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Evaluating forest product potential as part of planning ecological restoration treatments on forested landscapes

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Abstract

As landscape scale assessments and modeling become a more common method for evaluating alternatives in integrated resource management, new techniques are needed to display and evaluate outcomes for large numbers of stands over long periods. In this proof of concept, we evaluate the potential to provide financial support for silvicultural treatments by selling timber harvested during treatments designed to achieve non-timber objectives such as fire hazard reduction or wildlife habitat improvement. We introduce the concept of dimensionless indices to describe and compare physical accessibility, harvest and hauling costs, and potential revenue from wood products. These indices are combined into a composite utilization index that portrays the relative potential of each polygon for wood utilization and associated cost offsets from integrated resource management activities. To illustrate these concepts, we simulate vegetation dynamics, management interventions, and natural disturbances over a 100-year period and summarize results into both tabular outputs and maps for a 178,000 ha landscape with more than 50,000 stands.

Keywords: Forest products; Ecological restoration; Wood supply; Cost; Revenue; GIS; Landscape analysis; Landscape modeling; Ecosystem management

1. Introduction

A growing consensus suggests that active management to change vegetative condition is warranted to reduce fire hazard in many forested ecosystems in the western United States. This conclusion is reached in the scientific literature (Brown, 2000), by policy makers (Feinstein, 2002), technical organizations (Oregon Forest Resources Institute, 2002) and in the popular press (Bales, 2002; Cameron, 2002; Fitzgerald, 2002). In addition to concerns about fire hazard, managing habitat for wildlife species that require or prefer certain forest structural conditions has been another common driver for manipulating vegetation in this region's public forests; however, the details of treatments and schedule of activities appropriate for achieving a common objective are more contentious (Hill, 2000; Thomasson, 2002; Coile, 2003; Taylor, 2003).

When a proposed management action requires changes in forest vegetative structure, public land managers really only have three tools to choose from: prescribed burning (activities from broadcast burning to piling and burning ground fuels), mastication (mowing or grinding of unwanted vegetation onsite), and felling of trees. Depending on the circumstances, trees felled to achieve a desired vegetation structure might either be removed or left on site. From a financial point of view, prescribed burning and mastication are always implemented at a net cost because no merchantable products are generated to offset costs. Felling trees can result in either positive or negative net revenue (the difference between the cost of the treatment and the value of the wood removed) depending on a variety of factors including the size and species of the trees removed, the location of the stand, the complexity of the treatment, and prevailing economic conditions.

The fact that felling and removal of trees can sometimes pay for itself (positive net revenue) or at least offset some of the treatment costs is appealing to some people, but creates suspicion about actual motives for others (Brown, 2000; Hill, 2000). Not surprisingly, proposals to harvest and use timber from public lands in the western United States are frequently controversial and can result in heated public debate (Back, 2001;

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Milstein, 2004). The intensity of these discussions and likely public scrutiny of proposed management plans can cause technical specialists who design management alternatives and decision makers who select from among these alternatives to act differently than they might in the absence of such contentious public discussions. Public land managers cannot escape the fact that proposals to remove wood will almost certainly attract criticism from opposite perspectives, either because "not enough" wood is being removed to meet society's demands or because "too much" wood is being removed to maintain environmental quality. These two criticisms are routinely leveled at the same management action (Milstein, 2004).

Our objective is to provide objective tools that are useful in sorting out technical questions about when and where tree felling and timber removals can actually help to achieve other 11011-timber goals on a target landscape, when and where they might make conditions worse, and the financial costs or revenues from those treatments. We deal specifically with analysis of financial returns from treatments intended to meet the objectives of the Healthy Forests Restoration Act of 2003. At least in theory, access to better analytical capability could allow managers to design options that include objective consideration of the benefits of timber harvest. Understanding the costs and revenues of timber harvests is an important first step in conducting an unbiased analysis because it helps clarify the potential motivation for treatments involving removal of timber.

The techniques we describe here are intended to help managers to objectively assess financial costs and revenues of different management activities in the context of large landscapes and long planning horizons (in this case more than 50,000 stands and up to 100 years, respectively). When this information is combined with other analytical procedures developed under the Interior Northwest Landscape Analysis System (INLAS), it is possible for managers to evaluate the potential of timber harvest and other silvicultural treatments to reduce fire hazard (Hemstrom et al., 2007), enhance wildlife habitat (Wales et al., this volume; Graetz et al., 2007; Ager et al., this volume), change the susceptibility of trees to insect attack (Ager et al., this volume), or influence grazing by cattle, deer, and elk (Vavra et aI., this volume).

The INLAS utilization module (Barbour et al., 2004b) was developed to encourage managers to think about timber harvest in an integrated sense as they design strategies to meet ecosystem management objectives. It describes the potential revenues and costs associated with silvicultural treatments that involve harvesting, as well as a conceptual framework for calculating and displaying the "utilization potential" of landscape polygons (roughly equal to stands) and larger landscape units, such as watersheds or subbasins. We display utilization potential as a composite index (utilization index) derived by combining two other indices: accessibility index (physical access to the site) and net revenue index (estimated gross value minus logging costs). We describe and demonstrate the techniques needed to calculate and display these primary indices and to combine them to derive utilization indices for the upper Grande Ronde River Basin in northeastern Oregon, USA, the pilot landscape for the INLAS project (Barbour et al., 2004a). Our intent is to describe a set of techniques that managers could use to conduct analyses and provide information about cost effectiveness and economic consequences of a variety of management scenarios.

2. Methods

The simulation process requires three types of input data - spatial, tree list, and economic - that feed into the utilization module (Fig. 1). These data are used to calculate the accessibility and net revenue indices, which are combined into an integrated utilization index (Fig. 1).

