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Seeing the forest for the fuel: Integrating ecological values and fuels management

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Abstract

Management of dry forests often involves trade-offs between ecological values, particularly those associated with closed-canopy forests, and reduction of severe wildlife risk. We review principles and our ecological research that can be used to design stand- and landscape-level fuel treatments in dry coniferous forests of western North America. The focus of ecological values is on the ecological web that includes the northern spotted owl (*Strix occidentalis caurina*), its two primary prey species the northern flying squirrel (*Glaucomys sabrinus*) and bushy-tailed woodrat (*Neotoma cinerea*), and the vegetation (live and dead), mycorrhizal fungi, and arboreal lichens that support those prey species. For the landscape level, we describe an ongoing project to develop the *FuelSolve* computer tool that optimizes the area and location of a fuel treatment by minimizing potential fire behavior and minimizing loss of spotted owl habitat from treatment and potential fire. Some species will gain and some species will lose habitat when stand structure or composition is changed during fuel reduction treatments. Stand-level prescriptions might be altered to maintain or create patchiness of closed-canopy habitat elements, such as snags, down wood, mistletoe-infected trees, and large old trees, and open-canopy habitats can be tailored to ensure creation of suitable composition and structure for wildlife. Allocation of treatments across the landscape might be managed to minimize cumulative effects and impacts on target species populations. General approaches to landscape-level planning of ecologically sound fuel treatments include coarse- and fine-filter approaches. A coarse-filter approach would use some definition of the historical or natural range of variability to define the composition and pattern that might reasonably be expected to sustain the forest ecosystem. Three general approaches can inform fine-filter analysis and development of fuel reduction treatments at the landscape level. Population viability analysis provides sound principles based on attributes of the species population structure, life history and behavior, and environment (habitat) for guiding fine-filter analysis. Fine-filter analysis can be informed by operational modeling of treatment alternatives. Research publications can guide dry forest landscape management. Our *FuelSolve* optimization model described in this paper differs from other fuel planning models in this class by equally considering multiple optimization objectives for fuel treatment and ecologically important resources. We describe the results of *FuelSolve* prototype development, an evaluation of outputs for field use, and future development efforts.
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1. Introduction

Changed fire regimes and increases in lethal fire in dry forests of western North American during the last 80–100 years have been well described, particularly during the last 15 years (Agee, 1993; Hann et al., 1997; Schoenagel et al., 2004). Fire regimes in those dry forests have shifted mainly from low-intensity and high-frequency regimes to moderate- and high-severity regimes, with consequent increases in uncharacteristic large-scale stand-replacing fires. As a result, forest research, management, and policy have focused on ways to restore dry forest stands and landscapes to historically prevalent stand structures and landscape patterns that will minimize fire effects, support low-intensity fire regimes, and restore dry forest ecosystems (Hann et al., 1997; Graham et al., 2004; Raymond and Peterson, 2005).

Prescriptions for restoring dry forests generally have focused on reducing fuels and changing stand or landscape structure to minimize potential fire behavior. Stand-level prescriptions focus on reducing surface fuels, increasing height

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to live crown, decreasing crown density, and favoring fire-tolerant species, especially the largest or oldest trees (Brown et al., 2004; Agee and Skinner, 2005). Landscape-scale prescriptions likewise have the goal of minimizing potential fire behavior by either a strategic placement of fuel reduction treatments (Finney, 2001; Loehle, 2004) or by some optimal allocation of treatments based on ecological or economic constraints (Chew et al., 2004; Ramon Gonzalez et al., 2005; Calkin et al., 2005; Finney et al., 2006). In most approaches, ecological considerations are secondary objectives, or ‘‘constraints’’ in optimal modeling parlance.

Not ‘‘seeing the forest for the fuels’’, or a back seat for ecological considerations, can be a result of land management agency ‘‘culture’’, scientific and operational uncertainty about how to achieve ecological goals with fuel treatments, and concerns over unit-costs ($/ha of treatment). Excessive focus on keeping unit costs down can result in treatments that are the ‘‘easiest and cheapest’’ but not necessarily the most effective or ecologically important. In addition, many fire and fuels managers are not familiar and comfortable with interdisciplinary project planning where ecological considerations can be integrated into project design and implementation. Information and tools that help to achieve better resource integration of fuels reduction and ecological values are needed.

