market compensation). The primary contributions of this action research are in the development of the propositions and in their implementation using a stochastic approach (Monte Carlo simulation). Preliminary assessment of the propositions occurred, but further research is needed to more formally evaluate them. Some practical suggestions and additional research considerations are provided.

Keywords cartography, collaborative planning, land-use planning, opportunity cost, participatory GIS, PPGIS, resilience, systematic conservation planning, transparency, vision mapping, visualization

Collaborative and community-based approaches to conservation and natural resource management have many names and are often characterized by decentralization, citizen participation, stewardship, and a holistic worldview that seeks to simultaneously promote the environment, economy, and community (e.g., Weber 2000; McGinnis 1999).

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This movement is prevalent worldwide and is based on the assumptions that the people of a place know the land, have the largest stake in its sustainability, and if empowered with more information, trust, and responsibility would make wiser decisions than they are making now (Weber 2003; McGinnis 1999). While these approaches show great promise, they are also rife with challenges to be addressed.

In this "action research" (Baskerville 1999) case study, we were closely involved with an organization aiming to create and provide conservation priority area maps to the public in general, and to land-use stakeholders in particular, in an effort to facilitate stewardship of biodiversity. The problem was that many organizations were attempting similar efforts, both within and outside the region, and were being met with well-organized and vocal resistance. In many of these cases, the maps themselves were a flashpoint and were used to fan the flames of controversy (Walker and Hurley 2004; Cohen 2001; Taking Liberty 2005).

In the following subsection we provide the context of the study and specify the problem further. We then provide our research question and suggest the quantification and mapping of uncertainty as a general approach for mitigating the problem. The methods for mapping uncertainty and for mapping priority areas for conservation are overviewed. We suggest a particular type of uncertainty to map and detail the methods used in creating and communicating the resulting uncertainty map and associated animations. We performed preliminary evaluation of the products, but the contribution of this article lies mainly in the propositions and methodology. The reflection stage of the action research cycle (Baskerville 1999) led to further insights about the benefits and framing of the particular type of uncertainty. This, combined with the call to share rich learning experiences even if they do not rigorously support the hypotheses (Knight 2006), led to us to share this potentially fruitful research direction. To improve usefulness, the action research insights are woven into the appropriate sections of the article rather than solely summarized in the discussion.

Context

The Wildlands Network (TWN), formerly The Wildlands Project, is an international organization with an emphasis on conserving large core areas of wild nature connected by linkages of natural habitat. One of TWN's strategies is to inspire and empower people to identify and conserve the important areas of their home region. The Conception Coast Project (CCP) was a nongovernmental organization (NGO) formed in this manner, to help "protect and restore the natural heritage of the region [on the south-central coast of California] through science, community involvement, and long-term planning" (Gallo et al. 2005). The strategy that TWN endorsed at the time was for the regional group to create a conservation priorities map that was science-based and explicitly showed the most important areas to conserve. "When Nature's 'bottom line' is well articulated and widely understood through conservation planning, human creativity will be able to find solutions that meet the intertwined needs of both humanity and Nature" (Locke 2000, 5). The map and associated materials were to be shared with stakeholders, especially landowners, and agencies as a starting point and initial guide for conservation actions. The maps and materials were also meant to build collaborative relationships and leverage among conservation organizations while reducing duplication of effort. Such an approach had many potential benefits, such as helping society move from a focus on reactive and species-specific conservation toward proactive conservation of long-term ecological processes.

