THE COST EFFECTIVENESS OF MULTI-OBJECTIVE FOREST MANAGEMENT IN THE WILDLAND URBAN INTERFACE

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Abstract

Many cities and towns in the upland areas of the Southwest are built in the middle of dense forests and woodlands. These forests are prone to catastrophic wildfires, which are major threats to the cities and towns as well as the forest ecosystems themselves. One of these cities is Flagstaff, Arizona. The city is located at 7,000 ft above sea level and at the foot of a 12,500 ft mountain surrounded by the largest continuous ponderosa pine forest in the United States. Because of its location, the city enjoys a four-season climate, with one of the most beautiful landscapes and serene environments. Yet, it faces major threats from catastrophic wildfire and flash flood hazards. The latter may occur in the form of rapid flows down the side of the mountain following heavy rainfall or fast-melting snow events. This paper evaluates the cost effectiveness of minimizing both wildfire and flood hazards while increasing the area's amenity and commodity resources and maintaining its ecosystem integrity in a multi-objective framework. Amenity resources include aesthetics, ecosystem diversity, wilderness, environmental quality, and the area's historical and cultural values, whereas commodity resources are timber, water, forage, and other resources that have economic value. These different management objectives, and the various groups with stakes in the condition of the wildland-urban interface, are considered in determining the most cost-effective forest resources management scheme.

Introduction

Continuous growth and encroachment of cities and other urban communities into their surrounding wildland ecosystems is creating a new environment known as the wildland-urban interface (WUI). The wildland-urban overlap usually develops into a unique ecosystem with its own ecological, socio-economic, and safety issues. The uniqueness of these issues is based on climatic and biophysical characteristics as well as the affected communities' societal norms and economics. A significant number of the 65,000 residents of Flagstaff live in the WUI, which is characterized by a four-season climate consisting of warm summers, cold winters, and moderate periods between. Precipitation is almost equally divided between summer and winter. The vegetation consists mostly of ponderosa pine forests, which have become dense from wildfire suppression over the last century (Covington et al. 1997). Residential home developments and recreational facilities are encroaching heavily on some parts of this forest.

The interface of the ponderosa pine forest ecosystem with the expanding urban development, frequently recurring drought periods, and recent near-miss wildfires in the WUI have become cause for major concern in the community. This concern has led to a partnership of various interest groups whose aim is to develop sound ecosystem management in the WUI, to protect the community and the forest from catastrophic wildfires, and to promote diverse and healthy ecosystem conditions (Hill 1998; U.S. Forest Service and Grand Canyon Forests Foundation 1998). However, a number of other objectives also influence the management of the WUI, including developing and maintaining recreation opportunities, increasing or protecting aesthetic quality, preserving historical and cultural resources, optimizing operational and maintenance costs, and reducing the chances of flooding. This paper addresses these issues in a framework of cost-effectiveness analysis.

Problem Statement

The wildland ecosystems in northern Arizona have been exploited for their market-oriented commodities over the past century, mainly livestock grazing and timber harvesting, primarily old growth. These kinds of uses in combination with

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the exclusion of the natural fire regime have led to serious degradation of these ecosystems (Covington et al. 1997). Frequent low-intensity wildfires had been natural in the ponderosa pine forests and other ecosystems in northern Arizona. Overstory and understory vegetation, as well as the other components of the ecosystem, have adapted to this regime. Low precipitation rates cause dead woody debris to decompose very slowly. Under natural conditions, there had never been a large accumulation of fuel in this forest system. Further, the natural fire regime kept the regeneration of new trees in balance with the dying of old trees. However, government policies on fire suppression disrupted this normal process and brought tree density to dangerously high levels. The situation created the right circumstances, in the form of fuel accumulation on the forest floor and ladder fuels, for catastrophic wildfires to occur easily and more frequently than they would under normal conditions.

According to Hill (1998), the USDA Forest Service spends billions of dollars each year to suppress wildfires. Moreover, the amount spent on fire suppression each year has steadily increased with the increase in the size of forests to burn (Hill 1998). Hill's work was published before the severe fire season of 2000, which had been the worst, in terms of loss and costs, in more than 50 years (Associated Press 2000). Hill further argued that it would be less expensive to treat every acre of the 70 million acres of pine forests in the interior West with a combination of mechanical removal of vegetation and accumulated fuels and prescribed fire than to continue to pay for the increasing cost of suppressing wildfires. Preventive treatment of the 39 million high-risk acres at an average cost of $320 per acre would still be substantially less expensive than to continue suppressing wildfire in the West. His calculation does not take into consideration any non-market value lost in the fires or gained by restoration treatments. Under these circumstances, the monetary figures that Hill presented to Congress in his GAO report should be considered modest. Nonetheless, the estimated average cost per acre for prescribed burning in the Southwest is only $40.22 in 1994 dollars (Cleaves et al. 2000).

