Cost Impacts of Management Alternatives to Achieve Habitat Conservation Goals on State Forestlands in Western Washington

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ABSTRACT: *An optimization approach to sustainable forest management that combines proactive habitat conservation practices and financial goals across an unzoned landscape outperforms a conservative, passive approach based on minimum management within large protective zones. The proactive approach simultaneously solves the land allocation and harvest scheduling problem whereas the passive approach allocates land to restricted uses and then sequentially schedules timber harvests. Proactive management increases asset values, improves intergenerational equity, stabilizes revenue flows, and provides better habitat—especially for species requiring old forest habitat conditions. The magnitude of these differences is very large in the case tested—the development of habitat conservation plans for state trust lands in western Washington. West. J. Appl. For. 15(4) 217–226.*

The Washington State Department of Natural Resources (DNR) manages approximately 1.65 million ac of Washington State forestland within the range of the northern spotted owl. About 1.43 million of these acres lie in western Washington. In 1996, the DNR proposed a Habitat Conservation Plan (HCP) containing mitigation strategies for incidental take permits for two federally listed species—the northern spotted owl and the marbled murrelet (DNR 1996). The HCP also proposed conserving habitat for unlisted species, such as several salmonids, other state and federal candidate species, and other species. The plan also requested incidental take permits for seven upland species listed as threatened. In large part, these species live in habitats that are adjacent to DNR-managed lands or will be protected by the conservation of habitats under the proposed HCP.

The DNR is empowered by the Washington State Legislature to manage and regulate activities on the federal grant trust lands. As trust land manager, the DNR must adhere to the same common law principles of trust management that apply to private trusts. These principles include: (a) maintaining undivided loyalty and full disclosure to the trust beneficiaries, (b) making the trust productive while generating income for the beneficiaries, (c) dealing with the beneficiary in an open, fair, and honest fashion, (d) administering the trust while keeping and rendering accounts, (e) exercising reasonable care in managing the trust, and (f) preserving and protecting the trust in perpetuity (Souder and Fairfax 1996, Gregoire 1996, DNR 1992). Undivided loyalty means that trust assets may not be used to pursue other state goals no matter how laudatory they may be. It also implies that trust beneficiaries receive fair market value for the use or sale of trust assets. State courts have generally upheld these principles so long as all applicable state and federal laws are satisfied. See Gregoire (1996) and DNR (1992), Appendix C, for examples of specific legal rulings.

Developing an HCP for forest trust lands requires a careful balance of fiduciary responsibilities against legally mandated environmental and conservation objectives while satisfying all applicable state and federal regulations—including the trust principles listed above. Further, an HCP needs to be in the best interests of each individual trust and not simply the consolidated set of trusts covered by the plan. An opinion by the Washington State Attorney General concludes that the state's duties as trustee run separately to each of the trusts

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(Gregoire 1996). A consolidated land management plan such as an HCP is permissible when its serves the interests of each trust. However, the trustee may not manage trusts such that one trust benefits at the expense of another.

As part of its HCP planning effort, the DNR undertook an economic analysis of several HCP alternatives. A 1995 critique stated that the DNR analysis was insufficient to conclude that the proposed HCP was the best way to reach the intended conservation goals (Bare et al. 1995). DNR's economic analysis was not structured to look for management alternatives that satisfied conservation goals at the lowest cost to the trust beneficiaries. It incorporated a nondeclining timber harvest flow policy without considering more flexible allowable alternatives, and it identified large areas of forestland as passively managed reserves. In addition, comparisons of the HCP alternatives to a "no change" alternative were invalid because no meaningful baseline assessment existed against which the proposed HCP option could be compared. Costs of habitat protection embedded in the "no change" alternative were ignored in such a comparison. Neither the "no change" baseline economic analysis nor the HCP alternatives were performed at the individual trust-level, an apparent inconsistency with the Attorney General's opinion (Gregoire 1996). See Bare et al. (2000) for a detailed discussion of this issue. Lastly, the DNR approach involved a sequential analysis wherein major land allocation decisions were made before harvest scheduling was undertaken. As described by Johnson and Davis (1987), such an expedient approach is inferior to a simultaneous formulation that jointly searches for the best land allocation and harvest scheduling solution.

The nondeclining flow interpretation of sustained yield incorporated in the DNR HCP alternatives appears to go well beyond the statutory definition embodied in RCW 79.68.030 where sustained yield is defined as, "management of the forest to provide harvesting on a continuing basis without major prolonged curtailment or cessation of harvest." In June 1995, an Independent Review Committee concluded that,

> DNR's even-flow policy, as presently construed, may unduly inhibit DNR's ability to generate revenues on behalf of trust beneficiaries.

The committee stated that,

> ...in our view the even-flow policy may very well conflict with the trustee's fiduciary obligation to the beneficiaries.