2.1. Spatial data

The spatial data component for the module begins with a photo-interpretation map used to assign density, cover, and species composition to each polygon in the target landscape

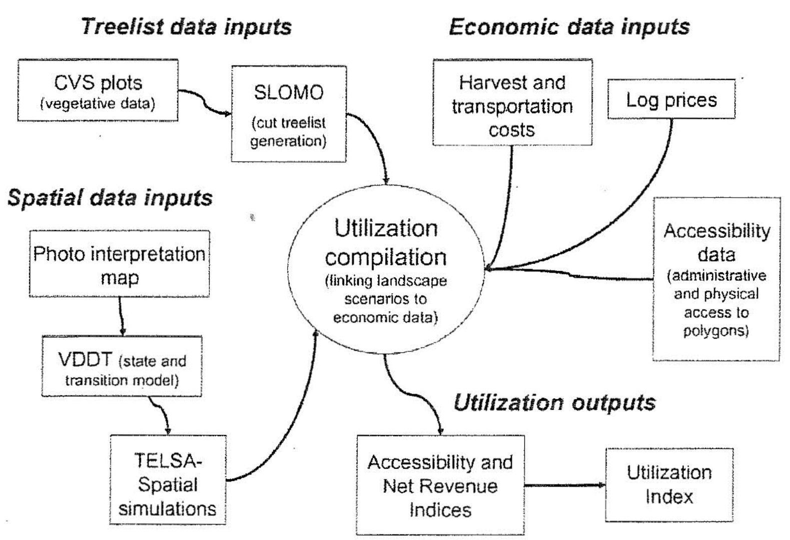

Fig. 1. INLAS utilization module analysis flowchart.

(Hemstrom et al., 2007). These photo-interpreted or PI polygons are further subdivided based on their management allocation (a political demarcation) and physiognomic characteristics (an ecological demarcation) to create a set of simulation or SI polygons. The vegetation in each SI polygon can change its structural state more or less independently of those around it as the simulation proceeds (Hemstrom et al., 2007). A current vegetative state and a set of probabilities for transition to other vegetative states are assigned to each of these simulation polygons, and a simulation is run by using the Vegetative Dynamics Decision Tool (VDDT) (Beukema et al., 2003). The transition probabilities include information on the administrative rules controlling accessibility or restricting management options for each simulation polygon. The results from the VDDT simulation are passed to TELSA, the Tool for Exploratory Landscape Scenario Analysis (Kurz et al., 2003), and TELSA then allocates simulation results spatially across the landscape. Output from TELSA simulations includes the cover type, structural class, and disturbance type for each polygon and for each year of simulation.

2.2. Treelist data

No individual tree data are available from VDDT and TELSA simulations, so a procedure was needed to estimate a list of cut trees for any polygon entered for tree removal or harvest, which is one of many possible silvicultural treatments that are referred to as "management disturbances" in VDDT. Cut tree lists for disturbances corresponding to specific management activities were generated independently of TELSA simulations then assigned to TELSA results. Current Vegetation Survey (CVS) permanent inventory plots (Max et al., 1996) were run through the Stand Level Optimization with Multiple Objectives (SLOMO) model (Graetz and Bettinger, 2005; Bettinger et al., 2005; Graetz et al., 2007). SLOMO uses a dynamic programming algorithm to find near-optimal solutions for a number of problem formulations, allowing users to enter multiple stands and many management objectives. SLOMO simulates stand dynamics internally with growth and yield equations from the Blue Mountain variant of the Forest Vegetation Simulator (Dixon, 2003). Prior to landscape simulation, the available CVS plots were run through SLOMO under alternative scenarios over a 100-year period to create a large number of cut tree lists.

These cut tree lists were then associated with an initial structure, cover type, and management disturbance. This information allowed us to estimate the amount and type of timber generated under a wide variety of treatments applied for meeting integrated forest management objectives. When a TELSA SI polygon made a transition from one vegetative state to another, a cut tree list was assigned based on the polygon's pre- and post-harvest (transition) cover and structure type and the type of harvest (disturbance).

2.3. Economic data

The next step involved processing the cut tree lists to determine the amount and gross value of potential wood products. Taper equations (Flewelling and Reynes, 1993) were applied to each cut tree to estimate the small-end diameter of each 4.8 m (l6ft) log, and log values and chip wood values were determined from current log prices for a given species and log size (Oregon Log Market Report, 2004). Chip wood included whole trees or logs that had a scaling diameter less than 12.7 cm (5 in.) for a 2.4 m (8 ft) log segment, as well as tree tops. In the last step, the total quantity and gross value of potential wood products was averaged for each cover-structure-disturbance class. This summary provided a database of potential wood product quantities and gross values that could be linked to output from TELSA.

After the TELSA simulation was completed for a given landscape management scenario, the gross value and volumes of potential wood products were determined from each polygon's structure-cover-disturbance class. Additional polygon information was retrieved, including area, slope, and access (defined as within or touching a 90 m [300 ft] buffer along any existing road regardless of whether the road is currently open or closed). Road data for the subbasin was provided by Aitken and Hayes (2006). Cable logging costs (manual felling and delimbing with cable yarding) were applied if the slope exceeded 35%, and ground-based (mechanical felling and skidder) logging costs were applied otherwise. A base harvesting cost for sawlogs for ground-based logging (slopes <35%) was estimated to be \$47.65 per m^3 (\$135 per ccf [hundred cubic feet]). A multiplier of 1.5 was applied to estimate harvesting costs for cable logging and a multiplier of 1.2 was applied to estimate costs for chip material (costs averaged from reports from local Forest Service sales in 2004). Harvest costs include moving from stump to truck, road maintenance and development, contracts, and post-harvest slash treatment. Haul cost estimates were \$5.65 per m^3 (\$16 per ccf) for sawlog material and \$8.12 per m^3 (\$23 per ccf) for chip material and were general estimates for the study area region (Ager, personal communication 2004. Operation Research Analyst, Pacific Northwest Research Station, Forestry and Range Sciences Laboratory, La Grande, OR, USA) (Note that since these haul cost values were early 2004 estimates they may underestimate current costs; [Burry personal communication 2006. Thomas Burry, Operations Forester, La Grande, Ranger District, Wallowa-Whitman National Forest, La Grande, OR, USA]). Finally, net revenue was computed as the difference between gross revenue and combined logging and hauling costs.

