Integrated Assessment and Priorities for Protection and Restoration of Watersheds

Keith Reynolds[1] and Scott Peets[2]

[1] U.S. Department of[1] Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331. kreynolds@fs.fed.us.
[2] U.S. Department of Agriculture, Forest Service, Northwest Region.

Abstract. This study prioritized watersheds and stream reaches for protection and restoration in the Chewaucan Basin (south-central Oregon, USA). Logic models evaluated reach and watershed attributes. Reach evaluations were performed with a landscape analysis decision support system (DSS) designed to process logic models. Reach evaluations were summarized by watershed and incorporated into watershed evaluations. An analytic hierarchy model (AHP) prioritized watersheds for protection and restoration, considering watershed condition and the feasibility and efficacy of restoration. A second AHP model prioritized reaches for protection and restoration, considering reach condition, watershed restoration priority, and reach-level feasibility and efficacy. The total analytical process demonstrates integrated landscape analysis in three dimensions: integrated assessment of landscape attributes within spatial scale, integration of information across spatial scales, and integration of analyses across phases of adaptive management. Collectively, the models provide a formal specification for well-integrated, repeatable analyses that provide consistent evaluations over time and space.

Keywords: watershed analysis, assessment, salmon habitat, restoration, watershed, stream reach, integration, knowledge base, model, logic

1 Introduction

The Forest Ecosystem Management Assessment Team (FEMAT) developed management alternatives for maintaining and restoring habitat conditions to support well distributed and viable populations of species associated with late-successional and old-growth forests in northwest California and western Oregon and Washington. Analysis of alternatives (USDA and USDI 1994a) led the USDA Forest Service and USDI Bureau of Land Management to adopt the ecosystem management strategy now known as the Northwest Forest Plan, contained in the Record of Decision (USDA and USDI 1994b).

Major goals of the FEMAT aquatic component and the ROD were to halt habitat degradation, maintain ecosystems that currently are in good condition, and aid recovery of freshwater habitats of at-risk fish populations. The Aquatic Conservation Strategy (ACS) is a region-wide strategy to retain, restore, and protect the processes and landforms that contribute habitat elements to streams and promote good habitat conditions for fish and other aquatic and riparian-dependent organisms (FEMAT 1993). Watershed analysis and restoration are two of four primary ACS components designed to maintain and restore the productivity and resiliency of riparian and aquatic ecosystems (FEMAT 1993).

Reynolds and Reeves (2001) developed a prototype logic model for use with a landscape analysis decision support system (Reynolds 1999a) to assess salmon habitat suitability of watersheds. The model was designed to support the watershed restoration objectives of the ACS. Complementing the assessment model, Reynolds (2001) designed a prototype decision model for prioritizing watersheds for salmon habitat restoration. The analysis strategy embodied by the two models was to cleanly separate restoration analysis into two distinct phases: evaluation of condition and setting priorities for protection and restoration.

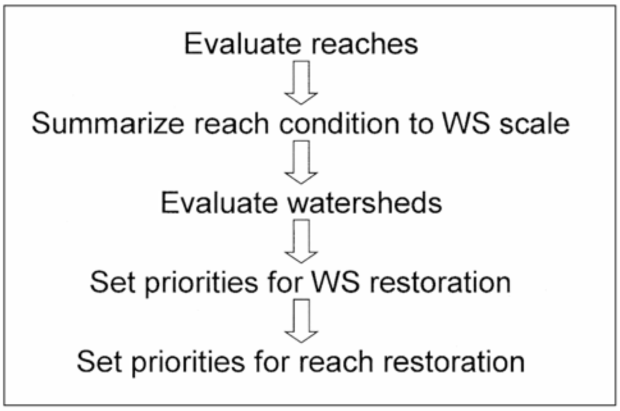

Fig. 1. General strategy for integrating assessment of stream reach and watershed conditions and setting priorities fir protection and restoration.