Overly restrictive interpretations of the sustained yield statute become even more onerous when habitat conservation constraints are introduced. Lastly, management flexibility and trust asset values are further compromised due to an excessive stratification of the forestland base. The DNR HCP identifies six planning units within western Washington for which a nondeclining harvest was developed. In determining the final sustainable harvest for western Washington under the HCP, nondeclining harvests were determined independently for 23 separate geographical planning units in western Washington. These planning units do not coincide with trust ownership boundaries. In this article, as for the DNR HCP, all analyses are conducted and reported in a "trust-blind" fashion. As reported earlier, this is an apparent contradiction of the Attorney General's opinion (Gregoire 1996).

Objectives

Believing that more cost efficient alternatives exist to the DNR HCP, we examine an alternative approach to the DNR HCP planning process for achieving habitat conservation objectives for western Washington State forest trust lands. Our approach simultaneously provides increased financial benefits to trust beneficiaries while searching for management alternatives that satisfy various target levels of multispecies habitat protection and harvest flow constraints on a sustainable basis. This is accomplished using a linear programming model that simultaneously allocates land and schedules proactive habitat conservation management treatments while maximizing the asset value of the trusts.

The basic premise of our analysis is that trust fiduciary responsibilities and multispecies habitat goals can be best met through a combination of proactive management on unzoned landscapes managed for the production of both habitat and timber value. This contrasts with the DNR HCP that involves extensive unmanaged set-asides or special emphasis areas established for particular species in combination with passive management. These two land management philosophies have different effects on financial returns to the trust beneficiaries as well as on the amounts of habitat produced over time.

The central issue raised concerns the fiduciary responsibilities of a trustee in managing trust assets to achieve conservation objectives under existing law. The proposed modeling framework uses existing resource data, measures of habitat, and stand structures. This information is integrated in an optimization framework that seeks to find the set of management alternatives that maximize financial returns while simultaneously satisfying habitat conservation, environmental, and timber harvest flow constraints (see Appendix 2). No new biological definitions or habitat measures are created. By adopting a more flexible approach to management, the study demonstrates that alternatives exist to the DNR HCP that produce higher financial returns for the trusts, are sustainable, and produce as much, or more, suitable habitat.

Existing Literature and Background Theory

The science of forest management planning was greatly advanced when linear programming was first applied in the early 1960s. Johnson and Scheurman (1977) produced the seminal work of their time by developing a unifying framework that included Model I and II timber harvest scheduling algorithms. More recently, Garcia (1990) and Gunn (1991) updated and extended this framework to include Model III. Other well known linear programming models are FORPLAN (Johnson et al. 1986), FOLPI (Garcia 1984, Manley et al. 1991), and JLP (Lappi et al. 1994). Davis and Johnson (1987) and Leuschner (1990) provide extensive discussions of linear programming and its uses in forest resource management planning. Our Model I linear programming optimization formulation is defined in Appendix 1.

Davis and Johnson (1987) discuss the pros and cons of sequential vs. simultaneous land allocation and harvest scheduling analyses. They conclude that the simultaneous approach is superior to the sequential approach. However, they also acknowledge that the latter approach is often used in practice because it is easier to implement, easier to understand, and keeps model size manageable.

The development of habitat conservation and ecosystem management plans is changing the way forest planning is accomplished. Cortner and Moote (1999) discuss the shift from utilitarian-based sustained yield resource management to ecosystem management, where more emphasis is placed on biodiversity, ecosystem protection, and attaining future desired states than on resource outputs. They also stress the social and political dimensions of ecosystem management. As discussed above, the development of habitat conservation management plans for state trust lands presents unique challenges because any plan must be in the best interests of trust beneficiaries, adhere to trust management principles, and satisfy all applicable laws.

Habitat conservation, as epitomized in the plan to protect the northern spotted owl on federal lands in Washington, Oregon, and northern California, is based on the premise that unmanaged reserves provide the most effective strategy (FEMAT 1993). Largely unrecognized is the large opportunity cost, incurred by present generations, in pursuit of this strategy and the opportunities forgone to dynamically produce habitat across the landscape by adopting proactive forms of management (Oliver 1998, Carey 1998). Under a proactive approach, ecosystem management becomes sophisticated instead of simplistic. Using linear programming to simultaneously examine land allocation, calculate harvest schedules, generate habitat, and attain conservation objectives provides an opportunity to move in this direction.

