A GIS-Based Framework for Evaluating Investments in Fire Management: Spatial Allocation of Recreation Value[1]

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Abstract

The U.S. Forest Service is responsible for developing tools to facilitate effective and efficient fire management on wildlands and urban-wildland interfaces. Existing GIS-based fire modeling software only permits estimation of the costs of fire prevention and mitigation efforts as well as the effects of those efforts on fire behavior. This research demonstrates how the economic benefits of fire management strategies also can be incorporated into a GIS-based planning structure. In this paper, spatially delineated wilderness recreation values are derived by allocating per-trip values for hiking from a travel cost analysis to the landscape using the viewshed tool in ArcGIS. Future work will incorporate water supply and real estate values, and develop a cost-benefit analysis framework. This research expands the economic capabilities of the Stewardship and Fireshed Assessment process by enabling decision makers to weigh the benefits of management activities against the costs.

Keywords: Fire management benefits, GIS, nonmarket valuation, recreation, San Jacinto Wilderness, viewshed analysis.

Introduction

The USDA Stewardship and Fireshed Assessment process utilizes fire modeling software that generates estimates of the costs of fire prevention and mitigation efforts and the effects of those efforts on fire behavior. However, this tool currently cannot estimate the benefits of those efforts making it difficult to evaluate investments in and trade-offs associated with fire management strategies. In cases where fire poses an imminent threat to life, crucial public infrastructure, or valuable private property,

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it is unlikely that decision-makers would undertake a formal cost-benefit analysis before taking action. But consider, for example, a fire in a remote location used exclusively for back-country recreation. Should resources be allocated to this fire at all? If so, which resources and where should they be located? Or consider the option to undertake fire prevention activities in a mixed use landscape. Where should brush be cleared? Where trees should be thinned? Which areas should be protected given limited fire prevention resources? Without the capability to assess the benefits of fire prevention and suppression activities in a spatial context, efficient resource utilization is difficult to achieve.

Assessing the benefits of fire management strategies in general requires information about market and non-market values of landscape features and how those values are impacted by fire. Resource economists traditionally have utilized a typology that classifies values as either use or non-use values (Freeman 2003). Use values include extractive use of a resource such as timber harvesting or water supply, or in-situ use such as recreation or tourism; while non-use values include the desire to preserve a resource for the intrinsic value of its existence or for the option to use the resource in the future. Use values also may derive from service flows that exhibit the properties of either public or private goods: public use values would include ecosystem service flows such as nutrient cycling or carbon sequestration from which many people benefit freely and equally; private use values would include recreation activities or home ownership that provide benefits exclusively for the individual engaging in the activity, even though the value received may depend on public goods such as the quality of the natural environment.

The focus of this research is on private use values in a forested landscape, specifically: water supply, land development (real estate), and recreation. The value of public infrastructure such as reservoirs and power lines typically is assessed at its replacement value: how much would it cost to find an alternative water or electricity supply for some period of time? How much would it cost to replace damaged infrastructure? The value of private property can be based on market prices or assessed values. Both types of values are relatively easily represented in a spatial context because they are derived directly from landscape features with specific locations themselves (e.g., a watershed or a building).

Recreation value can be determined from a statistical analysis of users, their frequency of use, and the time and money spent to reach the recreation site; this is commonly called a travel cost analysis. Assessing recreation value typically is more difficult than assessing infrastructure or property values because it is not possible to directly observe the price of recreation; instead the price must be estimated through a travel cost or similar analysis. Furthermore, traditional models of recreation demand have focused on a “trip” as the unit of analysis (Freeman 2003) without addressing the question of how the value of a trip is derived from the landscape in which the recreation activity takes place. That is to say, a recreation trip is valuable presumably because the user experiences an appealing landscape; but how can we use available data to determine which areas are more valuable than others? Spatially allocating the recreation value of a wilderness to the landscape is an essential part of any GIS-based benefits assessment, but the literature has yet to address this topic; this paper proposes a methodology for doing so.

This study ultimately will provide an analysis of water supply, real estate, and recreation values and demonstrate how they can be incorporated into a GIS-based planning structure and cost-benefit analysis framework. Such a framework is useful for public stewards who must allocate limited management resources across a landscape, ideally to create the greatest benefit for the public. This paper focuses on the spatial allocation of backcountry recreation value as this is one of the more novel and broadly applicable contributions of the research. In the sections that follow we present our data, methodology, and preliminary results. We conclude with a discussion of issues raised by this research and plans for future work.