2.4. Utilization outputs

To simplify the display of utilization revenue and cost information, two indices were computed - an accessibility index and a net revenue index - and these were summed to produce the overall utilization index. Accessibility index is a binary measure depicting whether or not a road reaches the target polygon (defined as whethera polygon is within 90 m of any existing road). This index takes on a value of 0 for no access and 1 for any access, with no attempt to scale the index by the quality of access. Net revenue index was scaled by the maximum and minimum net revenue observed in each VDDT/ELSA management scenario to result in values between 0 and 1; the lowest net revenue receiving an index value of zero and the highest net revenue receiving an index value of one. Standardizing allows each index to result in a more even weight of its contribution toward the utilization index, and allows between-scenario comparisons to be made. The utilization index is illustrated by the following formula:

$$UI = AI + RI \quad (1)$$

where UI is the utilization index, AI the accessibility index, RI the net revenue index $= (NR_i - Min(NR_j))/(Max(NR_j) - Min(NR_j))$, NR_i the net revenue/ha in polygon i, $Max(NR_j)$ the maximum net revenue among all polygons ($j = 1-n$) for a given scenario, and $Min(NR_j)$ is the minimum net revenue among all polygons ($j = 1-n$) for a given scenario.

Each index can be displayed either graphically in the form of maps or in tables. Managers can then assess the landscape not only in terms of overall wood utilization potential of each polygon during each period, but also in terms of the components contributing to that potential. Tabular displays of the raw data producing the various indices are not as simple to interpret when characterizing the landscape because they are not standardized.

2.5. Landscape scenarios

Utilization indices were computed for three management scenarios: (1) active forestry (AF)-active management to reduce fuels, with current administrative constraints on harvest and a moratorium on cutting trees with diameter at breast height (dbh) >53 cm (21 in.); (2) AF53-same as AF scenario but relaxing the moratorium on cutting trees with dbh >53 cm; and (3) AF53NC-same as AF53 scenario but relaxing administrative constraints on harvest in some areas where it is currently constrained (e.g., lynx habitat areas). The objectives of the AF scenario were to aggressively treat canopy and surface fuels within the first decade and maintain relatively low levels of canopy and surface fuels after the first decade. The treatments most applied in the first decade were mechanical fuel treatments, whereas prescribed fire was used more in the latter decades for maintenance of fuel level. Other treatments used throughout the simulation included precommercial thinning, commercial thinning, shelterwood harvest, and group selection harvest. More information on the management scenarios and their outcomes can be found in Hemstrom et al. (2007).

3. Results and discussion

The landscape analysis process considered changes in vegetative structure and composition by 10-year periods over 100 years of simulation. More than 50,000 polygons were analyzed in each 10 year cycle, so the large amount of fine-scale data generated by this process makes direct interpretation difficult. We approach this problem by first presenting broad-scale, non-spatial, information to describe general outcomes. The summarized information allows us to answer questions like, "Is wood utilization a good way to pay for vegetation manipulation that reduces fire hazard on landscapes that resemble the upper Grande Ronde River Basin?" We then examine finer scale and spatial information to illustrate how to identify places within a landscape like the upper Grande Ronde River Basin where utilization might pay for or reduce the cost of management activities. Maps provide visual information depicting the reasons why utilization might or might not support other management goals. Questions about the relations between stand location, vegetative structure, vegetative composition, and the ease of treatment can then be addressed. Throughout this analysis we believe it is best to think about results in terms of a subbasin that is similar to the upper Grande Ronde River Basin rather than thinking of our results as an exact representation of the upper Grande Ronde River Basin. In other words, the general conclusions about the basin and the watersheds that it comprises are realistic, but polygon-level conclusions are less dependable.

3.1. Broad scale non-spatial analysis

Information on the number of hectares in each net revenue class from negative $4000/ha to positive $1000/ha over the entire 100-year analysis period (Table 1) suggests that timber harvest is unlikely to provide much of a financial incentive or internal subsidy for silvicultural treatments. Long-term projections of the active fuels treatment disturbance scenario (Hemstrom et al., 2007) imply that, after the first 100 years or so, average tree size begins to increase considerably. Conceivably, this could

Table 1
Distribution of land by net revenue class for each scenario over the 100-year simulation period

Net revenue class ($/ha)	AF scenario			AF53 scenario			AF53NC scenario		
	Hectares in class	Proportion in class	Inaccessible hectares in class	Hectares in class	Proportion in class	Inaccessible hectares in class	Hectares in class	Proportion in class	Inaccessible hectares in class
<−4000	20,459	0.134	3,163	5,196	0.034	1,033	5,917	0.034	933
−3000 to −4000	15,242	0.100	1,544	9,743	0.064	971	9,372	0.054	879
−2000 to −3000	53,556	0.350	5,043	25,960	0.170	3,212	30,242	0.173	3,606
−1000 to −2000	44,994	0.294	3,905	19,949	0.130	1,894	23,231	0.133	2,305
−1000 to 0	14,664	0.096	2,059	70,117	0.458	5,897	85,572	0.490	6,754
0–1000	4,078	0.027	411	20,778	0.136	2,780	19,852	0.114	2,403
1000+	0	0	0	1,250	0.008	338	538	0.003	192
Total	152,993	1.0	16,125	152,993	1.0	16,125	174,724	1.0	17,072
Total with positive NR	4,078	0.027	411	22,028	0.144	3,118	20,390	0.117	2,595

make timber operations more profitable, but speculating about the profitability of timber production so far into the future is not particularly meaningful.

Over the first 100 years, relaxing administrative restrictions, such as the 53 cm (21 in.) maximum diameter limit and removal of prohibitions on harvest in some areas where it is currently constrained, results in about a fivefold increase in the number of acres with positive net revenues (Table 1). Even so, this is still only a small proportion of the analysis area (Table 1). With all of the restrictions in place, about 4100 ha have positive net revenues. Of these, about 3700 ha are physically accessible, so on average less than 40 ha each year over the 100-year simulation period have positive net revenue. Under the other two scenarios this number increases to about 180 accessible ha per year, still a very small portion of the upper Grande Ronde River Basin landscape. Nearly 153,000 forested ha are available under the most restrictive scenario and about 175,000 ha are available under the least restrictive scenario over the 100-year simulation period (Table 1). The difference in total area occurs because in each scenario some polygons are entered for harvest and counted more than once over the simulation period. If treatments were implemented on only those areas that generate enough utilizable materials to cover the cost of treatment, very little change in vegetative composition and structure would be accomplished across the landscape.