As CCP was developing its specific methodology and approach for making the conservation priorities map, various TWN partners and similar efforts were experiencing a surprisingly well-coordinated and vociferous resistance to their conservation priorities maps. Some vocal landowners saw the agenda and maps as a land grab, a global environmental conspiracy, or at least a huge increase in environmental restrictions (Walker and Hurley 2004; Cohen 2001; Pincetl 2006; Taking Liberty 2005). They often responded with fear and suspicion, thereby blocking any knowledge transfer or subsequent collaborations. A misinformation campaign ensued. One organization even created a website that could easily be mistaken as the official TWN website, while another fabricated a TWN conservation priorities map for the continental United States that was a sea of red (core reserves) and yellow (multiple-use zones) with miniscule dots of green (''normal use'') remaining (Sovereignty International 2000; Hurley and Walker 2004). The misinformation can be further illustrated by the claim that ''the goal of the environmental community and many in government is to own or control all of the land, and convert half of it to wilderness'' (Sovereignty International 2000, 1). The fear and suspicion spread. A rancher from Colorado summarized one of the major problems of the fear and suspicion backlash to collaborative conservation: ''The environmentalists and ranchers were squared off against one another, and while [we] were fighting, the developers were walking off with the valley'' (Pincetl 2006, 249).

Meanwhile, the land use politics in the CCP region were also reaching a particularly polarized crescendo. Four land-use initiatives of the years preceding illustrate this tension. The National Park Service feasibility study for federal involvement in conserving the rural Gaviota Coast (California) was met with such vehement opposition by some of the landowners that many onlookers proclaimed the effort ''dead on arrival.'' This proved to indeed be the case several years later. Second, Santa Barbara County Planning Department initiated a rural resources program designed to better identify ecologically sensitive locations, and to allow for streamlined permitting and regulation in the other areas. The effort involved stakeholder participation, but was derailed when the agricultural block of stakeholders left the process. Third, property-rights activists organized a voter initiative to split the county in half because they felt misrepresented in land-use and business issues. Last, a stakeholder-based collaborative process designed an oak tree protection compromise, but it was rescinded after the next election when prodevelopment county supervisors gained a board majority.

Faced with this evolving national and regional context, and with a budget that was miniscule compared to the local efforts that tried and failed to include stakeholders in conservation priority setting efforts, CCP made the difficult decision to change course and create the conservation priorities map and associated document using only participation from scientists, planners, and conservationists. The ensuing conservation priorities map was envisioned to be a ''voice for nature'' that could be used as a reference in the political arena, rather than being a broad community-based consensus around a scientifically sound vision.

The ''Action-Research''

This change of course reduced the number of questions that could be asked in the action research case study. A suggested best practice in collaborative and community-based conservation is to engage as many and as diverse of a set of stakeholders as possible, both at the outset of and throughout the conservation priority setting effort (Pincetl 2006; Knight et al. 2006; Reed 2008). Although our effort did not have the funding or political impetus to allow this, we realized that the CCP case could still allow research that could aid in such efforts. In such processes, there is almost always a stage where the geographic information systems (GIS) analysts and scientists present a ‘‘voice for nature’’ priorities map (or maps) to a committee of landowners and other stakeholder representatives for discussion and development of a plan. Some frameworks term this going from conservation assessment to conservation planning (Knight et al. 2006). Some permutation of the map is often eventually presented to the public as well. Careful attention to how these maps are created, displayed, and communicated, such that they are sensitive to perceptual differences of the proposed audiences, could help allay misunderstandings and conflict (Rejeski 1993), both in stakeholder workshops and for public release in general. This thinking led to our overarching research question: How could the conservation priorities map be improved such that its pros better outweighed its cons, namely, that its benefits of being a medium for sharing knowledge, building trust, and incubating partnerships outweighed its potential to spark controversy, engender fear, and galvanize organized resistance? Even though the emphasis of this case study was on private lands conservation, we recognized that conservation priority maps focusing on public lands can also be contentious, and may also benefit from the ensuing propositions and methodology.

