# Cost / Effectiveness Analysis of Ponderosa Pine Ecosystem Restoration in Flagstaff Arizona's Wildland-Urban Interface

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**Abstract**—Ponderosa pine ecosystem restoration in Fort Valley (located east of Flagstaff, Arizona) has been proposed as a method of restoring ecosystem health and lowering the risk of catastrophic wildfire in Flagstaff's wildland-urban interface. Three methods of harvest are being used to carry out restoration treatments: hand harvesting, cut-to-length harvesting, and whole-tree mechanized harvesting. This paper presents a theoretical application of a cost / effectiveness analysis to aid in recommendation of an optimum method of harvest for restoration treatments. Harvest methods can be compared on the basis of ratios of harvest cost / effectiveness. Effectiveness in this approach is defined as a harvest method's ability to carry out restoration treatment with the least negative impact on residual stand damage, soil impacts, and fuel loading.

## Introduction

Cost / effectiveness analysis is an economic tool that can help decisionmakers with limited financial resources select among alternatives to meet a predetermined objective. In the Fort Valley restoration project, the objective is an ecological restoration / fuel reduction treatment intended to reduce the number of small-diameter ponderosa pine (*Pinus ponderosa*) trees in Flagstaff, Arizona's wildland / urban interface. These small diameter trees inhibit growth of larger diameter trees and can act as fuel ladders in catastrophic stand replacing fires. Three treatment alternatives have been used to reduce current tree densities: hand-harvesting, cut-to-length harvesting, and whole-tree-mechanized harvesting. Each of these harvesting alternatives uses different mixes of equipment to obtain the given objective of restoration. Each mix of equipment has different costs for treating the stand and different environmental impacts on the stand after treatment. This paper reviews economic tools to aid in environmentally related decisions, and argues that cost / effectiveness analysis is superior to benefit cost ratio and impact analysis as an environmental decisionmaking approach for harvest method selection in the restoration projects. The paper introduces the Fort Valley restoration treatments as a case study, and covers the theoretical application of cost / effectiveness analysis for harvest method selection in the Fort Valley restoration treatments.

In: Vance, Regina K.; Edminster, Carleton B.; Covington, W. Wallace; Blake, Julie A. comps. 2001. Ponderosa pine ecosystems restoration and conservation: steps toward stewardship; 2000 April 25–27; Flagstaff, AZ. Proceedings RMRS-P-22. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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## Efficiency Analysis

Cost effectiveness analysis is one of many techniques that have been used to analyze the efficiency of environmental improvement or, conversely, to analyze the efficiency in avoiding the damage done by environmental degradation. The three techniques we review in this paper (benefit / cost ratios, impact analysis, and cost / effectiveness analysis) are all types of a benefit / cost analysis. Benefit / cost analyses are used to help policy and decisionmakers assess the desirability of specific government projects for environmental improvement, and to assess the desirability of new regulations to protect certain aspects of the environment from further degradation (Tietenberg 1996). The traditional economic efficiency analysis techniques are difficult to apply to environmental resources because of the lack of economic valuation for these goods and services (Tietenberg 1996). While demand curves for normal goods such as pizza or automobiles can be estimated from readily available market data, there are no such market data for environmental resources, because they do not pass through normal market transactions.

### Benefit / Cost Ratio Analysis

Benefit / cost ratios represent an approach to quantifying the social profitability of a project. In isolated situations where the end product of a project has a quantifiable market value, a benefit / cost ratio analysis can help decisionmaking by ranking alternate activities designed to complete the project (Weaver and others 1982). Alternative activities are ranked by relative efficiency, and the analysis is a formalized attempt to obtain the maximum efficiency from a given level of funding. The benefit / cost method evaluates each alternative on a comparison of an earning rate index based on dollar benefits and per project costs. When used to select a set of alternatives under a budget constraint (in other words, capital budgeting problem), benefit / cost ratios ensure that the alternatives maximize benefits from a given level of funding. Benefit / cost ratios can also guide decisions between mutually exclusive alternatives. In this case, the benefit / cost ratios are compared and the alternative with the highest ratio is selected. To provide valid comparison of alternatives, benefit / cost ratio analysis requires that all benefits and costs of a project are quantified in monetary terms and included in the ratio.