As managers develop tactics to reduce fire hazard across this landscape, they will want to consider a variety of activities that create desired conditions in treated stands even though individual treatments do not pay for themselves. For example, in some cases reaching a structural condition where prescribed fire is safe requires removal of excess flammable fuels such as small trees that create "ladders" for ground fires to spread into the main canopy. Timber harvest might provide a convenient way to accomplish this even when there is a net cost. In other situations, allowing some harvest of commercial timber might simply make fire hazard reduction treatments less expensive, even if removing the merchantable trees does not by itself affect fire hazard. This defrayment of cost could have the added benefit of ensuring that a larger portion of the landscape can be treated at a fixed level of operating funds. Revealing management intentions in situations like these could help some groups understand the motivations for timber removal and decide whether or not they support the activities (Brown, 2000).

Under the AF scenario, average subsidies of about *\$2500/ha* are required to implement treatments in every decade, although treatment costs do decline slightly over time (Fig. 2). The scenarios that allow harvest of larger trees and permit treatments in administratively restricted areas improve from -\$ *1500/ha* in the first decades to about -\$1000/ha in later decades. This coarse summary of the financial information suggests that implementing the types of treatments recommended under the AF scenario are unlikely to pay for themselves either in the short or long term. That result is consistent with other recent financial analyses conducted for the Blue Mountains (the geographic region that includes the upper Grande Ronde River Basin)where fire hazard reduction treatments on only about 2% of the acres available for

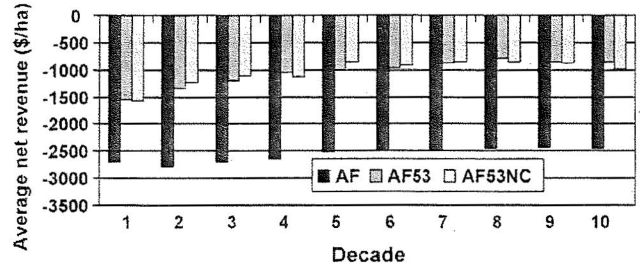

Fig. 2. Average net revenues for all harvested polygons summarized by decade.

active forestry might have positive net revenues (Rainville et al., in press).

In this analysis, when net revenues are summarized for all decades, 58% of the treatments under the AF scenario cost at least *\$2000/ha,* and 17% of the treatments have net revenues of less than *-\$3500/ha* (Fig. 3). Relaxing administrative rules under the AF53 and AF53NC scenarios improves the situation to the extent that nearly 75% of the treated area has net revenues above -\$2000/ha and 40-45 % of the area has net revenues between -\$500 and \$0/ha (Fig. 3).

For the past several years the U.S. Congress has discussed various ways to subsidize fire hazard reduction treatments in areas like the upper Grande Ronde River Basin. In 2001 the U.S. Senate passed S1731, the Agriculture, Conservation and Rural Enhancement Act of 2001 with a provision to subsidize transportation of forest biomass. In 2003 a similar provision was included in Sec. 206c of the House Energy Bill. Neither provision was included in final legislation by the full U.S. Congress, but discussion of this type of subsidy continues. We use the concept of a transportation subsidy for biomass removed during fire hazard reduction treatments as a unifying theme in the analysis throughout our discussion. Evaluation of this subsidy is by no means the only way this type of analysis can be used but we feel that using a common example will help tie the various components of the analysis together. Subsidies like the transportation subsidy are intended to encourage removal of the small, otherwise unmerchantable trees that increase the potential for undesirable effects of fire. In order to meet the intent of the subsidy, it is therefore necessary to know whether it actually encourages harvest of small trees or whether it simply promotes harvest of otherwise merchantable trees with high harvest costs

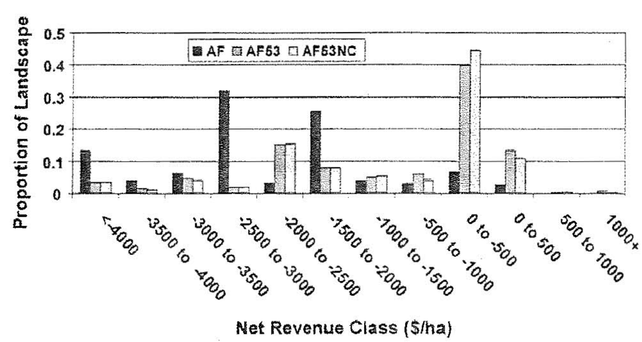

Fig. 3. Proportion of hectares by net revenue class for each scenario summarized over the 100-year simulation period.

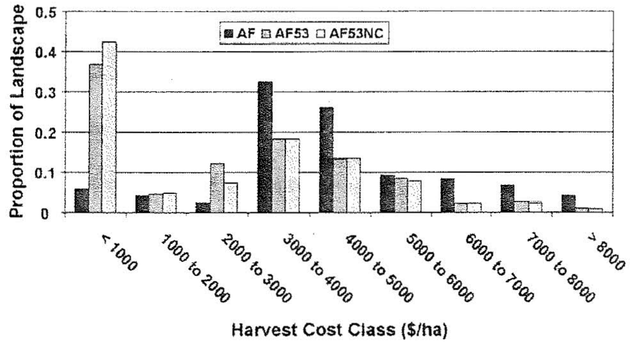

Fig. 4. Proportion of hectares by cost class for each scenario summarized over the 100-year simulation period.

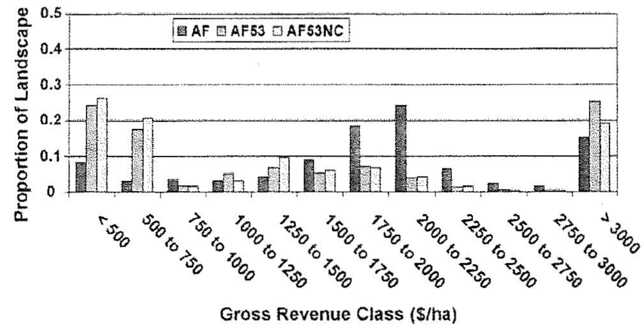

Fig. 5. Proportion of hectares by gross revenue class for each scenario summarized over the 100-year simulation period.

(for example, harvest of merchantable trees from stands on steep slopes where small volumes are removed).