Financial Approach to Habitat Conservation Planning

To demonstrate how financial performance changes under different stand treatment combinations, a set of proactive management treatments of sufficient diversity is examined. Each management treatment defines a set of possible management actions that can be assigned to any land type (i.e., a grouping of timber stands of similar character) and includes both naturally stocked and artificially regenerated managed stands. The management treatments examined include: (a) unmanaged existing natural stands converted upon harvest to an artificially regenerated 1-thin commercial thinning regime; (b) unmanaged existing natural stands converted upon harvest to an artificially regenerated 2-thin or 3-thin fast biodiversity regime; (c) a single partial cut in an existing natural stand converted upon harvest to an artificially regenerated stand as in either (a) or (b); (d) existing artificially regenerated managed stands retained in a 1-thin commercial thinning regime; (e) existing artificially regenerated managed stands converted upon harvest to either a 2-thin or 3-thin fast biodiversity regime, and (f) unmanaged natural existing stands set aside as reserves without management. These stand treatments are used for all acres contained in the upland land type. For the riparian land type, a partial cut sequence involving a continuous overstory and understory with natural regeneration is applied. Infrequent entries are assumed to avoid higher hydrologic risks than natural disturbances. Biodiversity regimes, which accelerate the development of old forest structures, are modeled after treatments developed in the Washington Forest Landscape Management Project economic analysis (Lippke et al. 1996).

Management treatments are combinations of silvicultural regimes and timing choices that produce different stand conditions over time. These conditions generate the parameters that indicate stand structure type, habitat class, habitat index, timber volume, and timber quality. DNR empirical timber yields are used for natural existing stands (Chambers 1974, 1980, Chambers and Wilson 1978), and DFSIM simulations (Curtis et al. 1981) are used to project silvicultural treatments for artificially regenerated future managed stands. Output information, such as trees per acre, snags per acre, tree diameter, tree height, merchantable volume per acre, woody debris per acre, and so on, is integrated with snag and woody debris strategies. Bare et al. (1997) describe the growth and yield simulations and the development of snag and woody debris strategies. This information provides the source data for the economic and biological habitat analyses.

For each management alternative, we estimate log volumes by log grade. Log grade values are based on a snapshot of prices between 1988–1992 (expressed in 1996 dollars). Deduction of log and haul costs produces an average stumpage value of $402/mbf for a 14 in. diameter stand. This value is approximately on the 25 yr trend line for DNR stumpage. Stumpage prices and logging costs are also indexed to increase 1%/yr (real), consistent with assumptions used in the DNR HCP. Timber and log volumes and prices are adjusted to reflect species mixes and woody debris and snag leave-behind strategies.

Habitat classes are defined for: northern spotted owl old forest, submature and young forest marginal, and dispersal, as well as non-spotted-owl habitat (Washington Forest Practices Board 1996). Marbled murrelet habitat is used as a distinct but overlapping category. The following eight stand structure classes, as defined by the Washington Forest Landscape Management Project (Lippke et al. 1996), are used: Ecosystem Initiation, Competitive Exclusion, Understory Re-initiation, Developed Understory, Botanically Diverse, Niche Diverse, Fully Functional, and Old-Growth (Carey et al. 1996). The combination of the last four stand structures defines the late seral class. Three multispecies habitat indices are also defined as a function of stand structure classifications (Carey et al. 1996). These three indices are consistent with the Washington Forest Landscape Management Project and are labeled ecosystem productivity, vertebrates, and forest floor.

Timber harvest flow constraints avoid excessive operational harvest volume changes that could incur increased costs. Nondeclining flow, used exclusively by the DNR, represents only one of the flow options examined. It leads to NPV reductions relative to more relaxed flow constraints that are consistent with the historical variation in harvest volume. Additional goals are developed as constraints on habitat classes and habitat indices to reflect various habitat conservation strategies across the landscape. Examples of such constraints include: (a) requiring a certain number of acres in given habitat classes to be present, (b) requiring timber harvest volumes not to fluctuate excessively over time, or (c) requiring specific percentages of the forest to be in given structural classes by a specific time period (see Appendix 2 for details).

A linear programming model is developed to select the optimal treatment schedule. The objective is maximization of net present value (NPV) using a 5%/yr (real) discount rate over all land types, thereby producing harvest volume, revenue, stand structure, habitat class, and habitat index schedules by decade over a 100-yr planning horizon. The linear programming model (see Appendix 2) is formulated using the AIMMS modeling language and solved using the CPLEX 4.0 solver (Bisschop and Entriken 1993).

For all analyses, riparian/wetland and upland land type acres are aggregated into 10 yr age classes that range from 0 –100+ yr, with an additional class representing 150+ yr of age. This aspatial representation is adequate to analyze and evaluate strategic goals. Tactical plans, developed over shorter planning horizons with additional spatial resolution, are assumed to follow. Bare and Liermann (1994) review modeling studies that link strategic, tactical, and operational levels of planning. They caution against excessive spatial constraints in strategic models, but endorse the concept of hierarchically linked models—each designed to address issues that arise at different levels of temporal and spatial resolution.

DNR'S Characterization of Forestland Base

The DNR prestratified the 1.43 million ac state forestland base in western Washington into 1.16 million ac that are harvestable and 0.27 million ac that are unharvestable. Within each of these classes, lands were further classified into the following zones: riparian; wetland; unstable slope; owl nest sites; owl nesting, roosting and foraging; owl dispersal; and marbled murrelet. Acres in these zones were allocated as shown in Table 1. Because these categories are not mutually exclusive and because acres not contained within one of these zones are not shown, they do not sum to 1.43 million ac. To retain comparability between the DNR analysis and our examination of alternatives, we retained their system of land classification. In the policy alternatives examined below, the number of acres contained in the various zones are shifted to reflect the intent of the alternative.