One of the researchers (JAG) was the founding director of CCP, and had stepped down to be on the Board of Directors at the time of these decisions. As part of this role, he was participating in a highly polarized stakeholder group tasked with working toward ‘‘common ground’’ for the Gaviota Coast. The other researcher (MFG) was on the CCP Science Advisory Board. Working with the rest of the CCP team, our synopsis of the core problem—based on the stakeholder meetings, experiences elsewhere in the region, those of TWN collaborators, and the literature—was that the resistance to collaborative conservation was rooted in fear. It was the rural private landowners' fear that they would be stripped of their private property rights and would either be forced to sell their land or be unduly regulated. Given this lens, we looked at the conservation assessment maps being produced throughout the country and realized they were miscommunicating the certainty of the scientific process that went into them, and as a consequence probably fueling this landowner fear. They showed very crisp boundaries around areas designated as ‘‘conservation priorities’’ or some other such term. They looked similar to zoning maps, which had strong legal backing. And yet, for the most part, they were supposed to communicate a very different message: Here is a map from a science-based process that considered the vast complexities of nature and society in sketching out a course of how we can move forward and effectively meet the needs of both. Further, the sketch was meant in nearly every case to be a reference, not a legally binding plan, with any conservation action being subject to landowner willingness. In other words, the entrance into conservation easements by a landowner, or a grant from the federal government to pay for natural resource management, or a sale to a land trust would be completely voluntary. How could the map be refined to better communicate these messages?

The maps might be improved if they were less crisp and more sketchy looking, as such characteristics infer that the information is still open for refinement and discussion (Krygier 2002; MacEachren 1995). There are methods for quantifying and mapping the geographic uncertainty of a spatial analysis (discussed later) such that the resulting maps display blurrier boundaries between map categories. The message of such a product would be less rigid, too, namely, that any particular site would have a relative certainty of being a conservation priority area, rather than being a definite priority area or not. This relative certainty could be more palatable to the landowner or manager of the site that would normally be marked as absolutely a priority area. Hence, we surmised that if some of the uncertainty involved in making the conservation priorities map was estimated and then displayed on the map itself, then the information released to the public or stakeholder committees might have a less negative impact than the traditional approach. We refer to this as the uncertainty map, in contrast to the map that does not display uncertainty (the standard map). The challenge became, how could the uncertainty be quantified and mapped? Can we surmise that doing this would help matters?

Quantifying Uncertainty

Geographic uncertainty measures the degree to which a representation such as a database leaves us uncertain as to the true nature of the world being represented. It can be formally defined using the tuple (x,G) (Zhang and Goodchild 2002). x refers to a location in time and space, and G stands for one or more properties, attributes, or things. Thus, if (x',G') is the statement (e.g., a point on a map and its elevation above sea level) of the true real-world tuple (x,G), then the measures of the differences, $(x - x')$ and $(G - G')$, are the uncertainties. (This tuple-based conceptualization only applies when G' is measured on an interval or ratio scale.) In this article, we focus specifically on $G - G'$, where G is the conservation priority value of a property (which will be more formally defined later). Can we know or infer anything about this difference in general, and for each property in particular? The answer is yes on both accounts, by applying uncertainty quantification techniques, as overviewed here.

In complex models, many input data layers are used. Some of these layers have uncertain data. An uncertain data layer can be an input to one analysis, creating an uncertain output, which then becomes an input into another analysis, and so on. The uncertainty can thus propagate, and do so in unexpected ways, including amplification (Heuvelink 1999). It is possible to examine this uncertainty propagation by using a stochastic approach. A Taylor series approximation is one such approach, but a more intuitive approach is the Monte Carlo simulation (Heuvelink 1999), and the one used in this article. A Monte Carlo simulation involves choosing one or several variables or data layers that are uncertain and that are propagating through the model in an unknown manner. Then the model is run many times in succession, and each time the analysis is rerun, the selected variable(s) is/are perturbed according to some underlying assumption (Mowrer 1997). The assumption is usually a random perturbation of the variable(s) based on a probability distribution function (PDF) (Mowrer 1997). If a PDF is used, then all of the output layers (realizations) have the same probability of being true and can be combined to find telling statistics for each mapped location x', such as its frequency index of G', mean output value of G', and/or variance of G' (Heuvelink 1999). These statistical values provide useful information about how the uncertain variables or data layers propagate through the complex model and manifest in the final output, and can be mapped in various manners, discussed later. The accuracy of the Monte Carlo simulation for one variable is inversely related to the square root of the number of runs that are performed (Heuvelink 1999). Similarly, if more than one variable is examined simultaneously, then the number of runs required for the same level of accuracy increases exponentially. The approach is computationally intensive, so the limiting factor in the number of runs achievable in a given amount of time is often hardware related.