Methods

This study examines backcountry recreation in the San Jacinto Wilderness in the San Bernardino National Forest in Southern California. The wilderness is located within a 2.5 hour drive of most of the greater Los Angeles, San Diego, and Palm Springs metropolitan areas and attracts roughly 60,000 backcountry visitors each year. Another 350,000 ride the Palm Springs Aerial Tramway into the Mt. San Jacinto State Park but do not enter the backcountry. The Pacific Crest Trail traverses the wilderness from north to south, and elevations range from 1,800 to 3,300 meters. The current drought has left the wilderness very dry and vulnerable to fire. In 2006 the Esperanza Fire severely burned a large area just to the northwest of the wilderness; currently campfires are not allowed even in designated campsites within the wilderness.

Backcountry access is regulated by two U.S. Forest Service Ranger Stations and one State Park office. Horses are allowed but bikes and motorized vehicles are prohibited. Day hiking is by far the most popular activity in the backcountry. All users entering the backcountry are required to obtain a permit, but the Forest Service estimates the compliance level is around 75% (Lyon 2007). Data needed to perform a standard travel cost analysis is available from permit receipts maintained by the Forest Service and State Park offices. Each permit lists the date of the trip, the number of people in the group, the entry and exit points, and the home address of the group leader. Most wilderness areas maintain similar records which helps explain the popularity and usefulness of travel cost models for estimating recreation value.

Using conventional methods as in Weber and Berrens (2003), we combine the permit data for 2005 with the most recent census data (U.S. Department of Commerce 2000) to construct a dataset containing the number of backcountry trips taken from each ZIP code within a 2.5 hour drive of the wilderness and certain population characteristics of each ZIP code that are likely to help explain variation in recreation demand across ZIP codes (e.g., race, gender, age distribution, education level, income). The price of a trip from each ZIP code is estimated to be the sum of driving costs (a function of distance) and time costs (evaluated at one-third of the wage rate). We also augment our dataset with voting records on environmental initiatives from the 2000 election (California Secretary of State 2000) to help control for variation in environmental attitudes across ZIP codes. This approach is commonly known as a Zonal Travel Cost model (Haab and McConnell 2002).

Space limitations prevent a thorough discussion of the model estimation, but our standard Poisson regression indicates that the average value for Southern California residents of a backcountry day trip in the San Jacinto Wilderness is around $76. Approximately $48 of this value is consumed by trip costs leaving an average individual consumer surplus of $28 per trip. With an estimated 60,000 backcountry users each year, the annual value of backcountry wilderness access is around $4.5 million. This is likely an underestimate of the actual value because day users living further than 2.5 hours from the wilderness who tend to have higher travel costs and thus higher values were not included in our regression sample.

A spatial representation of this value requires it to be allocated to the wilderness landscape according to some rational methodology. Ideally one would collect information, perhaps stated preference data, eliciting the welfare effects of severe fires or trail closures in different areas of the wilderness to determine the values of landscape features. Such data is costly and time consuming to collect; often analysts must work only with the type of data we have for this study (Moeltner 2003). From the permit data we can infer not only the value of a backcountry trip, but also how many people enter the wilderness at each trailhead and, with some information and assumptions about destinations and hiking speeds, we can infer the likelihoods of various paths taken through the wilderness. Thus we can allocate the wilderness value to various trail segments, but the problem of allocating it to the surrounding landscape still remains.

To proceed, we make the reasonable assumption that landscape values for backcountry hikers are closely related to scenic quality. Obviously certain unique landscape features may have particularly high values, but in a relatively homogenous wilderness such as the San Jacinto, we posit the value of any specific location in the landscape may be well approximated by its visibility to backcountry users. For example, land traversed by a popular trail is viewed up-close by many users; therefore it would have higher value than land which is viewed only at a distance and by a few users. Land which cannot be seen from any trails would have no recreational value.

A normalized weighting function can be calculated for each point in the landscape that indicates its relative scenic value for wilderness users. Consider a wilderness consisting of *J* points and with *K* trail segments, each traversed by n_k users during a recreation season. Each segment can be represented by a path in three-dimensional space from its starting point t_k^s to its end point t_k^e. At any point *t* on trail segment *k*, let $S_k(t)$ be the set of visible landscape points, and let $I_j(t)=1$ if $j \in S_k(t)$ and 0 otherwise. Let $x_j(t)$ be the distance between points *j* and *t*, and let $w(x)$ be a weighting function such that $w>0$ and $dw/dx<0$. For each trail segment *k*, we can then define the "absolute visual weight" of point *j* as: $v_{jk}=\int_{t_k^s}^{t_k^e} I_j(t)\,w\big(x_j(t)\big)\,dt$, and the "normalized visual weight" of point *j* as: $V_{jk}=v_{jk}\big/\sum_J v_{jk}$, such that $\sum_J V_{jk}=1$. If the value of a trip on trail segment *k* is p_k, then $\sum_K n_k p_k V_{jk}$ gives an estimate of the scenic value of point *j*.