Fuel reduction efforts, as described by Hill, have been conducted in the Flagstaff WUI on a very small scale. The efforts have remained relatively small in part due to the legal intervention by environmental groups concerned with renewed exploitation of natural resources under the umbrella of forest health (Center for Biological Diversity 1999). However, restoring and sustaining ecosystem health have enhanced various nonmarket values, such as wildland ecosystems, especially in the WUI (Kim 1999). Prescribed burning, in particular, was found to enhance the recreational experience (Shortess 1986).

Cost-Benefit Analysis Versus Cost-Effectiveness Analysis

Cost-benefit analysis has traditionally been used to quantify and rank different alternative projects, management activities, or any social or economic benefits on the basis of a set of criteria to help decision makers choose the most preferred alternative course of action (Weaver et al. 1982). However, economic appraisal of environmental policies and projects using this method is problematic, because some benefits cannot necessarily be measured in monetary terms (Macmillan et al. 1998). It is difficult to put market values on nonmarket goods and services. For example, it may be possible to figure out costs of maintaining and enhancing aesthetic quality and the preservation of historical resources (in terms of equipment, fuel, labor, and other costs), but it would be difficult to determine the benefits of these costs, if we don't know the real value of the resources we are attempting to protect and preserve. There are many indirect costs and intangible benefits involved, which are not estimated by normal market values, ranging from soil compaction to loss of biodiversity (Pinjuv et al. 2000). A more useful approach to evaluate such problems is using cost-effectiveness analysis.

Cost effectiveness is defined as a technique for choosing the most preferred course of action among given alternatives in terms of its cost and effectiveness to attain specified objectives (Livingstone and Gunn 1974). The evaluation process in this technique includes articulating project management objectives, listing all alternative actions, and specifying criteria to measure the effectiveness of the alternative actions to achieve the desired objectives. The advantage of this method is that it does not rely on monetary valuation, but rather selects projects on the basis of various criteria including nonmarket cost effectiveness in achieving the predetermined objectives (Macmillan et al. 1998). In land resources management practices, costs are usually considered together with environmental impacts and the use of available technology (Bureau of Land Management 1991). Costs are measured in the same manner as in the cost-benefit analysis method, in terms of use of equipment, manpower, and other resources, but benefits are assessed in terms of their effectiveness, where effectiveness is a comparative measure of the performance levels of different alternatives to achieve a given set of objectives (Pinjuv et al. 2000). When using alternatives that incur similar costs to achieve ecological objectives, cost effectiveness can be applied to select the alternative with the least negative environmental, social, cultural, and other impacts as the most effective solution. Yet another advantage of this analysis lies in its systematic and transparent use of judgment (Quade 1967). It allows decision makers to follow any analytical assumptions whether they agree or disagree and draw their own conclusions. The limitations of the cost-effectiveness analysis lie in selecting the measure of effectiveness. Because some of the attributes may not be directly measurable, the method is vulnerable to imperfect information and judgment (Livingstone and Gunn 1974).

Cost-Effectiveness in the WUI

Cost of Treatments

The application of cost-effectiveness analysis to land resources management (dollars per acre) is normally achieved by consolidating several individual projects into one (BLM 1991). For example, a recent study by Pinjuv et al. (2000) that evaluated the ponderosa pine ecosystem restoration in the Flagstaff WUI found cost-effectiveness analysis to be a "useful tool for optimum harvest recommendations." Further, it was calculated that depending on stand density, the treatment cost of merchantable and pre-commercial thinning ranged from $125 to $460 per acre. This cost estimate took into consideration the hand cutting of trees with a diameter at breast height of 5 inches and smaller. The hand cutting method has fewer negative environmental effects, such as soil compaction and damage to remaining trees, than machine harvesting, making it a more cost-effective method. The cost-effectiveness value for different harvesting methods in the Flagstaff WUI is evaluated by dividing the harvesting cost by the percentage of undamaged trees left in the ground. A higher cost-effectiveness value represents a more efficient method (Table 1), provided that the harvest cost also accounts for environmental and other non-market values, or the percent undamaged includes environmental ecosystem health, cultural, amenity, and commodity values.