If we assume a potential transportation subsidy of $18 per metric ton of bone dry (zero percent moisture content) wood removed from high fire hazard areas, our simulations show that on average about 13.5 metric tons should be removed per hectare. This would result in an average subsidy of about $243/ha. This level of subsidy would cover treatments on an additional 4% of the landscape under the AF scenario, giving a total of 7%. If this level of subsidy were applied in the other two scenarios, about 33% of the landscape could be treated.

Harvesting costs for silvicultural treatments on approximately 60% of the landscape were between $3000 and $5000/ha for the AF scenario (Fig. 4). Harvest costs under the two less restrictive scenarios are considerably lower with treatments on about 40% of the landscape costing less than $2000/ha (Fig. 4). About 50% of the hectares treated under the AF scenario have gross revenues of *$1750-$2500/ha,* and another 15% have gross revenues in excess of $3000/ha (Fig. 5). The two less restrictive scenarios have a larger number of low-value hectares; specifically, 40-45% of the area has gross revenues of *$750/ha* or less. A majority of these hectares have high quantities of low-valued chip material. For all scenarios, 15-25% of the hectares had gross revenues in excess of $3000/ha (Fig. 5). For the less restrictive AF53 and AF53NC scenarios, stands with positive net revenue tended to have similar amounts of sawlog volume as stands with negative net revenues. For these same two scenarios, harvests from the stands with negative net revenues tended to include much higher amounts of chip wood (small trees) (Figs. 6 and 7). This drives up relative harvest costs but does not generate much revenue. For the AF scenario, where only 3% of the landscape had positive net revenues (Table 1), stands with more positive net revenues tended to have very low volumes and costs, whereas the stands with more negative net revenues had high amounts of chip wood volume (Fig. 8). As indicated by the relation between gross value and costs (Figs. 9-11), the highest net revenues (vertical distance above the 1:1 line in Figs. 9-11) are captured from polygons across a large range in gross values, with the exception of the AF scenario.

Under all of the scenarios, high chip-log volumes were fairly common in negative net revenue stands (Figs. 6-8), and that chip volume is generally recovered from precisely the types of trees targeted under the proposed subsidy. This result suggests that subsidizing the transportation of otherwise unmerchantable trees would in fact make it easier to reduce fire hazard on this landscape. It is important to recognize the current lack of manufacturing capability from this type of material in the interior western United States. One element of that problem is the reluctance of industry to invest in manufacturing facilities because of lack of confidence in the supply from lands administered by the federal government. The availability of supply has political, technical, and economic facets that go well beyond this analysis. Conducting analyses like this over areas large enough to

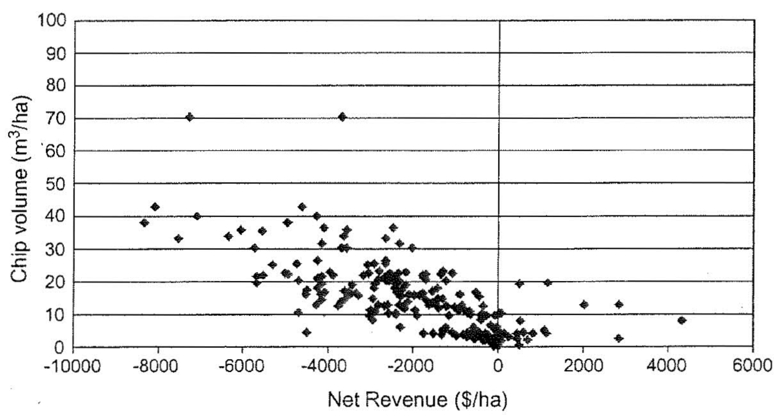

Fig. 6. Chip volume vs. net revenue for AF53 scenario.

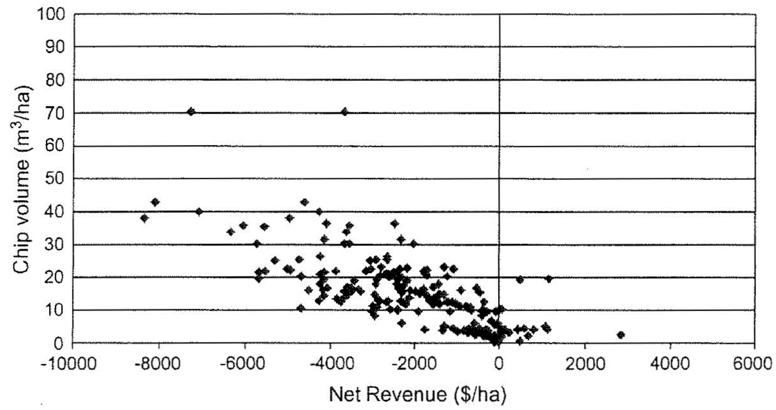

Fig. 7. Chip volume vs. net revenue for AF53NC scenario.

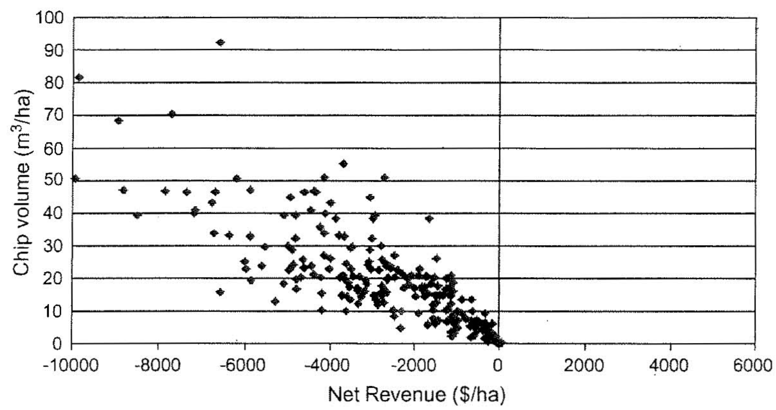

Fig. 8. Chip volume vs. net revenue for AF scenario.

serve as the working circle for manufacturing facilities, such as wood-fired electrical power plants or wood-plastic composite plants, could provide reasonable estimates of the amount and duration of supply. This type of analysis is currently being perfected by Fried et al. (2005). If the analysis were extended to include the other modules of the INLAS project (described in this volume) considerable information would become available about other resources such as likely reduction of fire hazard (Hemstrom et al., 2007) or improvement in wildlife habitat across the landscape (Wales et al., this volume); interactions of grazing by cattle, deer, and elk with other resources (Vavra et al., this volume); and influence of grazing on aquatic conditions (Wondzell et al., 2007). Barbour et al. (2007) discuss some aspects of combining these factors in the process of decision-making.