Uncertainty in knowledge and application of ecological forest restoration and disturbance management is high (Graham et al., 1999, 2004), and new knowledge is being acquired gradually as priorities for wildland fire research emphasize physical and social issues (~75% of US Forest Service National Fire Plan budget, E. J. DePuit, US Forest Service, Pacific Northwest Research Station, Wenatchee, WA, personal communication) versus integrated science and adaptive management (e.g., fuels reduction). Uncertain ecological objectives, then, are more difficult to integrate into fuels management compared to the relatively simple and better-known objectives and methods of fire and fuel management. Thus, fuel reduction programs tend to be oriented to fuels more than forest restoration, hence attract litigation or require extensive consultation on ecological effects, e.g., impacts on threatened or endangered species like the northern spotted owl (*Strix occidentalis caurina*) in the Pacific Northwest.

In this paper, we review principles and our published, or ongoing, ecological research that can be used to design stand- and landscape-level fuel treatments in dry forests. The focus of ecological values is on the ecological web that includes the northern spotted owl, its two primary prey species the northern flying squirrel (*Glaucomys sabrinus*) and bushy-tailed woodrat (*Neotoma cinerea*), and the vegetation (live and dead), mycorrhizal fungi, and arboreal lichens that support those prey species. For the landscape level, we describe an ongoing project to develop the *FuelSolve* computer tool that optimizes the area and location of fuel treatments that minimize potential fire behavior *and* minimize loss of spotted owl habitat from treatment and potential wildfire. The spotted owl habitat goal, however, could be generalized to model solutions for any ecological values that can be defined on a map.

2. Stand-level guidelines

Dry forest landscapes are heterogeneous in topography, microclimates, and fire regimes, especially in the northern parts of western North America (Brown et al., 1999; Agee, 2003; Ehle and Baker, 2003; Schoenagel et al., 2004). However, a basic and useful dichotomous classification of dry forest vegetation conditions and associated species describes closed-canopy mixed-conifer forest (e.g., Douglas-fir [*Pseudotsuga menziesii*] and grand fir [*Abies grandis*]) and open-canopy ponderosa pine (*Pinus ponderosa*) dominated forest. Most fuel reduction treatments reduce closed-canopy habitats and create open-canopy habitats by reducing the complexity of crown structure and reducing key dead-wood micro-habitats in the form of snags and down wood (Agee, 2002). Some species will gain and some species will lose habitat when stand structure or composition is changed during fuel reduction treatments. Yet, a summary of costs and benefits to species is not a simple calculation of closed-canopy habitat lost and potential gain in open-canopy habitat. Stand-level prescriptions might be altered to maintain most (e.g., Buchanan et al., 1993; Everett et al., 1997) or some important closed-canopy habitat elements, open-canopy habitats can be tailored to ensure creation of the suitable structure for focal wildlife species, and the allocation of treatments across the landscape might be managed to minimize cumulative effects and impacts on target species populations.

Within the spotted owl dry forest ecological web, the northern flying squirrel is a good closed-canopy focal species for designing ecologically friendly dry forest treatments. It is an important prey species for forest carnivores (Carey, 1993; Forsman et al., 2004). It is a critical link in the tree-truffle-carnivore ecological web (Fogel and Trappe, 1978; Maser et al., 1978; Carey, 2000a). Lehmkuhl et al. (2006b) showed that flying squirrel fitness is associated with understory vegetation diversity, dead wood, defective trees, and ectomycorrhizal truffle and lichen biomass and communities. Stand-level dry forest fuel reduction treatments might be modified in several ways to maintain or even enhance flying squirrel habitat, including habitats for fungal and lichen communities that support flying squirrels. Those same practices that retain dead wood and mistletoe-infected trees would also benefit the habitat generalist bushy-tailed woodrat, another key prey species of northern spotted owls and other forest carnivores (Lehmkuhl et al., 2006a).