To implement this valuation framework, we utilize standard tools available in ArcGIS (ESRI 2006). Our study area is divided into 30-by-30 meter grid cells within a Digital Elevation Model (DEM). Trails are divided into 42 unique trail segments, each connecting two trail junctions or a junction and a dead end. Each trail segment is divided into observation points that are located at intervals of 60 m along the trail. The visual experience of an individual hiker at each point is then simulated with the Viewshed Analysis tool. This tool identifies and calculates the number of times each parcel in the DEM is visible from the set of observation points by scanning the area surrounding each point. We set the scan angles to obtain a 180 degree vertical and a 360 degree horizontal scan. The offset value is set at 1.7 m, which corresponds to the average height of adult Americans. We limit the maximum search radius to 30 km as this is the maximum distance between any point along any of our trail segments and the boundary of our study area. As in previous viewshed studies (e.g., Llobera 2003), our analysis does not account for effects of varying atmospheric conditions or the presence of vegetation that could render the landscape less visible than implied by the viewshed results.

To define the weighting function, we rely on previous empirical work by Higuchi (1983) that establishes a method for measuring the quality of visual landscape characteristics based on their appearance from a given observation point. Using trees as the standard object of analysis, Higuchi creates distance indices that help identify at what point qualitative differences are discernible. He divides the landscape into the foreground, middle-ground, and background. Trees are discernible as separate units at short-distance, but are only visible as outlines and more recognizable as a forest unit at middle-distance. At long-distance, one can only observe major topographical features, such as mountains and valleys and colors differ only by shade contrasts.

In our study we modify the indices suggested by Higuchi and increase the short and middle distances to account for bigger trees in our study area (i.e., Yellow and Ponderosa Pines). In addition, we divide the far-distance band into two separate bands where the "far background" begins at 15 km, instead of having one far-distance band that extends past 5 km as described by Higuchi. This gives us four distance bands around each observation point: 0 – 0.2 km, 0.2 – 5 km, 5 – 15 km, and 15 – 30 km. To reduce our computational burden, each point in each band is assigned the average radius of the band from the observation point. We then calculate the weight of each parcel as: $w\left(x_j\right) = e^{-\bar{x}_j/10}$, where $\bar{x}_j$ is the average band radius in km. This gives us band weights of 0.99, 0.72, 0.34, and 0.10, from nearest to farthest.

Finally we must specify the number of people hiking each trail segment and the value of a trip on each segment. As is often the case with permit data, we do not have complete information about the specific routes taken through the wilderness by each hiker; but we do know entry and exit points for each trip and we know all trips are day trips. To proceed, we assume an average hiking speed of 3.3 km/h and a maximum round-trip hiking time of 8 hours, and we assume that when a trail junction is encountered there is an equal probability of taking each trail segment from that junction. This produces a relative trip frequency for each trail segment which, when combined with the number of entries at each trailhead, gives an estimate of the number of hikers on each segment, n_k. To calculate the value of a trip on each segment, p_k, we allocate the value of a trip taken at each entry point to the associated trail segments based on the relative magnitude of $\sum_J v_{jk}$ for each segment. This is because; all else equal, longer trail segments and segments with more expansive viewsheds tend to have larger $\sum_J v_{jk}$, and thus by our reasoning should contribute relatively more to the value of a trip.

Results

We obtain values ranging from \$3 to \$819 per 900 m^2 parcel, corresponding to \$36 to \$9104 per hectare, with a mean of about \$340/ha. Seventy-five percent of these values range from approximately \$33 to \$644/ha. As shown in figure 1, the highest values are concentrated in areas with the highest elevations, in particular around the high peaks in the northeast. These include San Jacinto and Jean Peaks with elevations of 3,302 m and 3,252 m. Because the high mountain peaks have the best visibility from most points along the trails, these parcels receive higher visibility weights and thus contribute more to the value of a trip. However, these values can only partially be explained by the visibility and elevation of these parcels as the final parcel value also depends on viewing distance and trail use frequency. In contrast, parcels located in relatively remote areas and on steep slopes descending away from trails generally have lower and sometimes zero values because of their limited visibility.

Discussion

Given the concentration of high values in a relatively small area in figure 1, and the broad expanse of low values across most of the landscape, it appears that the benefit of preserving recreation opportunities is significant only in a limited area of this wilderness. However, figure 1 should be interpreted carefully. If a fire in a low value area is expected to spread to a high value area, then resource allocation decisions clearly should incorporate this risk. Similarly, if a small fire is expected to spread to a large area of even low value landscape, this risk also should be incorporated. In both cases, prevention and suppression activities could be justified in any area regardless of its value to preserve nearby recreation opportunities. Therefore a spatial dynamic cost-benefit analysis framework is needed to properly evaluate management decisions. Figure 1 is most appropriately interpreted as an input to this framework.