3.2. Spatial analysis

Maps are powerful tools for displaying information. They quickly convey a sense of conditions across a landscape, but

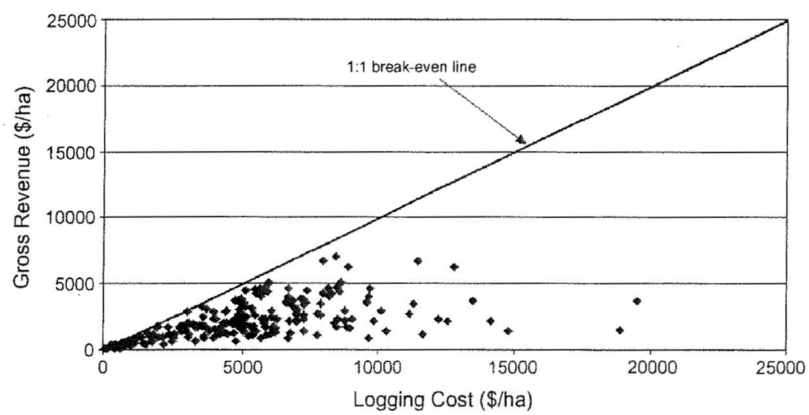

Fig. 9. Gross revenue vs. total harvesting cost for AF scenario.

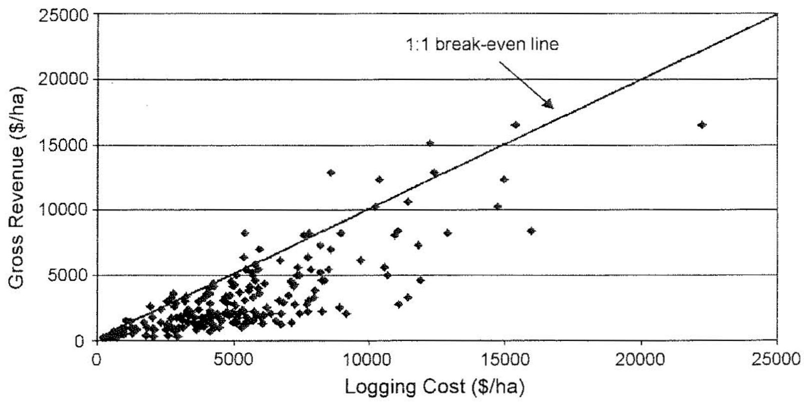

Fig. 10. Gross revenue vs. total harvesting cost for AF53 scenario.

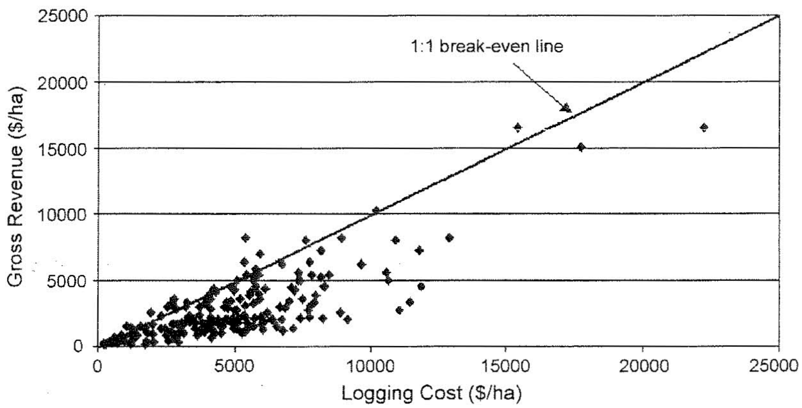

Fig. 11. Gross revenue vs. total harvesting cost for AF53NC scenario.

quantifying comparisons with a map among different conditions or over time is problematic. A map that shows one set of conditions for all of the polygons across a landscape the size of the upper Grande Ronde River Basin might give the viewer a sense that some conditions are more common than others or that some conditions tend to occur in certain parts of the subbasin more frequently than in others. It is, however, not easy to visually compare one set of conditions to another by using maps at this spatial scale and level of resolution. In this analysis, the upper Grande Ronde River Basin is represented by so many individual polygons it is difficult to even distinguish them on a map of the entire watershed (Fig. 12) let alone visually compare one map to another. Drawing any but the most obvious conclusions is simply not practical.

One solution is to summarize data to subunits larger than polygons. An ecologically meaningful way to subdivide a subbasin is by hydrologic unit code 6 (HUC6) areas, which we refer to as watersheds (Fig. 13). This approach is analogous to smoothing spatial trends by a moving average (Bailey and Gatrell, 1995), except that here the windows are stationary and they correspond to topographical features (i.e., watersheds). Again, individual HUC6 watersheds provide a convenient and ecologically reasonable way to break the subbasin up into manageable and meaningful units.

Another approach is to use maps of smaller areas where fewer polygons are displayed (Fig. 14a-c). The choice between these two methods depends on the purpose for making the map. In the case of utilization of forest products, it might make sense to use a two-stage process, first summarizing at the HUC6 level so that users could quickly get a sense of the general areas where timber extraction could pay for manipulations of vegetative conditions. Alternatively, the HUC6 maps could identify watersheds with

Fig. 12. The upper Grande Ronde River Basin showing each polygon boundary.