Table 1. DNR's base characterization of western Washington forestland base (ac).

Land class	Harvestable	Unharvestable
Riparian	131,618	48,522
Wetland	16,771	3,913
Unstable slopes	0	142,375
Owl nest sites	0	20,206
Owl nesting, roosting and foraging	104,322	38,855
Owl dispersal	96,336	19,553
Murrelet	0	20,309

NOTE: The total harvestable area in western Washington is 1.16 million ac and the total unharvestable area is 0.27 million ac. Because the zones shown above are not mutually exclusive and because harvestable and/or unharvestable acres not contained within one of these zones are not shown, the acres do not sum to the given totals.

Description of Policy Alternatives

Three alternative policies are examined:

1. *A low constraints baseline analysis.* This is the reference run for comparing all other policies. This run represents pre-spotted-owl Washington Forest Practices Act rules with riparian buffers on class type 1–3 streams. These streams are greater than 2 ft wide containing significant fish populations and habitat for many fish species such as coho, steelhead, and resident game fish. In all alternatives, harvest volume reductions are imposed to represent green tree retention on harvest units, greenup of adjacent harvest units, defect/breakage, and mensuration adjustments. These vary by management alternative but range from 16–26% of the standing volume. This run is used as the baseline in order to measure the opportunity costs of increasing habitat conservation and environmental goals.

2. *Simulation of the 1996 DNR HCP.* We formulate a linear programming model to simulate the strategy adopted by the DNR HCP. We use our log price assumptions, timber yields, and silvicultural costs to maintain comparability with ALTS. This run represents the strategy used in the DNR HCP. A total of 390,552 ac are classified as unharvestable in Run II. This constitutes 27% of the western Washington forestland base and illustrates the magnitude of the DNR's prezoned set-aside policy for achieving conservation objectives. A series of interim runs to assess the impact of various individual features embedded in the DNR HCP are also undertaken [see Bare et al. (1997) for details].

3. *Proactive alternative analysis (ALTS).* This demonstration run assumes an unzoned landscape and searches for the maximum NPV subject to meeting the habitat conservation goals produced by the DNR HCP. While ALTS uses an unzoned forest and minimum set-aside acres, it meets conservation goals through habitat constraints and the use of proactive biodiversity regimes. A total of 42,833 ac are classified as unharvestable in Run III—3% of the western Washington forestland base. These non-trust-land acres are located on Natural Resources Conservation Areas or Natural Area Preserves where no harvesting is permitted. A detailed description of these policy formulations is contained in Bare et al. (1997). Summaries of zonal acreage allocations for all policy alternatives are shown in Appendix 1.

The output from each policy run was evaluated for the impact of harvest flow constraint rigidity. Comparisons of a loose constraint that allowed a ± 25% fluctuation between successive decades as a representation of recent historical experience, a tighter ±10% change allowed between successive decades as a conservative operational

Table 2. The net present value for three policy alternatives

Run #	Description	Net present value ($ billions) Harvest flow constraints ±25%	±10%	NDF*
I	Baseline	15.85	15.14	13.91
II	Simulated DNR HCP	9.87	9.58	8.80
III	Alternative management (ALTS)	13.49	13.31	12.57

* NDF = Nondeclining harvest flow

constraint, and strict nondeclining flow between successive decades are shown.

In the three policy alternatives, the entire western Washington forest area of about 1.43 million ac is treated as a single planning unit. This recognizes that the largest area under constrained management will generally result in the greatest collective benefit to the trust beneficiaries. This limits our ability to prescribe habitat in specific locations unless it is in a set-aside such as a riparian management or spotted owl zone. However, region-specific habitat constraints can be imposed without expecting significant losses so long as harvest flow constraints are not binding within small planning areas. In the simulated DNR HCP, the use of six planning units in western Washington reduced the net present value 5% relative to the use of one unit.

Data limitations prohibit analysis of the policy alternatives on an individual trust by trust basis. Thus, neither the DNR HCP nor any of the runs defined herein are carried out at the level of geographic detail recommended by the Attorney General (Gregoire 1996). Examination of this issue is beyond the scope of this article, but interested readers may consult Bare et al. (2000). In addition to discussing the issue, they describe a procedure for assuring equitable treatment of individual trusts under a collective management plan such as an HCP.

Results of Policy Alternatives

Table 2 compares the estimated asset values of the western Washington state trust lands that result from application of the optimization model. The simulated DNR HCP (Run II) has low values relative to both the pre-spotted-owl regulations (Run I) and the optimized ALTS alternative (Run III). A loss in NPV of $5.56 billion relative to a low constraints baseline (Run I) is shown. The low constraints baseline (Run I) includes reductions caused by green tree retention requirements, greenup of adjacent harvest units, and buffers on class 1–3 streams but no spotted owl or marbled murrelet habitat requirements.