In continuing work with watershed analysis teams, including the Upper Chewaucan watershed analysis team, it became apparent that there was substantial interest in multiple scales of analysis. This analysis of the Upper Chewaucan watershed extends the earlier work of Reynolds (2001) and Reynolds and Reeves (2001) by developing and demonstrating a formal specification for multi-scale analysis, beginning with evaluation of stream reaches (Fig. 1). The scope of the original Upper Chewaucan assessment (Peets and Friedrichsen 1999) also is extended in this analysis to include decision protocols for prioritizing protection and restoration activities at watershed and reach scales (Fig. 1).

2 Materials and Methods

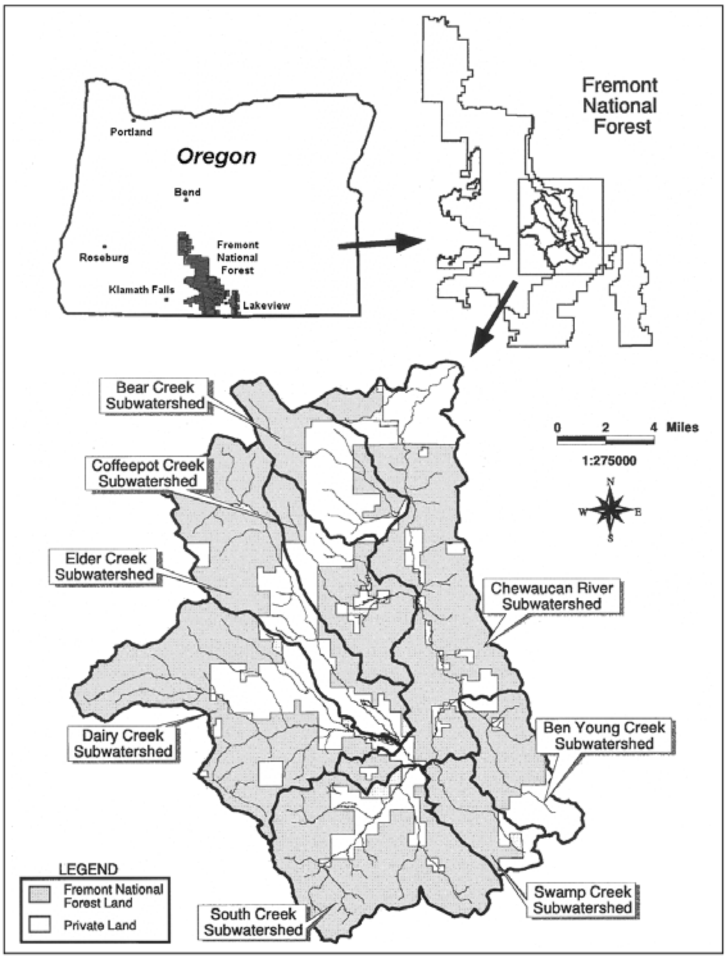

Fig. 2. Geographic context of the Upper Chewaucan assessment area.

The Upper Chewaucan is a 5th-field watershed located in south-central Oregon and contains nine 6th-field watersheds (Fig. 2). An initial assessment of the Upper Chewaucan was conducted by Peets and Friedrichsen (1999). Subsequently, we refer to the Upper Chewaucan watershed as the assessment area, and its 6th-field watersheds simply as watersheds. Peets and Friedrichsen delineated 104 stream reaches on the main stems of creeks in the assessment area in their original study. Nineteen reaches, crossing private ownerships and representing 17.9% of total main stem stream length in the assessment area, were excluded from the original study. Of the remaining 85 stream reaches, 42 were forested and 43 were nonforested, representing 39.3% and 42.8% of total main-stem stream length, respectively.

2.1 Evaluating Stream Reach and Watershed Condition

This study re-evaluates the Upper Chewaucan data from Peets and Friedrichsen (1999) with an adaptation of the logic model developed by Reynolds and Reeves (2001) for watershed assessment of salmon habitat suitability. The model of Reynolds and Reeves (2001) used many of the same attribute data as examined by Peets and Friedrichsen (1999) in their assessment, but the logic model initially was designed to use data summarized to the watershed scale. For this study, we decomposed the original logic model for watershed assessment into separate models for reach (Table 1) and watershed (Table 2) evaluation. Protocols developed by Peets and Friedrichsen (1999) for evaluation of data were implemented as fuzzy membership functions (Reynolds 1999b) in the new logic models (Tables 1 and 2).