Similar to recommendations by Carey (2000b) for flying squirrels in wet coastal forests in the Pacific Northwest, some form of variable-retention thinning for fuel reduction may create heterogeneous, or patchy, stand conditions that maintain key habitat elements for the owl ecological web (Lehmkuhl et al., 2006b). Open-canopy patches might favor the growth of fruit and mast producing shrubs that are important for flying squirrel recruitment and survival. Retention of down wood and cool-moist microenvironments in closed-canopy patches within treated areas likely would maintain diversity and production of truffle foods (Lehmkuhl et al., 2004) that are associated with high recruitment and survival of flying squirrels (Lehmkuhl et al., 2006b). Retention of large old trees in those same closed-canopy patches would retain the high forage lichen (*Bryoria*, *Alectoria*) biomass associated with old forests (Lehmkuhl, 2004). Retention of large snags, mistletoe-infected trees, and large down logs throughout the treated area would provide the structures associated with high-density bushy-tailed woodrat populations (Lehmkuhl et al., 2006a). Retention of live broken-top trees would provide nesting sites for primary cavity nesting birds like woodpeckers in the green stand and in the immediate post-fire environment in the case of unplanned stand-replacing wildfires (Lehmkuhl et al., 2003).

Requirements of open-canopy species are equally important to consider when designing dry forest fuel reduction treatments. Many of these low-elevation dry forest species have been considered at risk due to the closing of dry forest canopies with fire exclusion, loss of large old ponderosa pine trees to logging, decline of herb and shrub understories from stand-canopy closure, and exclusion of low-intensity burns (Lehmkuhl et al., 1997; Wisdom et al., 2000). The white-headed woodpecker (*Picoides albolarvatus*) is typical of this environment, and is a focal species for dry forest management in the eastern Washington Cascade Range. Fuel reduction treatments could be tailored for this species to maintain or develop an abundance of mature pines that produce large cones with abundant seed (food) production, a moderately open canopy (50–70% cover), and the availability of snags and stumps for nest cavities (Garrett et al., 1996). Estimates of the range of variability for large-tree and snag habitat components could be used to guide fuels treatment prescriptions and restoration treatments (Harrod et al., 1998, 1999). White-headed woodpeckers are most abundant in burned or cut stands with residual large live and dead pine trees (Raphael and White, 1984; Raphael et al., 1987). Similar management would also create habitat for the flammulated owl (*Otus flammeolus*) (McCallum, 1994), a sensitive species throughout much the dry forests of western North America (Hayward and Verner, 1994).

3. Landscape-level planning

3.1. General approaches

General approaches to landscape-level planning of ecologically sound fuel treatments include coarse- and fine-filter approaches. A coarse-filter approach would use some definition of the historical or natural range of variability to define the composition and pattern that might reasonably be expected to sustain the forest ecosystem (Hunter et al., 1988; Landres et al., 1999; Hessburg et al., 1999). Guidelines for dry forest historical ranges of variation in the Pacific Northwest can be found in Agee (2003) and Hessburg et al. (1999).

Fine-filter species or community-oriented approaches often need to supplement coarse-filter approaches where threatened, endangered, or sensitive species conservation is of concern (Hunter et al., 1988; Haufler, 1999). Three general approaches can inform fine-filter analysis and development of fuel reduction treatments at the landscape level. Population viability analysis (PVA) (Gilpin and Soule, 1986) provides sound principles based on attributes of the species population structure, life history and behavior, and environment (habitat) for guiding fine-filter analysis. A particularly useful example is assessing the relative importance of habitat loss versus isolation of habitat patches, either natural or created by management (i.e., fragmentation), based on the life history of the species. Fahrig (1999), for example, showed the threshold for incurring deleterious habitat fragmentation, or patchiness, effects on habitat connectivity and population persistence generally occurs at higher percentages of habitat in the landscape for low-mobility species than for high-mobility species. Research publications can guide dry forest landscape management. Franklin et al. (2000) described landscape habitat patterns in which spotted owls in dry forests of northern California, where dusky-footed woodrats (*Neotoma fuscipes*) are primary prey that thrive in open forests, had greater fitness in landscapes that had neither too much or too little old forest habitat. Finally, fine-filter analysis can be informed by operational modeling of treatment alternatives. Extant models use single-goal optimization (Chew et al., 2004; Finney, 2004; Finney et al., 2006) or subjective criteria (Bettinger et al., 2005) to solve fuel allocation problems with ecological constraints. Our *FuelSolve* optimization model described below differs from others in this class by simultaneously considering both multiple optimization objectives for fuel treatment *and* ecologically important resources.