Before detailing our methodology, a summary of conservation assessment is useful in its own right and in order to explain why we were able to use a very simple PDF. The standard approach for mapping conservation priorities is to first evaluate how well the current reserves in a study area are conserving a wide suite of biodiversity elements (e.g., species, habitats), which, taken as a whole, acts as a rough surrogate for the needs of all biodiversity (Margules and Pressey 2000). Then an effort is made to identify a solution set of additional sites (areas) that, if conserved, would combine with the currently conserved areas to cost-effectively meet the priority "needs" of all the measured biodiversity features (Sarkar et al. 2006). "Complementarity" is the context-dependent, marginal gain in biodiversity provided by performing a conservation strategy in any particular area (Faith et al. 2003); it is the degree to which conservation of a piece of land would contribute to the conservation of the region's biodiversity (Sarkar et al. 2006). In its essence, the conservation priority value of a site is this complementarity divided by cost. In a subtle but important nuance, the complementarity of a site, and hence the conservation priority value, can decrease over time even if the site itself stays the same; the change occurs because other sites that contain many similar biodiversity features get added to the reserve system.

Methods

To perform the standard systematic conservation assessment without uncertainty considered, we enhanced and applied an experimental methodology by Davis et al. (2006). The map of this output was the standard map. The details are provided in an online and open-access doctoral dissertation (Gallo 2007). It took many months to perform the first part of the analysis, and then, once installed, about 12 hours of processing time to perform the "optimal" site selection algorithm. Due to external deadlines, we had about 2 months to perform the uncertainty quantification and mapping. Most Monte Carlo examples exhibited hundreds of runs per variable. Even though we had access to three computers to run simultaneously, we realized that given these constraints, we could only effectively examine the propagation of one uncertain issue/data layer. Which one of the many should we choose?

In answering this question, we revisited our main motivations for mapping uncertainty—to allay the fear of landowners. Since we had observed or heard of several instances where conservation assessment maps were taken out of context by conservation opponents and used to incite resistance to collaborative and community-based conservation efforts (e.g., Walker and Hurley 2004), we surmised that it would be ideal if the map itself could reinforce some of the messages that needed to be conveyed in the stakeholder process. One such message was that landowners were not required to conserve their land even if it is mapped as a conservation priority: that conservation actions by the landowners were voluntary and subject to their willingness.

Hence, we chose to address the uncertainty in "landowner willingness to conserve" and how this uncertainty propagates through the conservation assessment model. It is extremely time-consuming to estimate the relative willingness of every landowner on a landscape to formally conserve their land in some way, such as by selling it to a land trust, or retaining ownership but committing to conserve it through a conservation easement. As a consequence, the standard practice in systematic conservation assessment (described later) is to not bother trying to gather these data, and to assume that all landowners would be willing to conserve their land given fair market value compensation. In this study, we explicitly acknowledged that this dearth of data regarding landowner willingness adds uncertainty to the conservation priorities map. We implemented the Monte Carlo method to quantify and map this uncertainty.

Monte Carlo Analysis

To create the uncertainty map, we first assumed that some of the landowners in the region would not be willing to conserve their land even if given fair-market monetary compensation. The ideal methodology given this assumption would have been to survey some of the landowners to estimate their willingness to conserve their land and then to use these sample data to create the PDF that could then be used for the Monte Carlo simulation. But the time and budget of the study did not allow this luxury. Instead, a less robust alternate approach was used to at least illustrate the concept and to provide an uncertainty map. This less robust approach was possible because of complementarity—the conservation value of a site was a function of not only the site characteristics, but also the characteristics of all other sites in the region (and their availability). This key point can be conceptualized with an example. If none of the current reserves in a region conserves a particular suite of biodiversity features X, Y, and Z, and an unreserved site, property A, is home to all of these features, then that property has high complementarity to the current reserve system. Further, if no other unreserved properties have the same suite of features, then it does not matter that we do not know whether landowner A and all other landowners would be willing to conserve their land or not—property A is a high conservation value regardless. However, if instead there were dozens of other nonreserve properties that had a similar and almost as high quality suite of features, then property A would not be as critical to conserve, as there would be alternative properties that could do almost as well. Hence, its true relative value would be much more dependent upon the conservation willingness of landowner A and the landowners of the similar properties. In both cases willingness data are not available, and it is in the second scenario that there would be less certainty that property A is the place to spend limited time and money. The Monte Carlo analysis will differentiate between these cases even if the less robust PDF is used. Because the less robust approach was used, there was a larger uncertainty to the uncertainty analysis. The relative degree of uncertainty among sites should remain the same in this case, regardless of the PDF, but the actual degree of uncertainty would be more certain with a more robust PDF. Quantification of this "second-order uncertainty" was beyond the scope of this article.