Table 1. Topic outline of logic model for evaluating stream reach condition.
[a]

Topic name [b]	**Datum evaluated or operation**[c]
Reach condition	Fuzzy AND
Riparian vegetation	Sum
Species comp	Similarity of existing riparian vegetation on reach to late seral species composition.
Seral stage	Seral stage of riparian vegetation.
Bank stability	Percent reach length with stable banks.
Width to depth ratio	Ratio of reach width to depth at bankfull stage.
In-channel	Sum
Woody debris	Average number of large woody pieces per mile of reach length.
Pool frequency	Average number of pools per mile of reach length.

[a]The outline form of the logic model is a simplified view of the full logic specification that is documented at www.fsl.orst.edu/emds/chewR.

[b]Each topic evaluates a proposition of the form, "X is in a suitable condition," where X indicates the topic name for the proposition. Topics in plain text evaluate a proposition about data. Propositions of topics in italic text depend on subordinate propositions (e.g., premises). Outline structure indicates dependency; for example, evaluation of the proposition for the *in-channel* topic depends on the subordinate topics, large woody debris and pool frequency.

[c]Topics that evaluate data (shown in plain text) use fuzzy membership functions (Reynolds 1999b) to evaluate an observation's degree of support for the proposition. In this model, all membership functions are dynamically defined at EMDS runtime by parameters supplied to the reach evaluation logic model as data. Fuzzy operators, used by topics with subordinate topics, are defined by Reynolds (1999b).

Table 2. Topic outline of logic model for evaluating watershed condition

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Topic name	Datum evaluated or operation
Watershed condition	Fuzzy AND
Upland condition	Sum
Upland cover	Fuzzy AND
Canopy density	Percent area of forest communities with canopy densities within historic range of variation.
Seral openings	Percent area of forest communities in young seral stage.
Road density	Miles of road (all classes) per square mile of watershed area.
Stream access	Percent of total stream length in the watershed that is accessible to fish.
Stream condition	Fuzzy AND
Reach condition	Length-weighted average of reach condition indices from reach evaluation logic model.
Spawning fines	Percent spawning habitat composed of sand or silt.
Water temperature	Maximum 7-day running average water temperature over the summer (degrees F).

[a]The outline form of the logic model is a simplified view of the full logic specification that is documented at www.fsl.orst.edu/emds/chewWS.

[b]See footnote b, Table 1.

[c]See footnote c, Table 1.

Analogous to the concept of a utility function, a fuzzy membership function maps the value of an observation onto an index that expresses the observation's degree of support for a proposition. Thus, leaf nodes (topics in plain text, Tables 1 and 2) in the logic model outlines evaluate propositions about data. In general, propositions about data are premises for higher-order, more abstract propositions. For example, evaluation of the proposition for the *Upland cover* topic (Table 2) depends on two premises, seral openings and canopy density.

To link reach and watershed scales of analysis (Fig. 1), reach condition (Table 1) within a watershed was summarized as the length-weighted average of reach condition indices for all stream reaches in a watershed (Table 2). Landscape application of the two logic models was performed with the Ecosystem Management Decision Support (EMDS) system (Reynolds 1999a).

2.2 Evaluating Protection and Restoration Priority of Watersheds and Stream Reaches

Decision models for prioritizing protection and restoration of watersheds and stream reaches were designed with DecisionPlus (InfoHarvest, Redmond, WA)[1]. As with the logic models for stream reach and watershed evaluation (Tables 1 and 2, respectively), an earlier prototype watershed decision model (Reynolds 2001) was decomposed into two separate models, one for each scale of analysis (Figures 3 and 4). Weights for relative importance of criteria and subcriteria were derived from matrices of pair-wise comparisons per the Analytic Hierarchy Process (AHP; Saaty 1992, 1994). Lowest-level criteria (e.g., attributes of alternatives) were evaluated with the Simple Multi-Attribute Rating Technique (SMART, Edwards 1977, Edwards and Newman 1982). Details of the AHP and SMART methodologies are presented in Reynolds (2001).