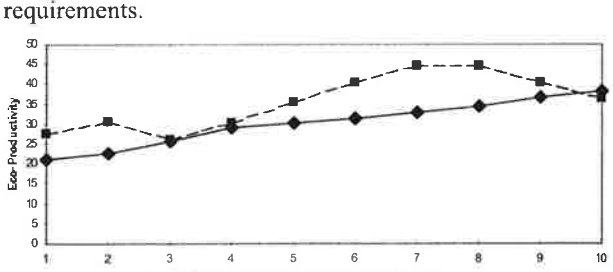

Figure 1. Ecosystem productivity index comparisons for the simulated DNR HCP and ALTS

Imposing DNR's assumption of nondeclining flow for the simulated HCP, when compared to the historically realistic ±25% fluctuation, causes the NPV loss for the HCP to increase to $7.05 billion. About $1.9 billion of this loss is caused by the restrictive harvest flow constraint rather than costs of increased habitat requirements.

The DNR HCP relies on a combination of prezoned conservation set-asides and harvest restrictions related to passive management treatments that are almost as severe as set-asides. This is a costly nonoptimized sequential approach. Run III (ALTS) allows proactive management treatments that accelerate the creation of desired habitat. This greatly reduces the cost of providing habitat through rigid habitat set-asides that have no ability to generate revenue from harvesting. Further, recognizing that forest structure is dynamic and manageable, ALTS produces asset values that are about 40% greater than those of comparable simulated DNR HCP alternatives.

The present value losses shown in Table 2 reflect only financial tradeoffs measured against the improved attainment of conservation goals. Figures 1 and 2 compare measures of biological performance over time. The ecosystem productivity habitat index (Figure 1) characterizes the quantity of the fruits of the forest and hence the food chain for species that do well in late seral forests. It provides a good multispecies index for the spotted owl and other species dependent upon late seral structures (Carey et al. 1996). The percentage of acres in late seral structures (Figure 2) also provides a good measure of biological diversity and multispecies habitat. Comparisons for all of the measured habitat classifications and indices are provided in Bare et al. (1997).

Figures 1 and 2 show that ALTS (Run III) produces at least as much habitat as the simulated DNR HCP (Run II). The ecosystem productivity index under ALTS is generally 25% higher than under the simulated DNR HCP. The acreage of late seral structures under ALTS rises by the sixth decade to twice as high a level—the target for reaching 25% late seral structures under ALTS. The tradeoff between financial loss and increased habitat acreage is not as straightforward as it first appears. The HCP strategy is financially much less efficient than ALTS in producing the same amount of habitat. There are almost certainly other alternatives that can produce better habitat at lower cost than the simplistic zoning approach embedded in the DNR HCP.

The spatial location of some habitat is not as narrowly confined under ALTS as it is under the DNR HCP. This is

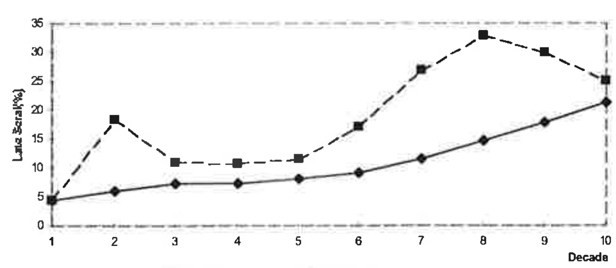

Figure 2. Late seral structure comparisons for the simulated DNR HCP and ALTS

appropriate because in a long-term habitat program, it is more efficient to manage for a dynamic diversity of forest structures than to maintain existing spatial patterns. Existing allocations will change over time. More importantly, they are designed mainly to provide habitat for a single species such as nest sites for owl or murrelet, and ignore the broader management objective of biodiversity.

ALTS does not maintain spatial features to the extent in the DNR HCP. ALTS does recognize a similar age class inventory structure for unstable slopes, riparian and wetland zones, and owl nests as does the DNR HCP. Under ALTS, partial cuts are allowed in riparian and wetland zones instead of de facto preservation as assumed by the DNR. Thus ALTS provides both biological and financial advantages on the same acres that DNR places in set-aside buffers. On unstable slopes, ALTS considers increased costs for operations rather than no entries as proposed by the DNR. ALTS retains 23% of the acres identified by DNR as owl nest sites in unharvestable acres. They are the same tracts as protected in the DNR HCP and could be assigned to a map in an operational plan.