The PDF used was that 50% of the sites from any given run had unwilling landowners, and hence those sites were unavailable for conservation. The result was the solution set of the available sites that, if conserved, would best meet biodiversity needs with the minimum cost. This was repeated 120 times, each time with a different set of randomly assigned unavailable sites. We arrived at 50% in the PDF after examining sample runs at several other percentages. It appeared to strike the best balance between the competing needs of maximizing variance between runs and minimizing the effect of the random allocation of availability.

The power of the uncertainty approach was exhibited in the next step. The 120 outputs were overlaid, and we tallied the number of times that each site was available to be chosen as a conservation priority and the number of times that it was chosen. The ones chosen with the highest frequency had the lowest uncertainty; they were high-priority sites regardless of where the unwilling landowners were. The others had higher uncertainty; their value was highly dependent upon who was willing or unwilling to conserve their land.

Communicating the Uncertainty

Given these data, there were several cartographic approaches that could have been implemented to map uncertainty (MacEachren 1992). Experimental results indicate that uncertainty issues may be best mapped using either saturation or texture (Leitner and Buttenfield 2000). A draft map was made in which the sites selected with the highest frequency were mapped in the highest saturation (bright red), and the others were shown in decreasing levels of saturation (shades of pink) proportional to their certainty value. CCP staff and board then required an alteration: All the sites that were selected in the standard run were mapped in a uniform color (bright red), and only the additional sites identified by the Monte Carlo analysis were mapped in decreasing levels of saturation. This became the uncertainty map, while the map with just the standard run sites mapped was the standard map.

The communication of spatial uncertainty is not simply about making a map, but includes other media as well (Rejeski 1993). Hence, we also drafted three PowerPoint animations, approximately 2 minutes each, designed to accompany the map on websites and during presentations. The *complementarity animation* was an introduction to the challenge and nuances of estimating an optimal solution-set of sites for conservation. It illustrated that conservation value of a site depends not only on what is on the site, but what is on all the other sites and if they are conserved or not.

An *uncertainty effects animation* illustrated how a very different optimal solution could occur even if only one landowner does not want to enter into a conservation agreement. In anticipation that acceptance of the uncertainty map might hinge not only on understanding the problem but also on understanding the quantification approach, a *Monte Carlo animation* was created.

Preliminary Assessment

The uncertainty products were preliminarily assessed during three workshops, one for each of the three advisory boards that were engaged throughout the conservation assessment process. The six CCP board and staff members were the first group. The Ecological Expert Board was comprised of 12 biologists with a variety of taxonomic specialties and professional occupations, including several environmental consultants. The Planners and Managers Board of 15 people was comprised of county planners, four land-trust directors, and resource-agency representatives (for