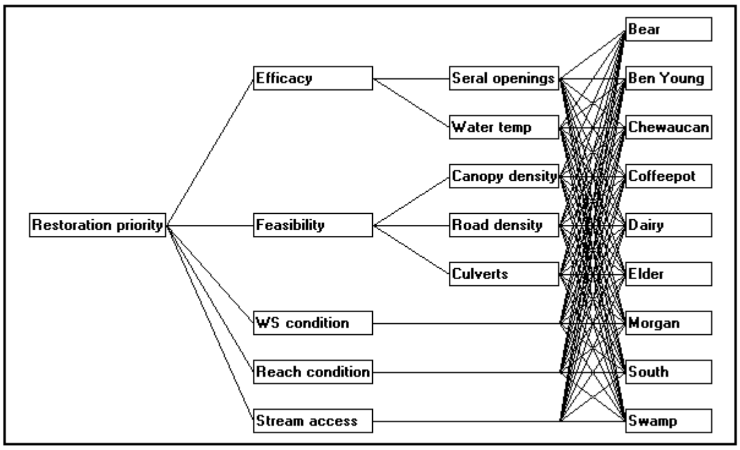

Fig. 3. Analytic hierarchy model for prioritizing watershed protection and restoration.

Values for the watershed condition attribute (WS condition, Fig. 3) and the reach condition attribute (Fig. 4) came from EMDS analyses of the two logic models for watershed condition (Table 2) and stream reach condition (Table 1), respectively. SMART utility functions for both attributes were designed to give highest priority to watersheds and reaches in best condition, so the two decision models (Figures 3 and 4) were based in part on a strategy of protecting and restoring the best landscape elements first. Separate decision models were designed for prioritizing stream reach protection and restoration for forested and nonforested reaches because the influence of reach attributes differs between the two contexts. For brevity, results of prioritizing reach protection and restoration are only reported for forested reaches in this paper.

[1] The use of trade of firm names in this publication is for reader information and does not imply endorsement by the U.S. department of Agriculture of any product or service.

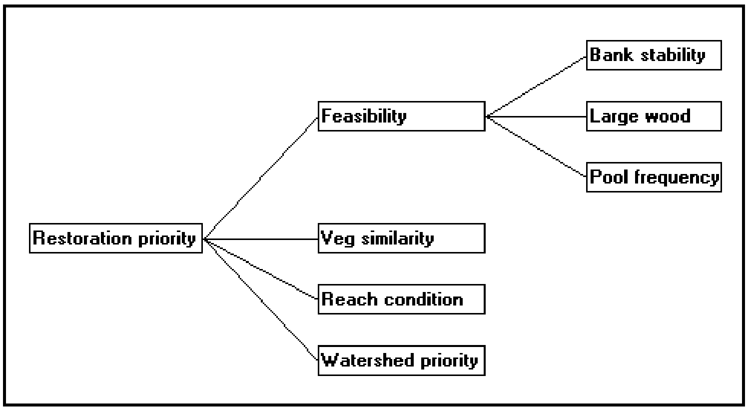

Fig. 4. Analytic hierarchy model for prioritizing protection and restoration of forested stream reaches.

Additional aspects of the protection and restoration strategy of both decision models were to 1) give highest priority to landscape elements for which restoration activities would yield the most improvement for least expense in the shortest time (feasibility criterion), and 2) give lowest priority to landscape elements for which short-term restoration potential was constrained by conditions that would require a long time to mitigate (efficacy criterion). Both decision models include efficacy and feasibility as primary criteria, but vegetation similarity (Veg similarity in Figure 4) is the only efficacy criterion for stream reach restoration. Finally, watershed restoration priority was included as a primary criterion of stream reach restoration (Fig. 3) to rate all forested reaches within all watersheds in a single analysis.