Table 1. Example of cost-effectiveness of different treatment methods in the Flagstaff WUI. Values exclude old growth harvesting (taken from Pinjuv et al. 2000).

Harvesting Method	Harvest Cost ($/Ha)	Cost (% undamaged) ($/%)	Cost Effectiveness
Whole tree	1098	1098/65	16.9
Hand harvest	1497	1497/95	15.8
Cut-to-length	1297	1297/80	16.2

The cost of prescribed fires, however, is less than that of harvesting. Based on a survey of 10 years of prescribed burning on Forest Service lands, Cleaves et al. (2000) found that the per acre costs of treatment in the Southwest vary from one type to another. For example the cost for slash reduction is $77.05 per acre. Prescribed burning costs $38.85 per acre for management ignited, $7.67 per acre for natural, $37.30 per acre for brush, range, and grasslands, and $40.22 per acre for all types together. But the survey also mentioned that the risk to structures and property damage was higher in the Southwest than in other parts of the country.

Effectiveness for Recreation

The steadily increasing number and high diversity of recreational users of forest lands have led to some social and managerial conflicts, both between recreationists and other forest uses such as mining, grazing, and timber harvesting interests, and among different recreationists themselves (e.g., motorists vs. non-motorists). According to the Multiple-Use Sustained Yield (MUSY) Act of 1960 and the National Forest Management Act of 1986, national forest lands are expected to be managed for multiple uses, including livestock grazing, maintaining wildlife habitat, water yield, timber production, recreation, and even scientific and educational purposes (Richards and Daniel 1991). However, with a rapidly growing population in Arizona as well as southern Nevada and southern California, the recreational activities in the forested mountains of Arizona have become more important than some of the other more traditional forest uses (Bureau of Business and Economic Research 1993). Timber harvesting, once an important source of income in Flagstaff, now employs less than 30 people in the county (High Desert Industries, personal communication 1999). Livestock grazing activities have been reduced dramatically in recent years (M. Lee, Northern Arizona University, personal communication

2000) and mining operations in the area are also coming to an end due to public pressure.

Today, mostly due to northern Arizona's unique physiographic features, a four-season climate, and scenic forest ecosystem, tourism is the major source of employment in Flagstaff (Arizona Department of Commerce 1998). Hence, multiobjective management of the forest system in the WUI should consider enhancement of recreational opportunities as one of the important management objectives. The USDA Forest Service has developed a recreational opportunity spectrum to systematically assess the recreational capability and potential of a management unit through inventory of recreation opportunity settings and a managerial framework (Richards and Daniel 1991).

Regardless of the recreational setting, the entire forest spectrum would benefit from restoration and fire prevention treatments. A catastrophic forest fire would render the forest aesthetically very unattractive for recreational activities. However, restoring the forest would help to prevent the occurrence of a major forest fire and would enhance recreation and other commodity and amenity resources in the WUI. Under existing conditions, the rising number of individuals recreating in wildland environments increases the chances for a catastrophic wildfire to occur, for example the "Leroux" fire in June of 2001 just outside of Flagstaff.

Effectiveness for Aesthetic Value

Seven million visitors pass through Sedona and Oak Creek Canyon, located just south of Flagstaff, each year (Stafford 1993) and many of these visitors come to enjoy the area's scenic beauty. This was demonstrated by Daniel and Boster (1976) who developed a method to estimate people's perceptions of scenic beauty. They called it the scenic beauty estimate (SBE). The SBE for a ponderosa pine forest is based on aesthetic values of different levels of timber stands expressed in square feet of basal area per acre. Applications of the SBE method in northern and central Arizona found that the general public prefers a forest density of 80–140 sq ft per acre of basal area (Tecle et al. 1998; Figure 1). The current level of average stand density in the forest around Flagstaff is about 200 sq ft per acre basal area (Tecle et. al 1998). However, restoration and fire prevention treatments can reduce the density of the forest to approximately 85–120 sq ft per acre of basal area depending on individual treatments. To be most effective, these treatments should include mechanical removal and prescribed burning (Hill 1998). Taylor and Daniel (1984) found that in addition toreducing fuels, light burning may also improve the scenic beauty of forest landscapes over time, whereas severe burning has a negative impact on scenic beauty.