Furthermore, the value surface in figure 1 is determined in part by our assumptions about how values are derived from the landscape. Therefore one of our immediate next steps is to collect additional data on actual routes traversed and times/distances traveled, as well as on the effects of hypothetical fire damage and trail closures on recreation behavior, in order to verify and calibrate our methodology. We also plan to augment this data layer with information about water supply and real estate values to provide a more complete picture of the spatial allocation of benefits derived from the landscape. Finally, a formal GIS-based cost-benefit framework will be developed that accounts for the impact of fire on benefits flows and thus can be incorporated directly into the Stewardship and Fireshed Assessment process.

Summary

This research demonstrates how the economic benefits of fire management strategies also can be incorporated into a GIS-based planning structure. Spatially delineated wilderness recreation values are derived by allocating per-trip values for hiking from a travel cost analysis to the landscape using the viewshed tool in ArcGIS. Values are found to range from $36 to $9104/ha, with a mean of $340/ha and with most values between $33 and $644/ha. Future work will incorporate water supply and real estate values and develop a cost-benefit analysis framework. This research expands the capabilities of the Stewardship and Fireshed Assessment process by enabling decision makers to weigh the benefits of management activities against the costs.

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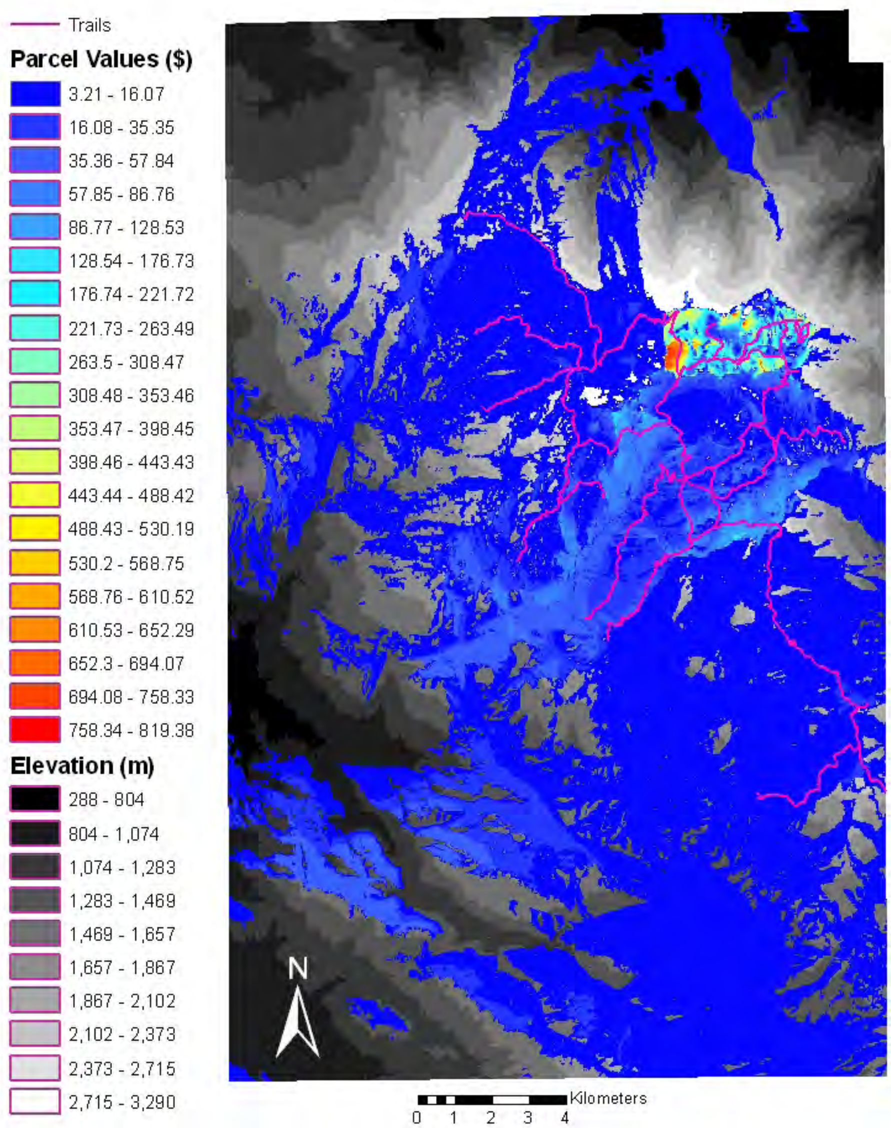

Figure 1 – Derived recreation value surface for the San Jacinto Wilderness. Values correspond to 900 m^2 parcels and are based on backcountry day trips only.

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