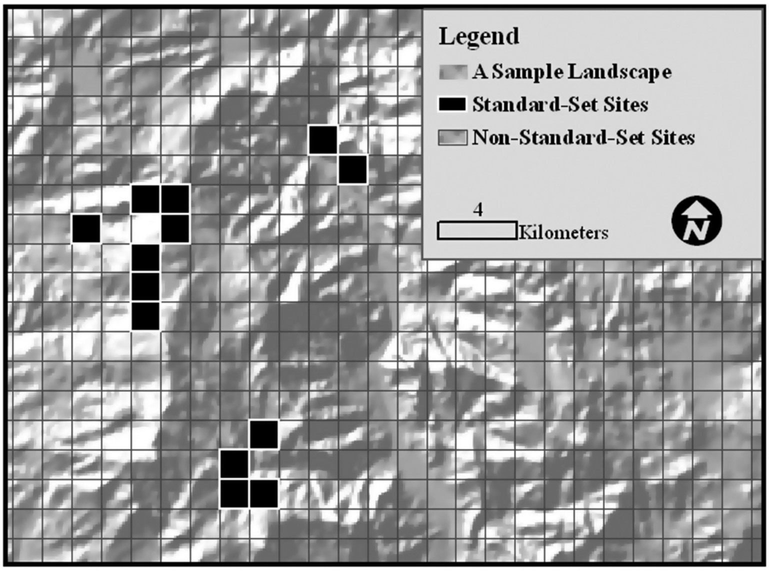

Figure 1. A simplification of the standard map presented at the workshops.

complete list of individuals, see Gallo et al. 2005). The first author was the presenter, and followed a topic guide of issues to be explored during the session, with key words and questions (Litosseliti 2003). The primary agenda was to determine which products should be released to the public, why or why not, and whether any refinement was needed first. The conservation assessment methodology was presented, followed by the complementarity animation, the standard map, the uncertainty effects and Monte Carlo animations, and then the uncertainty map. Discussions occurred between and after these presentations, and all were recorded on video. Subsequently, abridged coded transcripts were created with the left column of the spreadsheet being the time of a statement, and the all the other columns being a particular theme (Litosseliti 2003). Each important quote was then put into the appropriate box of the spreadsheet. The transcripts were then used to help summarize interpretations, to suggest potential general findings that can be explored elsewhere, to develop theory, and to develop hypotheses (Litosseliti 2003). Additional details about the methodology are provided online (Gallo 2007).

The standard map identified 180 1.5-km^2 sites in the 14,000-km^2 region as conservation priority sites. Hence, the solution space (the percentage of the region mapped as a conservation priority area of some degree) was about 2%. A simplified representation of the standard map is presented here (Figure 1). The uncertainty map showed these areas plus an additional 300 sites identified by the Monte Carlo analysis. This solution space was about 3.5%. The general interpretation of the uncertainty map by the participants was that it showed sites that were potential alternatives to the rigid set of sites shown on the standard map. The participants suggested that the sites identified by the Monte Carlo analysis be termed ‘‘alternative sites,’’ and that they be mapped on a scale of certainty rather than uncertainty (simplified representation in Figure 2).

The consensus of each group was that the uncertainty map was a substantial improvement to the standard map. The paraphrased reasons for this fell into two

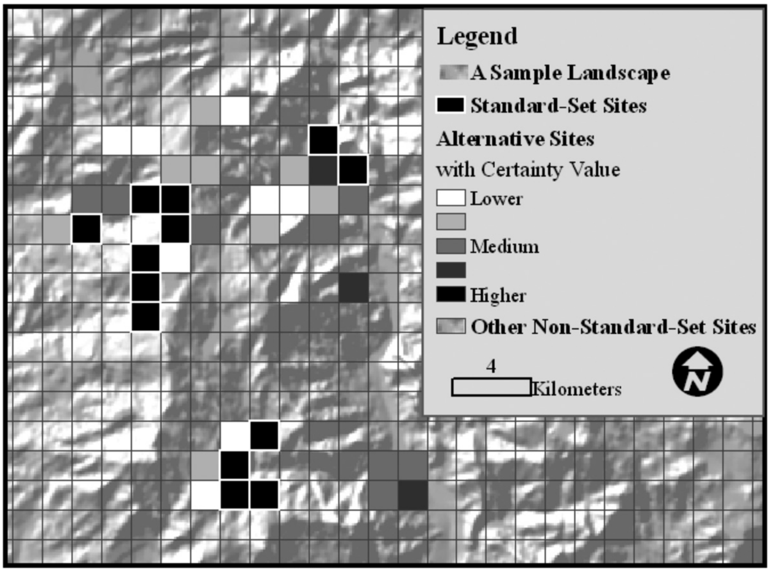

Figure 2. A simplification of the uncertainty map presented at the workshops. The actual map showed about 9,000 total sites on an 11×17 inch layout (~1:500,000), so the sites were smaller and "fuzzier." Various land use categories and geographic landmarks were also mapped, such as rivers, roads, and cities.

main categories: The first was that the uncertainty map provided the conservation organizations with alternatives and options to work with, thereby making their work more flexible. The secondary reason was the expectation that landowners would feel less threatened when they saw the map. To be clear, this does not prove how landowners would react; it only provides an indication.