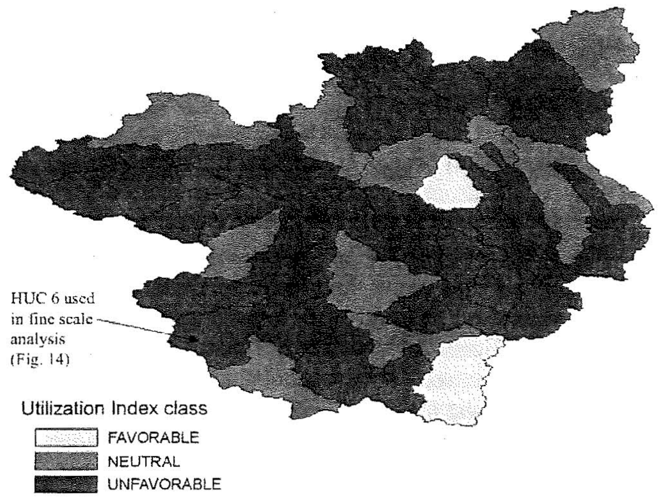

Fig. 13. The upper Grande Ronde River Basin showing the average utilization index for each of the 38 6th hydrological unit code (HUC6) watersheds that make up the subbasin.

financially unfavorable wood product potentials that meet some other ecosystem management objective. Once the most promising watersheds are identified, the finer scale approach might help users find the most potentially fruitful stands (polygons) to select for treatment.

As an example of the first approach, the utilization index for each of the 38 HUC6 watersheds was ranked as favorable, neutral, or unfavorable (Fig. 13). We chose three levels of the utilization index to illustrate the concept. They were: unfavorable = lower 50th percentile of observations, neutral = 51st to 67th percentile of observations and favorable = 68th to 100th percentile. Although decision makers or analysts working with an actual analysis might find fewer or more categories more meaningful and would likely choose different thresholds, this example serves to illustrate the concept. The resulting map shows the juxtaposition of the favorable, unfavorable, and neutral watersheds (Fig. 13). At a glance it is possible to see that most of the HUC6 watersheds (26) are not well suited to subsidizing fire hazard reduction through timber harvesting. Of the remaining 12 HUC6 watersheds, 10 are neutral and only 2 are favorable. It is important to realize that the results for an actual analysis

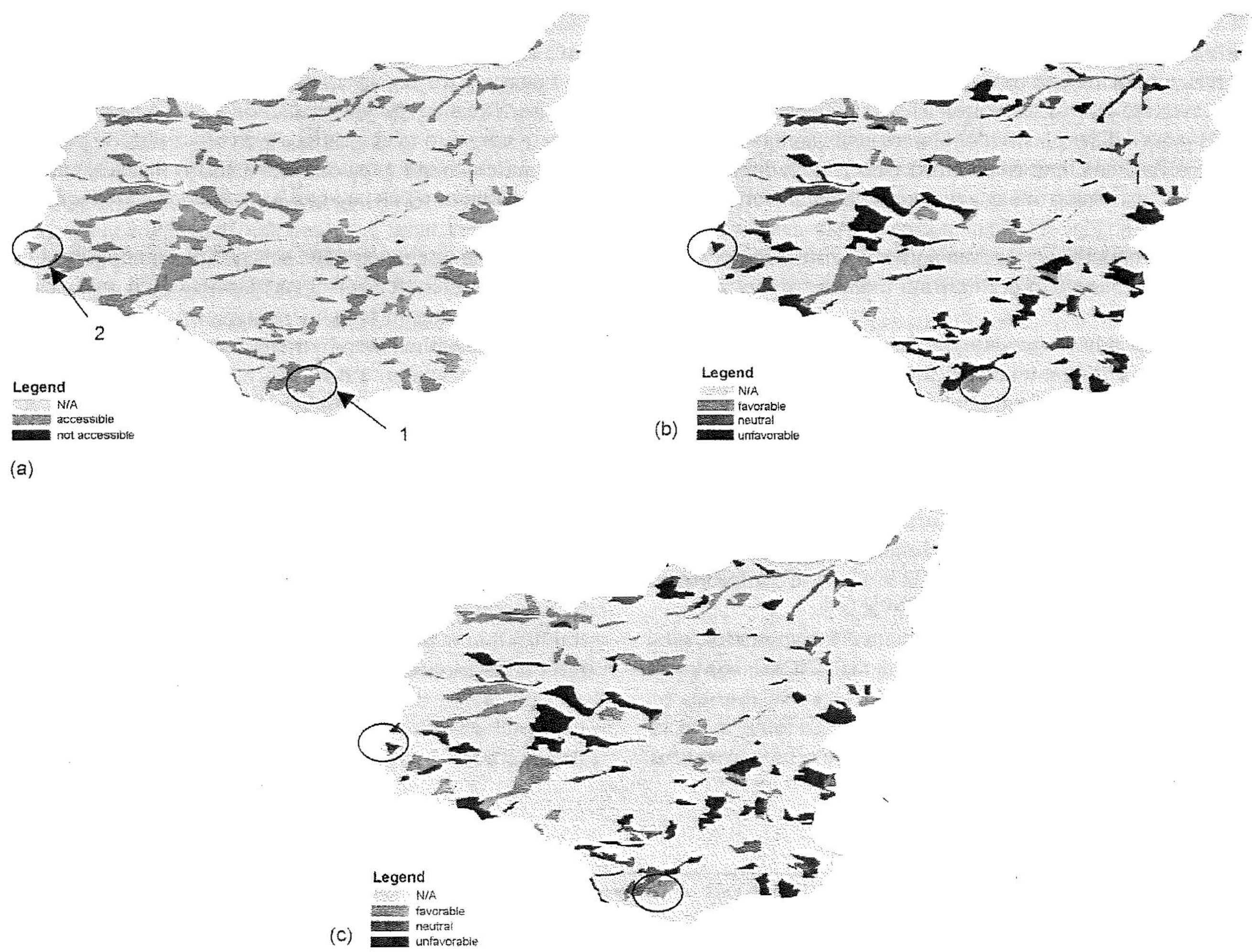

Fig. 14. One HUC6 watershed (Little Fly Creek) showing accessibility index (a), net revenue index (b), and utilization index (c) for the initial 10 years of the simulation. Arrows 1 and 2 indicate two polygons identified for further analysis.

on this landscape could be considerably different because managers might begin the analysis by using different assumptions and constraints.

Combining the information presented in HUC6 maps (Fig. 13) with similar maps depicting such conditions as current fire hazard and sensitive wildlife habitat, could help identify potential project areas with the highest probability of contributing to landscape management goals. If timber harvest were of primary concern then a watershed with a favorable utilization index would be chosen; however, in a landscape like the upper Grande Ronde River Basin under current management objectives, it is more likely that other concerns would take precedence. We, therefore, selected Little Fly Creek, a watershed on the southwest boundary of the subbasin, which ranked as unfavorable, to illustrate the fine-scale application of the utilization index concept.