3.2. FuelSolve optimization model

An important ecological value is the maintenance of habitat for the northern spotted owl within and outside of late-successional reserves. Given that some primary or secondary owl habitat may be a target for fuel reduction treatments, fuel reduction and ecological objectives may conflict and limit the ability to treat fuels and restore dry forest ecosystems. An important question is: ‘‘For any given landscape is there an optimal solution(s) for both maximizing fuel reduction treatments (i.e., minimizing potential fire behavior) and maximizing the maintenance of spotted owl habitat?’’

FuelSolve is a prototype optimization program under development by our team that addresses that question. The primary goal of the project is to utilize multi-criteria optimization in the design of spatial patterns of silvicultural treatments that minimize fire damage to owl habitat and late-successional reserves. It attempts to minimize the amount of fuel treatments needed to maximize the retention of late-successional forest habitats from wildfire. It helps design and evaluate the amount and juxtaposition of fuel reduction treatments needed to reduce the risk of high-severity wildfire in late-successional habitats. Impacts on late-successional habitat are a focus of the model, but the model could be used for conservation of any ecological value that can be mapped, e.g., riparian areas.

3.2.1. Model structure and processes

FuelSolve is the integration of several executable programs: *lcpmake*, *flammap*, *randig* and *Pareto_evolve* (Fig. 1). The first three programs are tools for the simulation of fire spread and were provided by Mark Finney at the Fire Sciences Laboratory,

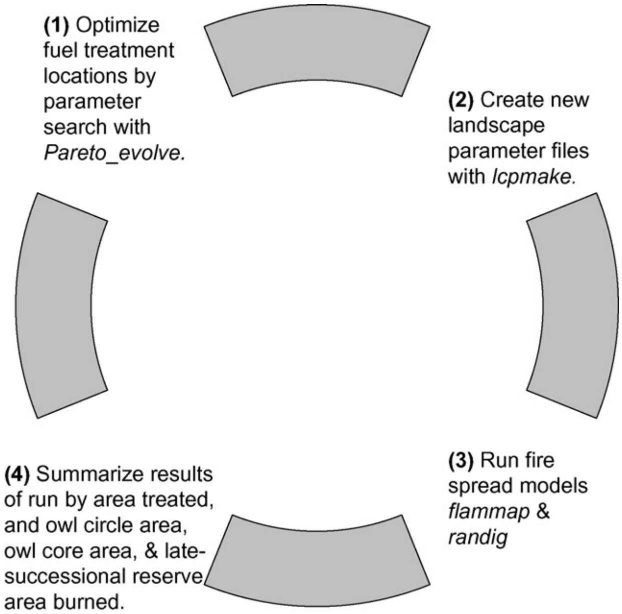

Fig. 1. Optimization procedure for *FuelSolve*. The project requires the integration of four software programs at different stages of the search.

Rocky Mountain Research Station in Missoula, Montana. The multi-objective optimization software *Pareto_evolve* was designed by the Ford lab at the University of Washington (http://faculty.washington.edu/edford/). It uses an evolutionary algorithm to search parameter values relative to performance on multiple objectives and find parameter sets that satisfy the objectives simultaneously (Reynolds and Ford, 1999). In the context of *FuelSolve* the objectives are related to the spread of fire to owl habitat and late-successional reserves balanced against the area treated to minimize the fire risk. The scale of application is for landscapes of <20,000 ha, i.e., for watershed-scale analysis.

Three types of data are required to run *FuelSolve*. Topography and vegetation data are used to define stands that are eligible for treatment and those that are not treated. At this initial stage of model development, we simulated a single intensive treatment that reduced canopy cover to 50%, canopy base height to 5.4 m, canopy bulk density to 0.03 kg m^3, canopy height to 30 m, and a surface fuel model (TL-1) of low flammability (Scott and Burgan, 2005). Maps define the location of the ecological resources to be analyzed: owl core areas, the larger owl management circles, and late-successional reserves (Fig. 2). Owl core areas and circles, which are official designations to regulate taking of habitat (US Fish and Wildlife Service, 1990), were defined as the area within 1130 and 2930 m, respectively, of owl activity centers active at least once between 2000 and 2004. Fuel characteristics were generated and mapped for the *flammap* fire model.