3 Results

3.1 Evaluation of Stream Reach Condition

The overall pattern of stream reach condition in the assessment area (Figs. 5 and 6) was relatively good. Reach evaluations indicative of moderate acceptability ($0 <$ index <1) tended to be concentrated near headwaters of watersheds (Fig. 5). Reach condition indices for eight of the 85 surveyed reaches evaluated to –1 (not acceptable) or nearly so (Fig. 6). The majority of reach condition indices were approximately normally distributed about the midpoint of the index range, but no reaches evaluated as fully acceptable (Fig. 6). Best average reach conditions were observed in Ben Young Creek, Coffeepot Creek and Elder Creek (Table 3).

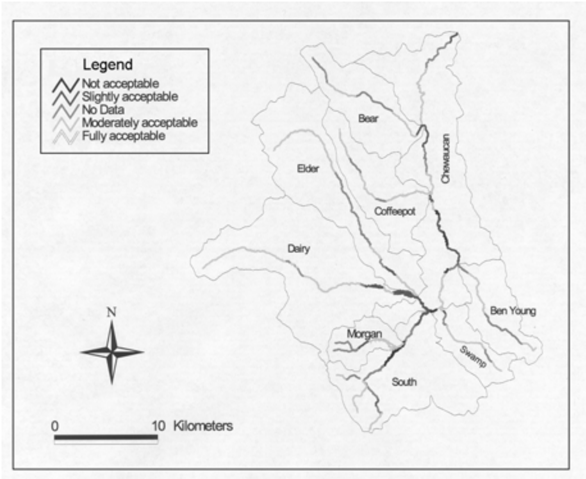

Fig. 5. Evaluation of stream reach conditions in the Upper Chewaucan assessment area.

3.2 Evaluation of Watershed Condition

Bear Creek and Dairy Creek evaluated as somewhat acceptable (-0.5 < index < 0.5) with respect to the watershed condition index, whereas the other seven watersheds evaluated as not acceptable (index = -1, Table 3). Unacceptable passage condition and unacceptable stream condition contributed to a conclusion of unacceptable watershed condition in three and four watersheds, respectively (Tables 2 and 3). Most watersheds evaluated as only slightly acceptable (-1 < index < 0) with respect to upland condition (not shown), but upland condition only contributed to a conclusion of unacceptable watershed condition in one watershed (Table 3). Among the three premises determining watershed condition (Table 2), evaluation of passage condition was the most variable (Fig. 7).

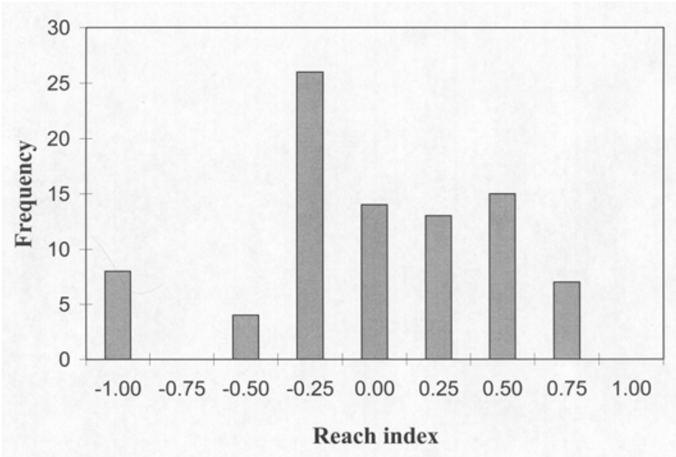

Fig. 6. Frequency distribution of stream reach condition indices for the entire Upper Chewaucan assessment area.

Table 3. Summary of Upper Chewaucan watershed assessment.

Watershed	Reach condition[a]	Unacceptable premises[b]	Watershed condition[c]	Restoration priority[d]
Bear Creek	0.10	None	-0.30	0.42
Ben Young Creek	0.33	Passage	-1.00	0.34
Chewaucan River	-0.10	Stream	-1.00	0.21
Coffeepot Creek	0.40	Stream	-1.00	0.20
Dairy Creek	0.29	None	-0.33	0.45
Elder Creek	0.39	Passage	-1.00	0.39
Morgan Creek	0.06	Stream	-1.00	0.25
South Creek	-0.07	Stream	-1.00	0.22
Swamp Creek	0.20	Upland, passage	-1.00	0.30

[a]Individual stream reaches in each watershed were evaluated with the logic model in Table 1. The range for the reach condition index is –1 (not acceptable) to 1 (fully acceptable). Values in this table were summarized for each watershed as the length-weighted average of reach condition indices for all surveyed stream reaches in a watershed.