The complementarity and the uncertainty effects animations were considered quite helpful. Most participants were unaware of the indirect effect of uncertainty in landowner willingness until it was explained in the animations. Meanwhile, the Monte Carlo animation was deemed complex, confusing, and unnecessary. It was suggested that a verbal description of what it did would be sufficient.

While the uncertainty map was preferred, there was not unanimous support for its public release. A few of the end-user advisors felt that the map was not "fuzzy" enough and did not have a big enough solution space. Another complaint was that the submodel used to estimate the cost of acquisition for every property was highly uncertain. This cost data layer was influential to subsequent analyses, thereby giving a high uncertainty to the final maps. This uncertainty was not quantified or mapped, thereby giving the products questionable utility. The suggestion was that there should be two final maps, one with and one without the cost submodel incorporated. Several other concerns with the model itself were voiced. Narratives of the transcripts along with 28 relevant quotes are provided online (Gallo 2007).

A near-complete reiteration of the entire modeling process was required if we were to refine the experimental product enough to make it acceptable for public release. For instance, a parameter set by the Planners Board was to identify the best solution set of sites that could feasibly be conserved in 10 years. If this was changed to 100 years then the solution space would have been an order of magnitude greater.

Unfortunately, several such changes were at the very beginning of the model preprocessing methodology, which had not been programmed, and would have required several months of step-by-step implementation. This would have been before implementing the 2-month-long Monte Carlo simulation, thereby making the project unacceptably late for funders and clients. There was an alternate solution recommended independently by several advisors that was to instead map and present some of the intermediate products of the analysis, namely, to ignore the challenge of trying for an optimal solution set and the challenge of mapping the effects of uncertain landowner willingness on this optimal set. In such dilemmas of action research, the ethical response is to choose the course of action best for the community, rather than what is best for the research agenda (Rambaldi et al. 2006). Hence, the uncertainty map was not revised in an attempt to make it acceptable for use and public release.

Discussion

In order for community-based conservation and natural resource management to reach its full promise many innovations are needed along with policy reforms and a broad realization that the separation between humans and nature is a false dichotomy (Pincetl 2006). This article provides initial development of a potential innovation. The primary contributions of this article are the two propositions for how to address some of the sociopolitical problems with conservation assessment maps, and a methodology for implementing these propositions. The *first proposition* was that when presenting sensitive and potentially contentious spatial information, quantifying and mapping some of the inherent uncertainty could decrease the volatility of the maps. The *second proposition* was that in systematic conservation assessment, if the effect of uncertainty in the "landowner willingness to conserve" is mapped, then landowner fear could be reduced. A Monte Carlo simulation was used to illustrate how this second uncertainty could be quantified and mapped. Preliminary assessment indicated that the map and animations that communicated uncertainty were an improvement over the conventional, standard map. If the analysis could have been revised in several ways, such as by increasing the implementation timeframe from 10 to 100 years, the solution space would have increased from 3.5% to around 35%, we expect that the uncertainty products would have been deemed suitable for public release. Clearly, further research is needed to evaluate the propositions and methodology.