The basic optimization process requires four steps that occur in an iterative cycle until an optimal solution, or solution set, is found (Fig. 1). First, potential treatment allocations are generated by the *Pareto_evolve* program. Fuel parameter files for the *flammap* fire model are then generated using the locally developed *lcpmake* program. Fire behavior of each solution is evaluated using the *flammap* and *randig* programs. The *randig* program generates five ignitions randomly distributed across the area, then potential fire behavior is evaluated over a 4-day time period with *flammap*. The results of the fire modeling are evaluated for three fire impact objectives: fire occurrence within an owl core, owl circle, or late-successional reserve. The fourth objective evaluated is the total area treated. The performance of each treatment allocation relative to all the others is then assessed by *Pareto_evolve* and ranked using the concept of non-dominance and Pareto optimality (Cohon, 1978: p. 70). Based on those rankings new treatment allocations are generated and the model is called again to calculate new criteria. This process is repeated for a specified number of generations, and the result is the set of best-ranked allocations through the history of the search.

3.2.2. FuelSolve results

Initial results from the prototype *FuelSolve* runs with a single intensive fuel treatment and four objective criteria generated an optimal set of 50 potential treatment alternatives. Given four evaluation criteria, it was not possible to extract a single ‘‘best’’ solution. However, most solutions converged on two basic patterns that either minimized area treated at the expense of more owl habitat burned, or minimized owl habitat

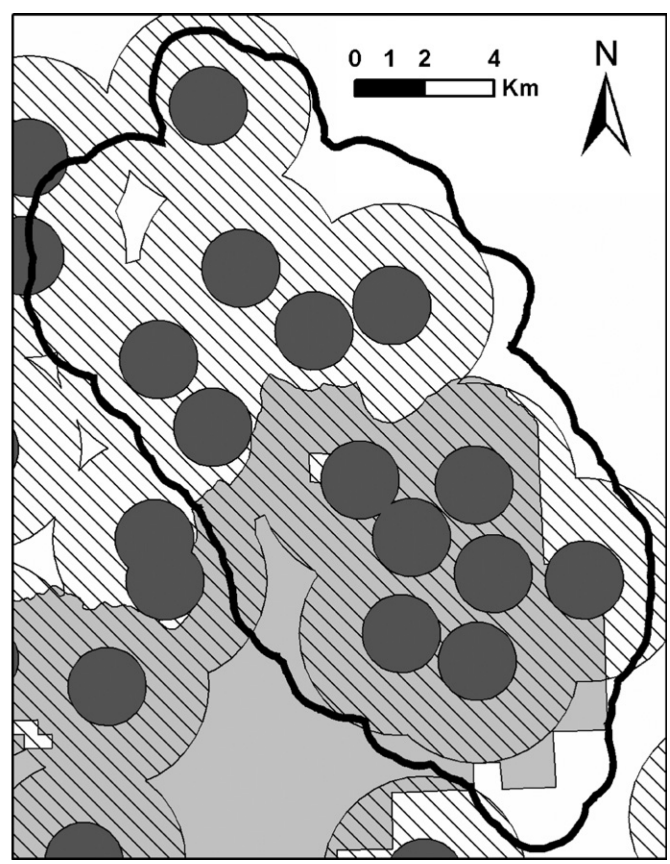

Fig. 2. Study area for optimization of fuel reduction treatments (bold line) and conservation of ecologically sensitive areas in the Mission Creek watershed, Washington. Ecologically sensitive areas are late-successional reserves (light gray), northern spotted owl core areas (dark gray), and the owl habitat management circles (hatched).

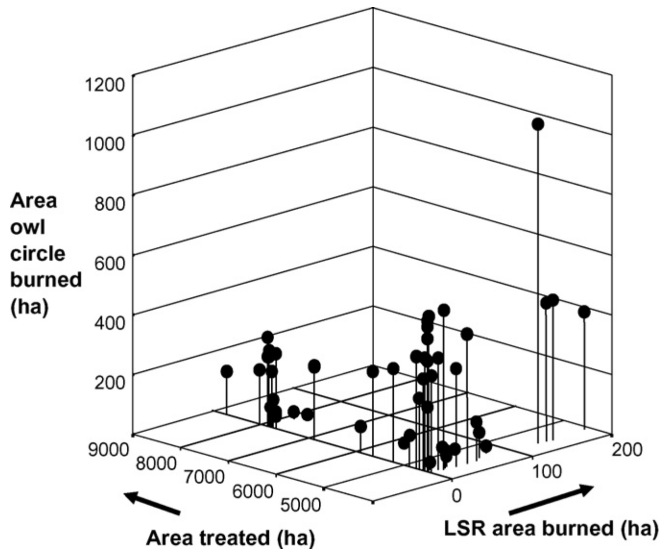

Fig. 3. Distribution of *FuelSolve* fuel treatment solutions relative to area treated for fuel reduction, area burned within northern spotted owl habitat circles, and area burned in late-successional reserves (LSR) in the Mission Creek watershed, Washington.