Therefore, the major difficulty in using benefit / cost ratio analysis for comparing environmental projects is that not all benefits and costs are easily quantified in monetary terms. Even if market prices exist for inputs and outputs, these market prices do not always reflect the full social value of goods produced, or costs of resources used (Clifton and Fyffe 1977). Even greater difficulties arise when the resources in question do not have market values or are not handled by normal markets. For example, what is the dollar value of forest soil compaction caused by various harvesting alternatives?

The direct financial costs of carrying out a project are generally the most straightforward part of the analysis to quantify. These costs can be measured in terms of equipment, fuel, salaries, and so forth Indirect costs and intangible benefits estimation often pose many difficult problems. Indirect costs and intangible benefits are inputs and outputs not covered by normal markets, such as soil compaction, habitat loss, forest health, and aesthetics. In environmental projects, the majority of cost and benefits often are indirect or intangible. Aside from the sheer number of inputs and outputs that require nonmarket valuation, attempts to value each benefit can encounter problems concerning differing individual values of natural resources (Stevens and Sherwood 1982). Additional difficulties arise when the analysis is applied in the context of benefits and costs associated with avoided damages, for example, pollution control (Tietenberg 1996).

Many of the benefits associated with restoration treatments are avoided damages. For example, some of the benefits derived from forest restoration in Fort Valley are the avoided cost of fire suppression and avoided damages from wildfire. In theory, the benefits gained from various levels of restoration could be quantified in terms of damages avoided. Some of the avoided damage could be quantified since market goods such as fire suppression or property values are affected. This type of approach could be used in Fort Valley, but the valuation of such goods is a project within itself, and no such valuation has been completed. The Fort Valley treatments also affect many nonmarket benefits such as wildlife habitat and recreational opportunity that are not easily valued for use in benefit / cost ratios.

## Impact Analysis

Impact analysis is an approach to quantifying the social, economic, and environmental consequences of various actions. Impact analysis is often used as a preliminary tool in developing environmental assessments. Unlike benefit / cost and cost effectiveness analysis, impact analysis makes no attempt to convert impacts into a one-dimensional measure to ensure comparability (Tietenberg 1996). Impact analysis also does not attempt to find an optimum of an economically efficient set of alternatives for accomplishing objectives. Rather it attempts to describe all impacts, quantitatively and qualitatively, as a way of evaluating proposed actions.

In the context of the Fort Valley restoration project, USDA Forest Service personnel completed an environmental impact analysis to evaluate the impacts of different treatments (in other words, silvicultural restoration prescriptions) on the landscape and surrounding community (USDA 1998). The focus of the analysis was to compare effects of different thinning intensities (in other words, different residual densities of trees per hectare) proposed in the restoration treatments. The analysis did not attempt to quantify all costs and benefits in terms of monetary units, and made no comparison of different harvesting procedures and equipment mixes to be used to carry out the treatments. While the impact analysis provides necessary information to determine if the overall project was worth undertaking, it did not provide information that would facilitate the selection of the optimal harvesting alternative.

## Cost / Effectiveness Analysis

Cost / effectiveness analysis is a technique designed to assist a decisionmaker in identifying a preferred choice among possible alternatives. The analysis involves a comparison of alternative courses of action in terms of costs and effectiveness in attaining some specified objective (Quade 1967). Cost estimation is identical to direct cost estimation used in a benefit / cost ratio analysis. Direct costs are measured in terms of equipment costs, fuel costs, and salaries. Cost / effectiveness analysis avoids some of the difficulty in quantifying economic benefits of various alternatives by replacing dollar measurements of benefits and indirect costs with the concept of "effectiveness," where effectiveness is a comparative measure of an alternative's ability to meet project objectives.

In its simplest form, a cost effectiveness analysis is equivalent to a minimized cost approach. If all alternatives are equally effective in accomplishing project objectives the cost effectiveness ratio becomes (cost / 1). In this case the lowest cost alternative is optimal. Alternatively, in the case that different alternatives (for example, different harvesting techniques) have different impacts on the site, then effectiveness measures are selected to calculate these impacts.

A cost effectiveness analysis requires the analyst and decisionmaker to choose (1) a specific set of objectives, (2) a complete listing of the alternative solutions to be considered, and (3) acceptable measures of effectiveness in meeting the objectives. The first two decisions are common to all project analysis techniques. The third decision, selection of effectiveness measures, is unique to cost effectiveness analysis and makes this analysis subjective because of analyst assumptions. The analyst and decisionmakers must select attributes, which quantify the ability of an alternative to meet project objectives. In environmental decisions, these attributes are most often measures of damages avoided. To be useful the expected value (or effectiveness score) of attributes must vary across alternatives.