Other suitable habitat (i.e., owl nesting, roosting and foraging; owl dispersal; and murrelet habitat) is not spatially constrained by ALTS over the remaining acres (and stand structures). However, it should be possible to operationalize ALTS while retaining more spatial adjacency requirements (such as proximity to federal forests). But, harvest flow constraints cannot be apportioned to these same smaller land areas. ALTS allows more substitution of acres with similar characteristics than is possible under the DNR HCP primarily because ALTS does not force nondeclining flow constraints on small planning units. There will not be significant costs of locating habitat in specific locations as long as substitution is possible across acres within the broader region. Adaptive operational plans can be more specific spatially without introducing excessive costs.

Intergenerational Equity Considerations

Combining nondeclining flow and prezoned habitat conservation constraints causes a substantial NPV loss associated with DNR's HCP. Nondeclining flow constraints may create stable revenue flows where the age-class structure is fairly uniform and the size of the acreage being managed is relatively large. Imposing additional habitat constraints and subdividing the forest into small planning units cause the problem to be over specified such that mutually conflicting constraints reduce outcomes. Figure 3 compares the simulated DNR HCP and ALTS. The intergenerational revenue flow stability (as measured by the coefficient of variation of decadal revenues) under ALTS is only slightly larger than that under the simulated DNR HCP [the exception is under nondeclining flow (NDF)]. The NPV associated with ALTS is always larger than that for the simulated DNR HCP. The last 2 decades of the 10 decade period are omitted to reduce any truncation errors, but the result is clear. There is a large price paid for timber flow constancy.

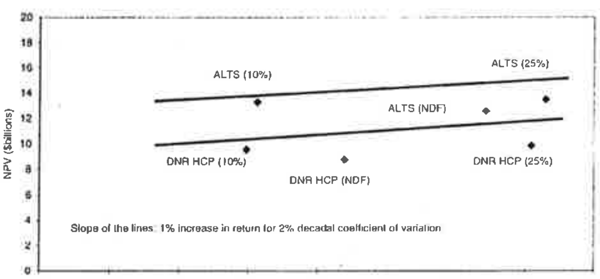

Figure 3. Coefficient of variation of decadal revenue flow for the simulated DNR HCP and ALTS.

The coefficient of variation of the mean DNR HCP revenue for the first 8 decades under nondeclining flow is 22 vs. 16% for ALTS with ±10% harvest flow constraints. And, as shown in Figure 4, ALTS generates $240 million more revenue per year in the first decade. In both the ALTS and simulated DNR HCP alternatives, ±10% harvest flow constraints produce more revenue stability than do nondeclining flow constraints. The simulated DNR HCP produces significantly lower returns to current generations relative to future generations. In ALTS (±10% harvest flow constraints), more revenue is generated in all 8 decades.

Nondeclining harvest flow does not maintain intergenerational equity. At best, the DNR can stabilize sales but not harvest flows and the subsequent generation of revenue. By stabilizing sales in fluctuating markets, timber is withheld from good markets and forced into poor ones generating lower total returns. DNR's sales strategy in the 1970s and 1980s allowed short-term fluctuations up to ±25% from year to year. This allowed DNR to match harvest activity to market cycles —thereby increasing the value to the trusts without contributing to intergenerational inequities.

The harvest level determined for the first decade under the DNR's HCP is linked to neither the actual sale level from the previous year nor the sustainable harvest level from the prior nondeclining flow analysis. As a result, the DNR HCP causes a major departure that reduces intergenerational stability and the predictability that many beneficiaries seek. Any serious attempt to provide intergenerational revenue stability or habitat availability should look beyond harvest flow constraints to fiscal procedures that maximize returns. Revenue excesses over the strategic plan's long-term average could be placed in a diversified stock portfolio for future use. Revenue stability could be achieved at a low harvest opportunity cost for individual trusts using a diversified portfolio. Before this can be done, the Washington State Constitution needs to be amended.

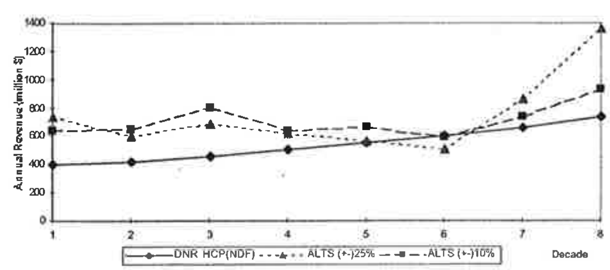

Figure 4. Revenue flow for the simulated DNR HCP and ALTS.

Identifying the Differences

Lower NPV for the simulated DNR HCP relative to ALTS is caused by: (1) set-aside acreages identified as unstable slopes with no harvest (7%), (2) increased riparian acreages over that for type 1–3 streams with essentially no harvest (11%), (3) treating owl nests as unharvestable while providing a substantial area of suitable owl nesting, roosting and foraging (NRF) habitat (9%), (4) treating murrelet habitat as unharvestable (5%), (5) too passive and too costly silvicultural treatment options to create habitat (11%), and (6) excessively constrained NDF harvest flow constraints (13%).