burned at the expense of more area treated (Fig. 3). Within each of the two groups, a largely similar set of stands was treated in the different solutions, with minor variation in stands included or not. The spatial distributions of stands across the landscape for the two groups appeared to be mirror images of each other, where stands treated in one group were unlikely to be treated in the other group solution.

Among all optimal solutions in the set, a median 22% (range 20–41%) of the area was treated (Fig. 4), which matches well with other optimal estimates of the minimum treatment area (~20%) required to minimize landscape fire behavior (Finney, 2001; Loehle, 2004; Finney et al., 2006). A median 1.3% of the area within spotted owl circles was affected by simulated wildfires (surface, understory, or crown fires) in optimal solutions (Fig. 4).

One potentially useful way to condense the solution set was to estimate the probability that a stand was treated in a solution (Fig. 5). Stands that had a >66% chance of being included in an optimal solution covered 24% of the area. This set of stands could be used as the basis for selecting a preferred project alternative. However, the high-probability stands are the pooled members of two different groups with contrasting solutions, as noted above; so, choosing stands from that particular pool would be a doubtful solution to designing a fire-resistant landscape. Future improvements on the *FuelSolve* prototype, however, may produce less contrasting solution sets, which may make the probabilities of treatment by stand a useful summary of the solution set.

As an alternative to using stand treatment probabilities, we identified *ad hoc* a "best" mapped solution by equally weighting all four objective criteria (values in the 50th percentile or greater). This solution was number 6 (Fig. 6) in the set, hence called *FuelSolve* (FS) 6. With FS 6, 22% of the total area was treated and 235 ha in owl circles potentially could burn by crown or understory fires, which approximated the