The virtue of the cost / effectiveness analysis lies in a more systematic and transparent use of judgment than any of its alternatives (Quade 1967). While effectiveness analysis may appear subjective in terms of analyst judgment of effectiveness measures, the analysis is presented so the decisionmakers can follow the analytic assumptions. Decisionmakers can choose which assumptions they agree with and arrive at their own conclusions. Other efficiency analysis techniques often mask assumptions in the assignment of dollar values to nonmarket benefits.

The selection of effectiveness measures also poses limitations that must be considered when using cost / effectiveness results. Results of an analysis (in other words, alternative rankings in terms of cost and environmental damage) must be interpreted by qualified and informed decisionmakers. Decisionmakers must understand the assumptions made by the analyst to arrive at the results, such as selecting attributes of effectiveness and assigning importance weights to attributes. The measurement of effectiveness is limited by selected attributes, and these attributes are often constrained by the cost of measurement and other factors that the analyst may not be able to take into account (Livingston and Gunn 1974). Thus, the results of effectiveness analysis are not intended to provide understanding and prediction, as are the results of science. Rather, the results are intended to serve primarily as recommendations or suggestions for selecting among courses of action (Quade 1967).

A cost / effectiveness analysis is most appropriate when used to choose a preferred alternative among possible alternatives that have the same project objectives. This analysis can rank possible alternatives that have a nonmarket nature to their benefits and costs, a situation that fits many restoration activities. The following description of the Fort Valley restoration project sets a base for a theoretical application of a cost / effectiveness analysis, which can be used as an aid in recommendation of an optimum harvest method.

## Application of Cost / Effectiveness Analysis to Fort Valley Restoration Treatments

The Fort Valley restoration project is a series of ecological restoration / fuel reduction treatments, guided by pre-Euro-American settlement conditions (prior to 1870). The restoration treatments cover approximately 1,376 ha (3,400 acres), and incorporate various mixes of equipment to complete harvests. The goals and objectives of this ecological restoration and fuel reduction project as stated in the Fort Valley Environmental Assessment (USDA 1998) are to create a mosaic of open, parklike forests that approximate conditions present before Euro-American settlement. The project will also reduce the hazard of catastrophic crown fires.

Three harvesting methods were used to meet the objectives of the Fort Valley restoration project: (1) hand harvesting, (2) cut-to-length harvesting, and (3) whole-tree-mechanized harvesting. The hand harvesting treatment method consisted of a classical sawyer operation. Trees of 12.7 cm (5 inches) diameter at breast height (d.b.h.) and greater were cut, limbed, and bucked into 4.9 m (16 ft) log lengths by hand. Processed logs were transported to waiting trucks at the log landing using a tractor with a log grapple. The merchantable activity was simultaneously accompanied by the cutting, scattering, and lopping of the very small, nonmerchantable trees.

The cut-to-length mechanized harvesting method consisted of a single grip harvester, a forwarder, and hand sawyers to cut and lop all nonmerchantable trees. A tractor with a log grapple forwarded all logs cut and processed by the harvester. The logs coming from trees 12.7 cm (5 inches) and greater in diameter were forwarded to waiting trucks at the log landing.

The whole-tree-mechanized harvesting method consisted of one feller-buncher, whole-tree skidders, a delimber, and a loader to process merchantable trees 12.7 cm (5 inches) and greater. Whole trees were cut and piled using a tree-to-tree feller-buncher. Whole trees were skidded to the landing using a rubber tired grapple skidder. Trees were processed into logs at the landing using a delimber and loaded onto waiting trucks. Hand cutting, scattering, and lopping of the less than 12.7 cm (5 inches) diameter trees followed the merchantable activity (Larson and Mirth 1999).

The effectiveness of these harvesting alternatives depends on the degree to which the stated goals have been obtained. All three of these harvesting techniques performed the same ecological restoration treatments, leaving the same residual stand density, species composition, and age class distribution. The different alternatives also achieved similar reductions in risk of catastrophic crown fire, which was primarily dependent on the treatment prescription rather than the harvesting method. The benefit side of the project objectives does not vary significantly between the harvesting alternatives, and therefore are not useful in selecting the optimum-harvesting alternative. In addition, many of the benefits from restoration currently do not have quantified market value, or established nonmarket value. The absence of economic quantification of returns from restoration precludes the use of benefit / cost analysis (Weaver and others 1982).