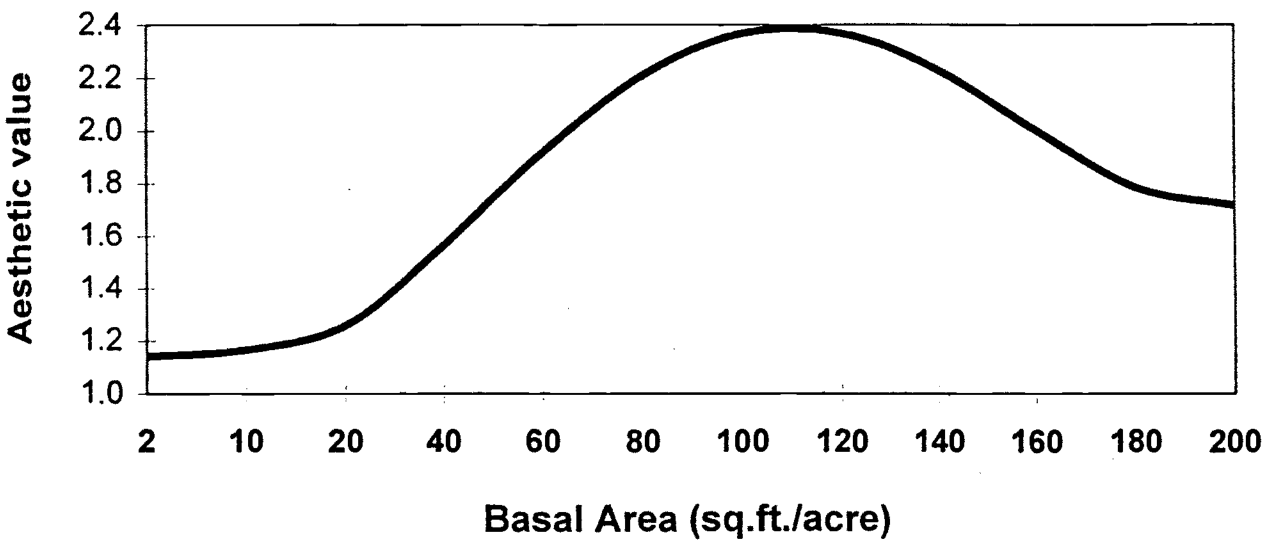

Figure 1. Forest aesthetic value response to changes in residential tree basal area (Tecle et al. 1988).

Effectiveness for Historical Resources

Despite the fact that Flagstaff is only 120 years old, it has many historical resources. The dry climate preserves artifacts and ecofacts quite well (Price and Feinman 1997). Ecofacts are any remains of plants, animals, sediments, or other unmodified material that results from human activity. Flagstaff and its historic sites would be at risk if a catastrophic wildfire were to erupt southwest of the town. Simulation results using fire area simulator-model development and evaluation (FARSITE; Finney 1998) showed that a fire starting in the forest southwest of town would spread rapidly into the city with the help of prevailing winds.

There are also many Native American historical and cultural resources in the greater Flagstaff area (USDI National Park Service 1995). The region was home to the Anasazi, Hohokam, and Sinagua Indians from approximately 850 to 1400 A.D. (Price and Feinman 1997). These tribes have left their traces, which are important to preserve. In this case, fire may not be the major threat to the preservation of these historic and cultural sites, but people are (Fink 1998; L. Farnsworth, USDA Forest Service, personal communication 2000). Curious recreationists, hobby archeologists, and pottery collectors have done the most damage to Indian cultural sites (USDI National Park Service 1999). In this instance, the most efficient management decision is to keep such people away from sensitive sites. This has been done successfully on the San Francisco Peaks and several other areas in and around Flagstaff (M. Lee, personal communication 2000).

Effectiveness for Optimizing Operational and Maintenance Costs

One source of problems with preserving Indian cultural sites is roads. There have been several instances when road construction teams have mistakenly excavated Indian burial sites (L. Farnsworth, USDA Forest Service, personal communication 2000). Thus, new roads being constructed or existing roads being expanded on U.S. Forest Service lands now require archaeological evaluations to determine that projects do not have significant effects on cultural sites (L. Farnsworth, personal communication 2000). Similar regulations apply to timber harvesting sites and other developments in accordance with the National Environmental Policy Act of 1969 (Vogt et al. 1997). Another way of optimizing operational resources is to reduce the number of roads in the forest around Flagstaff. The overall dry weather followed by intensive thunderstorms causes roads to degrade very quickly, and they require a great deal of maintenance.

Another important aspect of optimizing operational and maintenance costs is to ensure that forest restoration or fire prevention treatments in the WUI are designed not only to protect the residential homes within the interface as well as the city proper from a catastrophic wildfire, but also to protect the wildlands from fires that start in the residential areas.