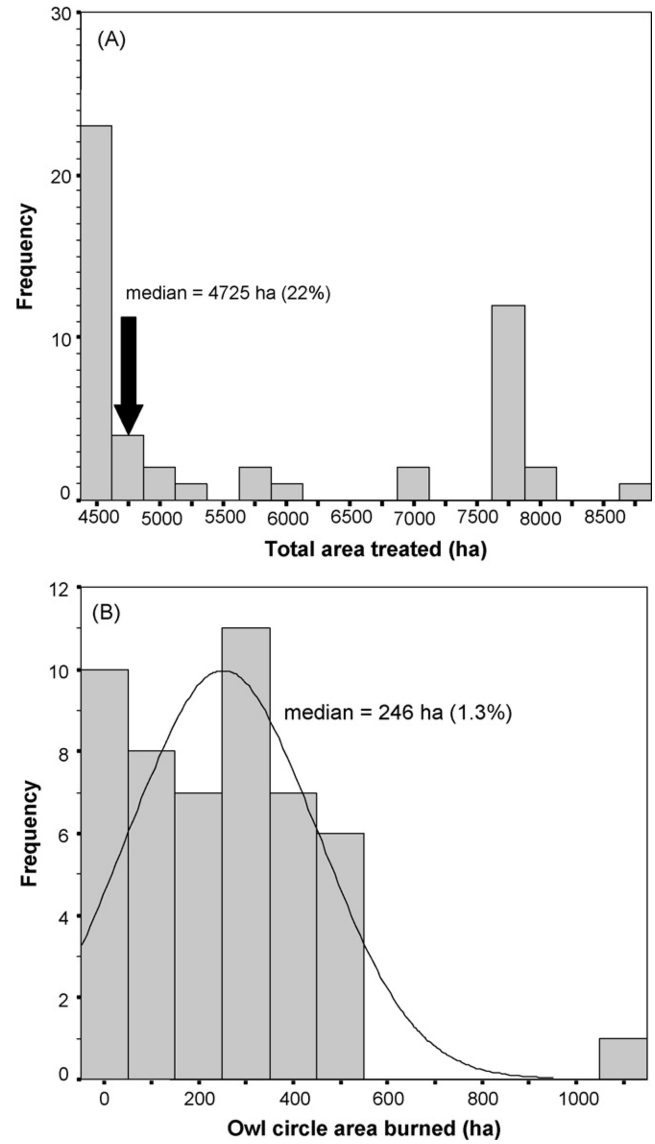

Fig. 4. The distribution of values for total area treated and area burned in northern spotted owl circles (area within 2930 m of owl activity center) among an optimal set of 50 landscape-scale fuel treatment solutions estimated by the *FuelSolve* program for Mission Creek, Washington.

median values of the solution set. Treatment was allocated proportionately among the forest cover types: about 67% of the treated areas was in open and closed ponderosa pine forest, 17% in Douglas-fir and grand fir forest, and the remainder in higher elevations. About 21% of the spotted owl nesting, roosting, and foraging (NRF) habitat was treated, with the remainder of the treated area in dispersal habitat and non-habitat stands.

3.2.3. Post-modeling evaluation

How does the FS 6 solution compare with fuel-reduction projects that might be designed by a fuels specialist on a Forest Service Ranger District? An initial evaluation of FS 6 revealed several differences in the way a person might manually allocate units across the landscape to achieve the same objective. *FuelSolve* treatment units were somewhat smaller than might be designed manually. Other logistical (e.g., access from roads,

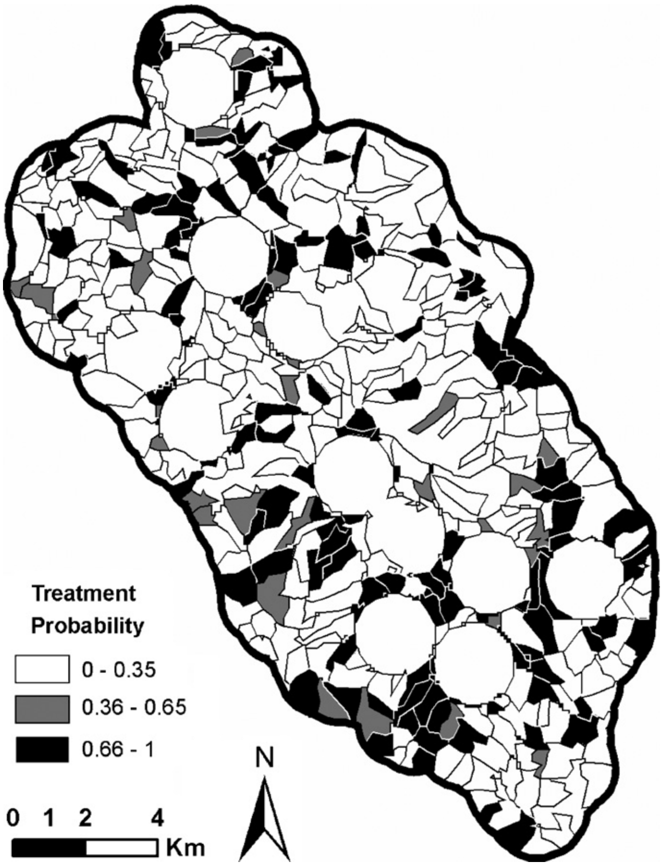

Fig. 5. Probabilities of stands being treated for fuel reduction within the optimal solution set ($n = 50$) of landscape treatment alternatives estimated by program *FuelSolve* for Mission Creek, Washington. Areas within northern spotted owl cores areas were not subject to treatment.