These three harvesting alternatives are expected to have had different impacts on the residual forest condition. The key differences between the alternatives are how the trees were felled and processed, piled, and transported to the log landing. These differences will have caused variation in residual stand damage, amount and distribution of logging slash, and degree of soil impacts. While these impacts (indirect costs) are also not easily quantified in terms of dollar values, they are amenable to effectiveness analysis.

Because the alternatives are similar in primary goal accomplishment, the primary benefits are nonmarket in nature, and the alternatives differ in direct and indirect costs, and cost / effectiveness analysis is the most appropriate technique for selecting the optimum alternative. The direct cost of each method can be quantified in terms of dollars. In the absence of differences in indirect costs, the cost effectiveness ratio would reduce to cost, and the minimum cost alternative would be preferred. If indirect costs of residual stand damage, fuel loading, and soil impacts were easily quantifiable in dollar value, then any of the efficiency measures (for example, benefit cost ratios) could be used. Cost / effectiveness analysis avoids the problem of the nonmarket nature of these indirect costs by using them as effectiveness measures. Cost / effectiveness analysis can evaluate the alternatives in terms of their direct cost and relative effectiveness in avoiding these adverse impacts. The primary criteria for attributes to quantify these impacts are data availability, and the attribute's correlation to the impact costs.

The following is a short description of each of three proposed effectiveness attributes for residual stand damage, soil compaction, and fuel loading and a possible method for measuring each. Residual stand damage may be quantifiable as percent of residual trees undamaged, with damage defined as visible wounds, broken tops, and broken branches. Stand damage is important because bole damage (for example, cat faces caused by equipment) is a primary point of entry for diseases such as decay fungi to enter the tree (Storer and others 1997). Broken tops and branches can also leave the tree in a state of low vigor, increasing the possibility of insect and disease mortality. This attribute can easily be measured by inventory plot procedures using a fixed radius plot or strip cruises.

Soil impacts measure damage to soil structure. This attribute was selected because compacted and disturbed soils from machines and humans can impede surface water entry into the lower layers of the soil (Seixas and McDonald 1997). Disturbed soil can also provide a growing habitat for invasive exotic weeds that can out-compete native vegetation, reducing habitat for native wildlife and insect populations. Compaction can be measured with an infiltrometer, and be converted to percent change in compaction. Disturbance can be visually estimated as a percentage of disturbed soil, using a plot or strip inventory procedure.

Fuel loading measures the downed woody material left on the forest floor after treatment. In a study on biomass and nutrient removal, Giles (1979) found that removing whole trees, as opposed to stems only, could increase biomass removal by 28 percent in coniferous forests. Increased removal of biomass and nutrients may cause a decline in soil nutrients and forest productivity. Branches cut from trees in the limbing process contain many of the tree's resource of nutrients. Removing this material from the harvest site and accumulating large amounts at landings can cause effective nutrient mining of the site, can be a breeding center for decay fungi and insects that can spread into the residual stand, and can be a fire hazard. Fuel loading can be measured along transects, giving a measure of average diameter of fuels deposited throughout the site (Brown 1974).

The attribute scores should be measured so that cost / effectiveness ratios for each treatment are the highest when they have the highest cost, and hence least effective. This convention requires that each attribute be measured so those alternatives that cause greater impacts have lower effectiveness scores. Attribute scores may be weighted to reflect relative importance by multiplying the percentage amount of each attribute by an importance weight (Macmillan and others 1998).

The overall effectiveness of a harvest alternative can be quantified by summing attribute scores (percent measurements of each of the above attributes) for each treatment. Along with these effectiveness measurements, each harvesting method must be quantified in terms of the financial cost required to implement each harvesting treatment. Direct costs for the Fort Valley restoration project were estimated by the use of a cost analysis completed by Larson and Mirth (1999). This analysis estimated direct logging costs using the method of implementation costs, modeling equipment sets, and operational procedures for hand, whole-tree, and mechanized harvesting methods. Table 1 presents the direct cost of the harvesting alternatives. The whole tree harvesting method was the least cost approach in all forest conditions calculated. Cut-to-length was the second lowest cost in all conditions, and it equaled the whole-tree cost in the yellow pine stand condition. The hand-harvesting method had the highest cost in all conditions. Unless the effectiveness of the methods varies, a rational decisionmaker would select the whole-tree method as the optimal alternative.