Accessibility, net revenue, and utilization indices were displayed for the polygons within this HUC6 watershed that were treated over the first l0-year period (Fig. 14a-c). Displaying the results for only a single 10-year period simplifies the map and makes demonstration of the concept simpler. This watershed, like most of the upper Grande Ronde River Basin, has a high road density (Aitken and Hayes, 2006), and, as a result, physical accessibility almost never plays a role in determining the utilization potential of polygons on this landscape (Fig. 14a). In contrast, the net revenue index does vary considerably across the watershed (Fig. 14b). As was seen in the non-spatial analysis, the trees removed during silvicultural treatments on this landscape are typically small, and combined with relatively high harvest and haul costs, leads to many polygons with unfavorable or neutral rankings (Fig. 14b). Since accessibility index was almost always favorable the net revenue index was the primary driver for the results seen in the utilization index for this watershed (Fig. 14c).

Looking at how accessibility and net revenue indices combine to create different outcomes for utilization index provides additional insights into the potential of wood utilization as a mechanism for financing vegetation manipulations on landscapes like the upper Grande Ronde River Basin. By simply inspecting the maps of individual indices it is possible to find polygons with a variety of index rankings that result in different utilization outcomes (e.g., see clusters of polygons indicated by arrows and the numbers 1 and 2 in Fig. 14a-c). Information about these polygons is provided in Table 2.

Returning to the example of a potential transportation subsidy presented in the previous section, the HUC6 analysis gives decision makers the ability to assess the potential impacts of the subsidy for alternative project areas. Examining the cost and revenue detail within a polygon can reveal certain treatment considerations (Table 2). Consider the index values for polygon 1, which all resulted in favorable rankings (Fig. 14a--c and Table 2). If a subsidy for moving woody biomass from the forest to wood processing facilities were available, it might make sense to look for places where logging costs are relatively low and wood product potential (depicted by volumes and gross revenue) is also low, which is the case for polygon l. Areas with relatively low logging costs offer an opportunity to remove low-value wood (presumably small trees) relatively inexpensively. A transportation subsidy would improve the situation by effectively decreasing the cost of non-merchantable trees, thereby helping land managers to change conditions in places where small low-value trees increase ladder fuels and therefore the likelihood that ground fires will spread to tree crowns. A decision maker could apply this type of analysis to examine a landscape and find places meeting the intent of the subsidy, rather than simply using the subsidy to remove and transport high-cost merchantable timber whose removal might not actually reduce fire hazard.

Consider another polygon where the accessibility index is favorable and net revenue index is unfavorable (e.g., polygon 2 in Fig. 14a--c). These two conditions result in an unfavorable utilization index. Despite a high amount of sawlog volume and high gross value, this polygon has a high volume of chip material (Table 2), which contributed to high overall harvesting costs and negative net revenue. In this case, a decision-maker might choose to treat this polygon because the merchantable trees could supply timber to a local mill that provides family-wage jobs in a rural area. In order to do this, the decision maker might combine treatment of this polygon with others where the utilization index is either neutral or favorable. By adding some polygons with favorable utilization indices, and presumably positive net revenues, the decision maker could generate the funds necessary to pay for treatment of high-cost polygons.

In the Blue Mountains of northeastern Oregon, a recent analysis of the potential to reduce fire hazard and produce timber found that treatments on about 17% of the administratively-accessible, federally managed lands could be made financially feasible by using this method (Rainville et al., in press). Simply finding places where the value of harvested wood equals or exceeds treatment costs, however, might not provide the incentive necessary to interest contractors in bidding on the work. It also might not effectively alter the spread of large fires across the landscape (Finney, 2001). By treating some polygons with neutral utilization indices the decision maker might also make the project large enough to attract bids from contractors and create the opportunity to strategically place treatments that do not pay for themselves in ways that alter landscape-scale fire behavior (Finney, 2001).

Table 2
Attributes for the polygons featured in Fig. 14

Polygon	AI	RI	UI	Gross revenue ($/ha)	Logging cost ($/ha)	Net revenue ($/ha)	Sawlog volume (m^3/ha)	Chip volume (m^3/ha)	Chip (t/ha)
1	Favorable	Favorable	Favorable	99	108	−9	1.7	0.07	0.04
2	Favorable	Unfavorable	Unfavorable	2051	7016	−4965	63.8	22.5	14.0

These two examples are intended to demonstrate how decision makers might use the spatial information generated by this analytical approach. The list of other possible applications is obviously much larger. Displaying spatial results as maps assists people in quickly assessing the total area of polygons meeting important management criteria and the spatial arrangement of these polygons across the landscape. A quick visual inspection identifies areas where further analysis is warranted. Subsequent analyses would typically focus on tabular data (e.g., Table 2) as well as information on the potential effects on other resources like wildlife (Wales et al., this volume), water (Wondzell et al., 2007), and ungulates (Vavra et al., this volume).

4. Conclusions

Using revenues from the sale of wood products to subsidize silvicultural activities that promote non-timber values appeals to some people and is abhorrent to others. As a result, personal opinions often cloud discussions about whether this strategy results in vegetative conditions people want. An underlying problem is that we do not have good ways to simply and clearly display information about the ecological and financial costs and benefits of such actions. We realized that truly useful techniques must convey information about where, when, and why removal and sale of wood products either helps to move landscape conditions toward or away from desired conditions. Summarizing the mass of data generated by landscape analyses into readily interpretable information is, however, challenging. We think that a combination of data tables and maps could help. Tabular outputs are useful for summarizing raw data over the broad landscape. This is difficult to do with a map because information either becomes so vague that it is meaningless or so detailed that it is impossible to interpret. With maps we created a set of standardized indices that could be combined into an overall index to display utilization potential. Mapping the resulting utilization index helps to identify places where utilization makes sense. Evaluating the component indices either with maps or tabular outputs provides information on why the utilization potential is high or low. Repeating the process during different periods in the landscape simulation conveys information about when the sale of wood might play a role. Both the indices and their source data can be displayed on a stand-by-stand basis or summarized at a variety of spatial scales.

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