[b]Topics in this column are primary premises of the watershed condition topic (Table 2). Condition of a premise was considered unacceptable if the corresponding index for that topic evaluated to –1.

[c]The range for the watershed condition index is –1 (not acceptable) to 1 (fully acceptable).

[d]The range for restoration priority is 0 to 1, with 1 indicating maximum priority.

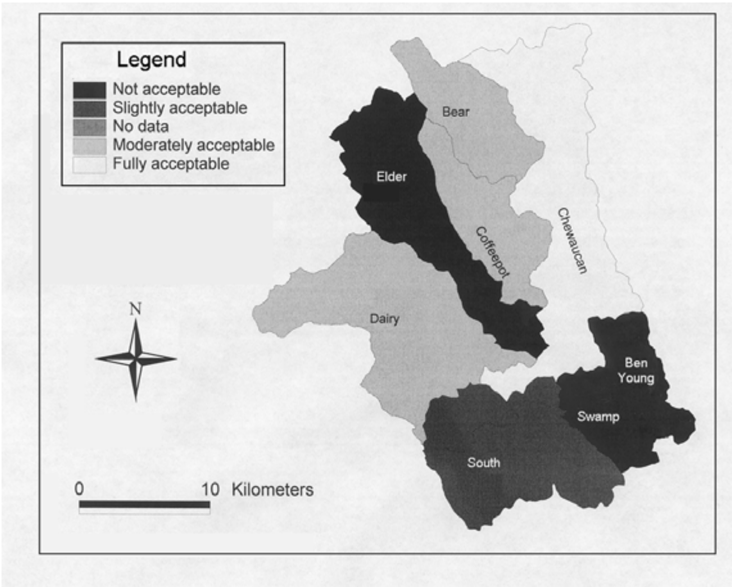

Fig. 7. Evaluation of passage condition in the Upper Chewaucan assessment area.

3.3 Evaluation of Watershed Protection and Restoration Priority

The priority score for protection and restoration is based on a [0, 1] scale, with an ideal score of 1.0 indicating a watershed in very good condition, and therefore not requiring any restoration. Such watersheds, however, would be ideal candidates for protection. For practical purposes, watersheds receiving a priority score ≥ 0.9 could be considered minimally impaired, and, therefore, also would be good candidates for protection. Priority scores for all watersheds in the assessment area were low to moderate (Table 3). Bear Creek and Dairy Creek were the only watersheds for which none of the premises determining watershed condition was fully unacceptable, and these two watersheds were rated highest for restoration, based on high scores for both efficacy and feasibility. Ben Young Creek and Elder Creek were rated as next highest in priority, based on better ratings for efficacy and feasibility compared to all other remaining watersheds. Morgan Creek, South Creek, and Swamp Creek all received low priority ratings based on low ratings for efficacy, feasibility, or the combination of the two criteria.

3.4 Evaluation of Protection and Restoration Priority for Forested Stream Reaches

Priorities are summarized for the 25 highest-rated forested stream reaches (Fig. 8). As discussed above in the context of watershed priorities for protection and restoration, scores ≥ 0.9 indicate reaches with minimal impairment, so all reaches in