Effectiveness for Flooding

A large portion of the city of Flagstaff, including about 70 percent of its Historic District, is built in the floodplain of the Rio de Flag (U.S. Army Corps of Engineers 1999). In spite of this, the risk of flooding is a factor that is often overlooked in Flagstaff's WUI activities.

The original settlement of Flagstaff was located a couple of miles east of the current downtown. But after that settlement burned down twice, in 1882 and 1884, the town was rebuilt around the new train depot, which was located on the Rio de Flag floodplain close to the stream because the latter provided easy access to water for the steam locomotives passing through the city. As the town continued to grow, development occurred generally by expanding outward from the city center, within the topographic depression around the train depot. This area was and still is subject to inundation from Rio de Flag flooding events. The continued development of the land resulted in rerouting of the natural Rio de Flag channel and further encroachment into the floodplain (U.S. Army Corps of Engineers 1999). Even though minor floods were recorded in Flagstaff's early history, the transient population in those early years was oblivious to any potential flooding and the area continued to develop and became more densely populated. There have been a total of 17 recorded floods in Flagstaff since 1888 (U.S. Army Corps of Engineers 1999). However, development in the floodplain continued until the Federal Emergency Management Agency's (FEMA) flood insurance policy was adopted in 1983. Since then, any structural development within the floodplain has been required to have its base elevated above the 100-year floodplain zone. More than 100 years of unregulated development in the floodplain has left the Rio de Flag channel very narrow and shallow throughout its course in the city. In contrast, upstream and downstream of

Flagstaff the natural channel of the Rio de Flag is very wide and deep and is surrounded by a dense forest. Though residential and commercial development varies from light to heavy along the tributaries, it is extensive along the banks of the main Rio de Flag channel passing through town.

There is a major risk in the extensive development of the Rio de Flag floodplain in Flagstaff. Therefore, in the event of a major flood occurring, there would be substantial structural damage and economic loss throughout this portion of the city. Possible structural types that would sustain damage include historic properties, public infrastructure and services, parts of Northern Arizona University, and the Burlington Northern & Santa Fe Railroad east-west main line. At present, nearly half of the 100-year floodplain along the Rio de Flag is zoned as residential and almost a quarter as commercial. In the event of a major flood, transportation problems would make a large portion of the city inaccessible for a few days.

Further, if Flagstaff does not protect itself and prepare for a major flood, it will continue to be at risk and may suffer substantial economic, social, and environmental damage in such an event. Approximately 1,500 existing structures, worth $385,000,000, could suffer about $93,000,000 worth of damage from a 100-year flood event without considering possible damages to historical structures (U.S. Army Corps of Engineers 1999).

The possibility for a peakflow flood event would increase significantly after restoration or fire prevention treatment in the WUI, as demonstrated in the Beaver Creek experimental watershed south of Flagstaff (Brown et al. 1974). However, the effects of treatments on flood peak may not last long as herbaceous and tree seedlings start to cover the treated landscape, slowing surface runoff and dissipating peak flows within a short time. Even though there may be substantial costs in property damage from a severe flood event within the city of Flagstaff, the damage caused by a catastrophic wildfire in the WUI may potentially be higher, depending on the location and size of the fire. The damage from forest fires may include losses to wildlife habitat, recreational areas, aesthetics, and property damages, especially in areas located outside the city limits.

Conclusion

The prevention of catastrophic forest fires is one of the major objectives of a multi-objective forest management plan in the wildland-urban interface around Flagstaff, because almost all other objectives are in one way or another affected by the threat of a wildfire or any restoration or fire prevention treatments. Management issues influenced by such treatments are recreation opportunities, aesthetic quality, historical and cultural resources, operational resources, and flooding. Recreation and aesthetics are two management objectives that would suffer most severely from a burned forest ecosystem, which would have adverse effects on the tourism economy in northern Arizona. However, the effects of prescribed burning to reduce catastrophic wildfires may have insignificant impacts on recreation and the area's scenic beauty. Operational resources would also be saved, because the preventive measures are by far less expensive and more effective than reactive measures, such as fighting wildfire and rehabilitating burned areas. Although a reduced stand density might make the WUI around Flagstaff and the city itself prone to flooding, the cost of a catastrophic wildfire is potentially much higher than damages from flooding. In short, restoration, fire prevention treatment, or both in the WUI seems most cost effective, especially if the treatment level is carefully selected to meet the other forest ecosystem management objectives, including minimizing the flood hazard.

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