The estimated NPV impacts cited above are not independent and assume ±10% harvest flow constraints for ALTS. The share of each impact will differ if they are developed in a different order. However, the cumulative total will not change. Not included above is the NPV loss of 9.5% caused by riparian buffers on class type 1–3 streams, harvest volume reductions for green tree retention on harvest units, and the greenup of adjacent harvest units. When these are considered, they bring the cumulative regulatory NPV impact to 50%. When defect/breakage and mensuration adjustments are added in, the total impact rises to 55%.

Cost Effectiveness in Reaching Habitat Goals

The widely varying NPV losses across policy alternatives suggest that some alternatives meet habitat conservation goals much more efficiently. This can be measured by calculating the dollar loss to produce one unit of a particular habitat class. The late seral indicator is the best measure for old growth dependent species. Table 3 analyzes the dollar loss for each 1% increase in late seral structures by the fifth and ninth decades. ALTS is five times more cost effective than the simulated DNR HCP in supporting late seral goals by the fifth decade and seven times more efficient by the ninth decade. Since ALTS achieves a larger increase in late seral as well and the unit cost would increase as the late seral target is set higher, ALTS may well be even more cost effective than shown.

Conclusions

This analysis has demonstrated that financially preferred policy alternatives exist to the DNR HCP. This is largely the result of using an optimization formulation that combines proactive habitat conservation practices and financial goals to simultaneously solve the land allocation and harvest scheduling problem. This approach outperforms a conservative, passive approach where land is preallocated to large protective zones, followed sequentially by determination of timber harvest schedules. The proactive approach produces as least as much multispecies habitat with much less financial loss to the trusts.

DNR relies on nondeclining flow harvest constraints to produce intergenerational equity. These constraints are not required by statute. The above analysis demonstrates that they do not contribute to intergenerational equity or short term stability. Nondeclining flow does, however, cause substantially lower asset value to the trust beneficiaries. It is a high cost specification that does not achieve its goals. Relaxed harvest flow constraints produce greater intergenerational equity and stability with higher financial returns.

Given the substantial financial losses associated with the DNR HCP, it is unlikely that the HCP can produce a higher expected NPV than by managing under no HCP even assuming increasing conservation standards over time. However, since the ALTS losses are not significantly larger than the current minimum standards, a risk analysis would probably support adopting an ALTS-like strategy as the basis for an HCP to reduce future risk.

The optimization methodology demonstrated herein is consistent with the best science that can be used to develop an alternative to the DNR HCP. An optimized alternative substantially increases returns to the trusts collectively and probably individually. The demonstration does not have the same spatial detail as in the DNR HCP. Tactical modeling can augment spatial detail. The demonstration does provide substantial insight into the biological and financial implications of alternative policies. This is an essential part of the analysis that is necessary to evaluate whether the plans are efficient and in the best interests of the trusts.

The optimized alternatives are shown to produce superior habitat in almost every respect to that provided in the traditionally zoned and overconstrained DNR HCP. This demonstrates the advantages of adopting a proactive approach to management utilizing biodiversity regimes and less reliance on prezoned reserves. The strategies demonstrated herein form a basis for further negotiations with regulators if a revised HCP is pursued. This, unfortunately depends on the regulators having a more sophisticated understanding of ecosystem dynamics than is revealed in contemporary regulations.

Table 3. Economic efficiency for increased late seral (LS) habitat.

		Cost /1% LS increase (million $)		Late Seral % increase (million $)	
Run	Description	5th decade	9th decade	5th decade	9th decade
II	DNR HCP (NDF)	941	540	8	18
III	ALTS (± 10%)	182	77	12	30

NDF = Nondeclining harvest flow.
± 10% = The allowable percentage change in harvest volume from one decade to the next.

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APPENDIX 1 Description of Policy Alternatives

This table contains the acreage assumptions used for the three alternatives as well as the rationale for each run.

Run identifier	Description of run	Planning area	Management units	Harvest flow constraints	Habitat constraints	Riparian	Wetlands	Unstable slopes	Owl nest	NRF zone	DSP zone	MM (ac)	
I	Baseline	One westside	All upland and riparian combined into 10 yr age classes	±25%, ±10%, NDF	None	131,618	16,771	135,541	15,862	135,909	115,534	19,415	harvestable
						48,523	3,913	6,834	4,344	7,268	355	893	unharvestable
						180,141	20,684	142,375	20,206	143,177	115,889	20,308	total
								Total on base	1,356,227				
								Total off base	69,867				
								Total	1,426,094	(these acreages account for overlaps)			
II	Simulated DNR HCP	One westside	All upland and riparian combined into 10 yr age classes	±25%, ±10%, NDF	None	0	0	0	0	104,322	96,336	0	harvestable
						180,141	20,684	142,375	20,206	38,855	19,553	20,308	unharvestable
						180,141	20,684	142,375	20,206	143,177	115,889	20,308	total
								Total on base	1,035,542				
								Total off base	390,552				
								Total	1,426,094	(these acreages account for overlaps)			
III	ALTS	One westside	Separate upland and riparian 10 yr age classes	±25%, ±10%, NDF	Yes[1]	176,792	20,121	135,541	15,862	135,909	115,534	19,415	harvestable
						3,349	563	6,834	4,344	7,268	355	893	unharvestable
						180,141	20,684	142,375	20,206	143,177	115,889	20,308	total
								Total on base	1,383,261	(189,223 riparian + wetlands; 1,194,038 uplands.)			
								Total off base	42,833				
								Total	1,426,094	(these acreages account for overlaps)			