The cost / effectiveness ratio of each harvesting alternative can be computed by dividing the alternative's direct cost by its restoration effectiveness score. Table 2 presents a hypothetical example calculation of cost effectiveness ratios for the black jack stand condition, using only residual stand damage as the attribute of effectiveness. In the example, we assume that the percent of stand damaged is higher for the lower cost methods (30, 20, and 5 percent for whole-tree, cut-to-length, and hand harvesting, respectively). If these values match actual stand damage, then the optimal decision would switch to hand harvesting because it has the lowest cost / effectiveness ratio. In the example, stand damage values reverse the optimal ranking from the least cost approach.

The sensitivity of a decision to effectiveness score depends on the ratio of direct cost of the alternatives. Alternatives with similar direct costs (ratio near one) are more sensitive to effectiveness measures. Table 3 demonstrates this sensitivity of cost / effectiveness ratios to direct cost differences. In the black jack stand condition, whole-tree direct costs are 73 percent of hand harvesting cost. For the decision of optimum harvest method to switch from whole-tree to hand harvesting, whole-tree effectiveness would have to be less than 73 percent of the effectiveness of hand harvesting. In the yellow pine condition direct cost differences are similar, and whole tree effectiveness must be at least 90 percent of hand harvesting effectiveness in order to remain the optimal choice.

**Table 1**—Direct cost ($/ha) of restoration harvest alternatives by stand condition.

| Harvesting method | Stand condition: Black jack | Black jack / yellow pine | Yellow pine |
|---|---|---|---|
| Whole tree | 1,098 | 931 | 818 |
| Hand harvesting | 1,497 | 1,397 | 909 |
| Cut-to-length | 1,297 | 1,210 | 818 |

**Table 2**— Hypothetical example of cost / effectiveness ratios for black jack stand condition and residual stand undamaged attribute.

| Harvesting method | Harvest cost ($/ha) | Cost/(percent undamaged) ($/ percent) | Cost effectiveness |
|---|---|---|---|
| Whole tree | 1,098 | (1,098)/65 | 16.9 |
| Hand harvesting | 1,497 | (1,497)/95 | 15.8 |
| Cut-to-length | 1,297 | (1,297)/80 | 16.2 |

**Table 3**—Sensitivity of cost / effectiveness ratios to direct cost differences, or percent effectiveness required to change decision from minimum cost approach. Percent effectiveness is the level of effectiveness that the lower cost alternative must achieve relative to higher cost alternative in order to remain the optimal decision.

| | Stand condition | |
|---|---|---|
| | Black jack | Yellow pine |
| Whole tree direct cost ($/ha) | 1,098 | 818 |
| Hand harvesting direct cost ($/ha) | 1,497 | 909 |
| Required percent effectiveness (percent) | 73 | 90 |

## Conclusions

This paper demonstrates cost effectiveness analysis as a useful tool for optimum harvest recommendation for ecological restoration treatments such as those in Fort Valley. Harvest methods may be compared on the basis of ratios of harvest cost / effectiveness. Effectiveness measures can be defined as a harvest method's ability to carry out restoration treatment with the least negative impacts in terms of residual stand damage, soil impacts, and fuel loading. Cost / effectiveness analysis avoids the valuation difficulties with the nonmarket nature of indirect costs by using them as effectiveness measures. Thus, it avoids problems associated with benefits estimation encountered with traditional benefit / cost approaches.

Important issues must be addressed in the use of a cost / effectiveness analysis, such as the proper selection of effectiveness measures and the weights given to these measures. Weights given to effectiveness measures must appropriately reflect not only their importance with respect to other measures, but also their ability to effect optimum harvest choices.

Possibilities for future use of this approach may incorporate a more objective presentation of results. Analyst assumptions in effectiveness weighting could be partially eliminated from this analysis by presenting cost / effectiveness ratios in a table showing effectiveness weights calculated a variety of ways. For example, if the weighting of each effectiveness attribute is removed (all attributes are assumed to be equally important) the cost / effectiveness ratio for each harvesting treatment may change. Attributes could be weighted or not weighted in order of importance, effectiveness could be calculated in each instance, and ratios could also be reported in a table. The table format would give more interpretive decisionmaking power to the reader and make the entire analysis less subjective. Aside from objective presentation techniques, further investigation into the sensitivity of effectiveness measures is also an important consideration for a meaningful analysis.

## Acknowledgments

The authors thank Dr. Deb Larson and two anonymous reviewers for constructive comments on this manuscript. This research was partly funded by the USDA Forest Service, Rocky Mountain Research Station contract No. RMRS-98159-RJVA-01.

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