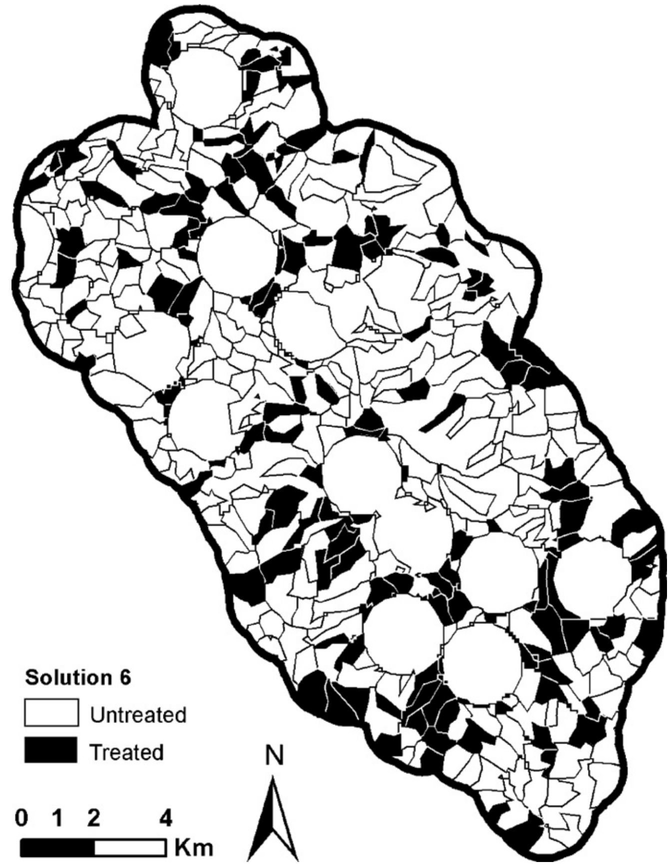

Fig. 6. Pattern of fuel treatment for *FuelSolve* Solution 6 in Mission Creek, Washington. Blank circular areas are untreated core areas around activity centers of northern spotted owls.

etc.) and associated cost considerations were not constrained in the *FuelSolve* selection procedure at this stage of development. All stands outside of owl core areas were eligible for treatment with *FuelSolve* for the prototype development; whereas, a person might rank available stands based on fuel model and associated risk, restoration priorities, or other objectives. Cost, management, and other ecological considerations could be incorporated relatively easily into *FuelSolve* model runs, and will be the basis for further development of *FuelSolve*.

Several improvements to *FuelSolve* have been identified during prototype development and from the above evaluation. Because it searches for optimal solutions among many iterations, the program takes days to run on a fast research computer. Four developments are planned to reduce processing time. Further work will be done on a parallel computer system at the University of Washington. The program operating system will be changed to UNIX, and the *Pareto-evolve* software will be optimized specifically for *FuelSolve*. Finally, the search criteria will be simplified by focusing on minimizing area burned in late-successional reserves and owl core areas. We anticipate that the solution set will be reduced from 50 to a smaller more workable set of solutions. Ultimately, *FuelSolve* run times will be improved, but using the program may require processing projects on a large computer versus a desktop computer application.

Other refinements of the prototype model and processing of outputs are suggested by our analysis. More realistic criteria could be used to model optimal treatment patterns. We plan to add a ''light'' surface-fuel treatment to model both the current intensive (surface plus canopy) treatment and the light treatment in future developments. The current model attempts to find the best way to reduce fuels and maintain spotted owl habitat by treating any forest stand in the watershed that is outside owl core areas. As shown in our evaluation, more realistic constraints for dry forest management, specifically, might be made by removing stands that are unlikely to be treated because of low fire risk (e.g., high elevations), that are low priority for restoration, or that are too costly to treat (e.g., steep slopes or distant from existing roads). Fire weather parameters might be varied to model the implications of different wind patterns in particular. To meet the needs of the users for environmental assessments, an explicit process is being developed to take *FuelSolve* solutions and evaluate the implications for changes in vegetation and fuel patterns, potential fire behavior, and wildlife habitat.

4. Summary

Restoring stable fire regimes to dry forest means restoring forest ecosystems, rather than just reducing surface and canopy fuels in the forest. Fuel treatment projects need to work at both stand and landscape levels to achieve multiple resource objectives. Although there is no single best prescription for success, mimicking natural patterns and processes provides a sound guiding principle. Other guidelines for ecological management can come from ecological theory and the literature. This would include natural history information for focal species, landscape design for biodiversity conservation, and application of natural range of variability theory to guide fuels treatments and forest restoration. Models, such as the *FuelSolve* optimization model, can help to design and evaluate treatment alternatives that integrate fuel management and ecological objectives. Ultimately, theory or models can never be specific enough to solve local problems, but they can inform the process by making assumptions and objectives explicit and by removing some subjective design criteria that may impede implementation in the field.

Acknowledgements

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