NOTE: Table shows how DNR's zonal acreage allocations (see Table 1) are treated in each run. No accounting for overlapping acreages made in his table. NRF = Nesting, roosting and foraging; DSP = Dispersal habitat; MM = Marbled murrelet habitat.

[1] At least 73,381 ac of old forest suitable spotted owl habitat required per decade. At least 71,589 ac in submature and young forest plus old forest suitable spotted owl habitat starting in decade 1, increasing 21,270 per decade until decade 6, when a total of 177,939 are required. At least 57,945 ac in dispersal spotted owl habitat are required per decade. At least 20,308 ac of marbled murrelet habitat are required/ decade. A target of at least 25% of the forest acres in late seral stand structure classes by the end of the 100 yr planning horizon.

APPENDIX 2

This appendix describes the Model I linear programming model used to analyze the three policy alternatives described in this article. Strata-based Model I formulations rely on the definition of homogeneous but noncontiguous analysis areas. The model uses upland and riparian land type strata that are further broken into 10 yr age classes.

For each land type, a set of possible management actions is defined. Each management action specifies how a given land type can be managed over the entire planning horizon of 10 decades. The following terms are defined:

X_{fcm} = the number of acres in planning area *f*, land type *c*, assigned to management action *m*.

For the three policy alternatives examined in this article, only one planning area (i.e., western Washington) is used. A management action defines how a land type is to be managed. This involves both *current* and all *future* timber crops. It reflects the type of silvicultural regime and other variables of interest, such as habitat class, habitat index, timber inventory, and timber harvest. Let,

V_{fcmt} = the per acre harvest volume in time period *t*, harvested in planning area *f*, land type *c*, if management action *m* is assigned, and

W_{fcmth} = per acre habitat index and/or habitat class *h*, in time period *t*, generated in planning area *f*, land type *c*, if management action *m* is assigned, and

I_{fcmt} = the per acre standing timber inventory in time period *t*, generated in planning area *f*, land type *c*, if management action *m* is assigned.

A variety of constraints are needed to model the three policy alternatives. One set of constraints is needed to ensure that no more acres are assigned to management actions than there are acres available. Let,

$$\Sigma X_{fcm} \le A_{fc} \qquad \text{for all } f,\ c$$

The sum on the left is taken over all management actions. The A_{fc} represent acres that must be provided as user input.

Another set of constraints restricts the flow of harvest volumes over time. These timber harvest flow constraints are used to smooth the production of wood over time to better meet mill capacity and market requirements in the short term. It is assumed that these flow constraints operate across western Washington, although they may be altered to operate at the individual planning area level.

$$\Sigma V_{fcm(t+1)} X_{fcm} \ge (1-\alpha)\Sigma V_{fcmt} X_{fcm}$$

and,

$$\Sigma V_{fcm(t+1)} X_{fcm} \le (1+\beta)\Sigma V_{fcmt} X_{fcm}$$

Summations are taken over all land types, management actions, planning areas and relevant time periods. Also, $0 \le \alpha, \beta \le 1$. Normally α and β are set to a value between 0.10 and 0.25 and refer to the allowable decrease and increase, respectively, of harvest volume between consecutive time periods. For nondeclining flow, set $\alpha = 0$ and $\beta = \infty$. This is implemented by deleting the second set of timber harvest flow constraints.

Another important set of constraints included in policy alternative three relate to the required minimum number of wildlife habitat acres. The number of acres that fall into various habitat classes as defined by the Washington Forest Practices Act (e.g., for spotted owls and marbled murrelets) and the number of acres occupied by various stand structure classes are tracked. These constraints are expressed as follows:

$$\Sigma W_{fcmh} X_{fcm} \ge A_h \qquad \text{for all } h$$

The numbers of acres represented by A_h are provided as user input. As with the harvest flow constraints, summations are taken over all land types, planning areas, and management actions. In the third policy alternative, a requirement that at least 25% of the forest area be occupied by late seral forest structure at the end of the planning horizon is added:

$$\Sigma W_{fcmh} X_{fcm} \ge 0.25(1{,}426{,}094) \qquad \text{for } h = \text{ late seral forest structures}$$

The objective function for the model is to maximize net present value (NPV) of harvest incomes. Therefore, a set of costs and stumpage prices as well as a discount rate (expressed in real terms) are needed. These values are used to calculate the per acre NPV for each management action for a given land type.