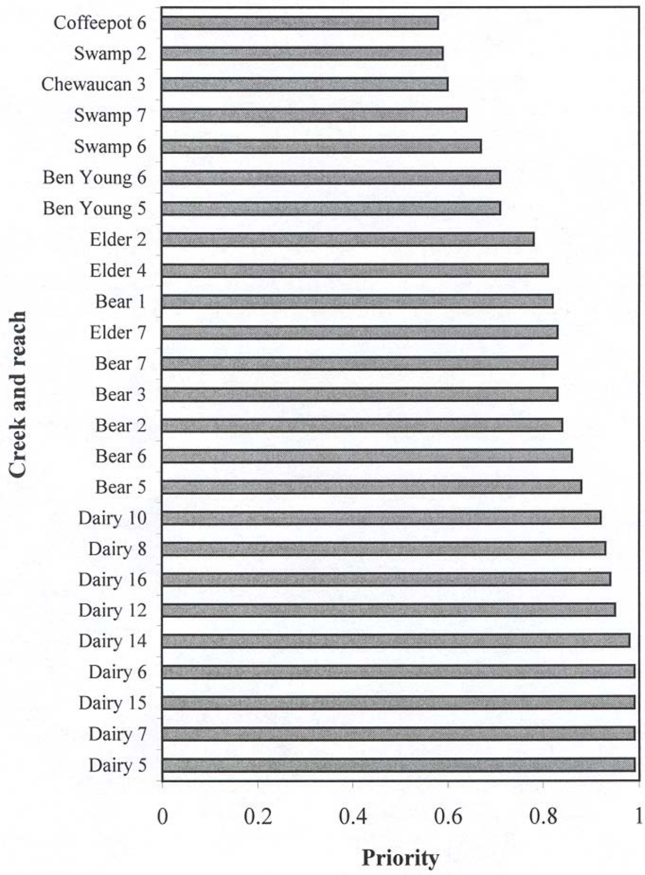

Fig. 8. Priorities for protection and restoration of forested stream reaches in the Upper Chewaucan assessment area.

the Dairy Creek watershed (in the figure) would be prime candidates for protection measures. Some stream reaches in the Bear Creek and Elder Creek watersheds also scored relatively high and would be likely candidates for restoration measures.

4 Discussion

The distribution of reach-index scores (Figure 6) provides a specific example of how basic model results from EMDS can easily be summarized to provide a more synoptic view of the total analysis. The basin-level view of the distribution of reach indices provides a snapshot of the Upper Chewaucan at a single point in time, and suggests a straightforward approach to evaluating the effectiveness of management practices over time. If the same set of reaches were evaluated again, say 10 or 20 years later, and a new distribution of reach indices were generated (similar to Figure 6), then the two distributions can easily be compared with a simple nonparametric test such as the Kolmogorov-Smirnoff statistic to test for significant change.

In addition to providing specifications for repeatable analyses that can be consistently applied, both EMDS and DecisionPlus include explanatory tools that not only document how an analysis was performed, but also provide clear and intuitive explanations for the derivation of model results. In complex landscape analyses, such explanatory capabilities are powerful aids, allowing analysts to effectively communicate results of analyses to a broad audience. These same tools also can be used to delve deeper into the analytical results. Again, for brevity, we have omitted detailed examples, but, in DecisionPlus for example, the analyst can easily examine the numeric contributions of primary criteria to the overall priority rating to distinguish between alternatives with similar overall ratings but that may differ in degree of feasibility.

The total analytical process presented in this study (Fig. 1) is a practical demonstration of integrated landscape analysis in three distinct dimensions: 1) integrated assessment of system states within spatial scale, 2) integration of information across spatial scales, and 3) integration of analyses across phases of the adaptive management cycle. The logic models for evaluation of stream reach condition (Table 1) and watershed condition (Table 2) each demonstrate integration within spatial scale. Integration across scales occurs twice: first, in the initial three synthesis steps (Fig. 1), fine scale reach information from step 1 is summarized at step 2 and incorporated into the watershed evaluation at step 3; second, in the last two "step-down" steps, evaluation of watershed priority at step 4 is incorporated into the final reach priority evaluation. The final dimension of integration is illustrated by the two sets of complementary evaluation and priority models. In each set, basic evaluation results (e.g., watershed condition and stream reach condition) are incorporated into the priority model as primary criteria, along with a re-evaluation of assessment data from the perspectives of efficacy and feasibility.

Collectively, the logic models, their landscape application in EMDS, and the AHP models provide a formal specification for well-integrated, repeatable analyses that provide consistent landscape evaluations over time and space. Although our example is relatively small and simple, the basic strategy of synthesis upward through successively coarser spatial scales and a step-down process for setting priorities is readily extendable to multiple spatial scales as well as larger and more complex logic models.

5 Acknowledgments

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