Considerations for Future Research and Practice

We provide some thoughts, advice, and additional research directions to researchers and practitioners considering this or a similar uncertainty mapping approach. Our biggest lesson learned was that it is important to develop and use a conservation assessment modeling system that allows researchers to easily remove and add criteria, change the relative weight among criteria, expand or diminish the solution space, and even change the resolution of the outputs. Further, canned software should be used (e.g., Brown and Heuvelink 2007), or a program written, such that the Monte Carlo Analysis is facilitated, and ideally can start and run to completion automatically. Ideally both the conservation assessment and Monte Carlo programs are integrated. With these changes and the exponential improvement in computer processing speeds in the last decade, it is feasible for an entire set of core data and parameter changes to be implemented in hours and days rather than months. In cases that have not yet reached this level of automation, it may save time to first scope out the cartographic issues before starting the uncertainty analyses; discussing sample maps with local advisors could indicate the map extent, resolution, "fuzziness," solution space, and combinations thereof, that would be sufficiently nonthreatening while still providing as much detailed information as possible (Gallo 2005).

The Monte Carlo simulation performed in this study was a sketch-up of a more robust simulation. The use of the simplified PDF here yields a product that is quite similar to the measure of irreplaceability (Sarkar et al. 2006), which is a useful conservation assessment metric that can usually be obtained via less round-about procedure. Future applications should gather one or several data sets relating to landowner willingness (e.g., Knight et al. 2010). These can be based on interview data and/or expert opinion and/or modeling. Such data could be combined to give a "landowner willingness" estimate from 0 to 1 for every site with data. These data do not need to be gathered for every landowner in a region, rather, the data sample could be used to build the PDF that could in turn be used to populate all of the other unknown sites for each Monte Carlo scenario (Mowrer 1997; Aerts et al. 2003). A uniform PDF can be used for the entire study area, or several PDFs could be made that each applies to different subregions or to other descriptive covariants. The implementation of the Monte Carlo analysis would modify slightly with the use of such data, as the perturbation would be on this data layer rather than simply the binary designation of a site as available or unavailable.

It may be that mapping the uncertainly in the variety of human and social factors that relate to conservation opportunity, not just willingness to conserve, would be more effective. An example is the champion factor—the leadership role of the landowner among their neighbors. Knight et al. (2010) provide a justification, framework, and associated questionnaire for quickly gathering data about these various factors during quick, one-time discussions with landowners. It seems that the expected benefits listed earlier of mapping landowner willingness uncertainty effects would also apply in such an analysis, and quite possibly be magnified.

To be clear, there are many different ways to implement proposition one, not just Taylor approximation and Monte Carlo approach. For instance, one of the uncertainties in conservation assessment is in estimating the mathematically optimal solution set that maximizes benefit and minimizes cost. For thousands or millions of sites in a region, this is incredibly complex and usually estimated with a heuristic. MARXAN (Ball and Possingham 2000) uses a sophisticated heuristic, and one of the outputs is not only the best estimated solution set, but a frequency distribution of all the other solution sets that were not quite as optimal. Mapping this frequency distribution would be a way to implement proposition one.

There are many problems with presenting uncertainty that should be considered when deciding if it will be a wise use of time and energy, and if so, what type of uncertainty to map. For instance, communicating uncertainty can slow down or muddle a process, and some people who favor the status quo conveniently call for inaction until the uncertainty is "solved" (Stocking and Holstein 1993; Friedman et al. 1999; Kinzig 2003). Similarly, people who disagree with the findings can try to use the uncertainty as a means of discrediting the science. It may be that proposition two may help address these problems. The fundamental source of the uncertainty in this case is the freedom of landowners to sell, develop, or conserve their land. Thus, arguments to "solve" the uncertainty might not arise, as this would entail that landowners commit to a set future, which is the opposite of what is wanted. This idea is untested.

There are also other benefits to consider when scoping the application and/or research of uncertainty mapping. For instance, many people view scientific models with a level of mistrust, knowing that the model cannot replicate the world's complexity or incorporate their own innate knowledge (Wynne 1992; Gregory and Miller 1998). This mistrust of models is often ignored or unknown to scientists (Wynne 1992). Acknowledging and mapping the uncertainties of a model improves its honesty (Rejeski 1993), which can build trust. Further, end users will understand which results are more reliable, and hence can make a more informed decision (Flather et al. 1997; Mowrer 1997; Regan et al. 2005; Rejeski 1993). In some cases, making decisions without the uncertainty information is misleading and leads to biodiversity loss (e.g., Regan et al. 2005).

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