Using the Analytic Hierarchy Process for Decision-Making in Ecosystem Management

Daniel L. Schmoldt, Southern Research Station,
Blacksburg VA 24061-0503
David L. Peterson, USGS, Biological Resources Division,
Seattle WA 98195

Many decision-making situations involve preferential selection among some finite set of alternative items or events or courses of action. For a land manager, the list of alternatives might contain possible timber harvest levels, inventory and monitoring activities, or watershed analyses. Under ideal circumstances, there might be some intuitive measurement scale (e.g., cost) that a manager could use to compare competing alternatives. The best choice among the available alternatives then would have a high (or low, for cost) score along that scale. By ranking alternatives on the basis of numerical scores, we create an implied priority for those alternatives. When the selection criterion is "least cost" for example, the measurement scale is obvious and choosing among the alternatives is easy. In most real-world situations, however, there is often no single, simple scale for measuring all competing alternatives. More often, there are at least several scales that must be used and often those scales are related to one another in fairly complex ways. In broad-scale, participatory decision-making, alternative courses of action arise from different stakeholders with different value systems, and yet this diversity must be accommodated and integrated.

The analytic hierarchy process (AHP) is relevant to nearly any ecosystem management application that requires multiple opinions, multiple participants, or a complex, decision-making process. Considering the complexity of most ecosystem management issues and compliance regulations, the AHP could extend to a wide array of managerial and planning tasks. For example, management and planning for a large watershed may include issues related to water quality and quantity, forest management, wildlife management, and recreation. Input is required from subject matter experts in each of these disciplines in order to establish priorities and make informed decisions regarding spatial and temporal distributions of resources. Because watersheds generally involve the flow of materials between public and private lands, additional input is often needed on social, legal, and political aspects of resource condition and value.

The Analytic Hierarchy Process

The AHP (Saaty 1980) has been applied to a wide variety of problems (Zahedi 1986). Two important components of the AHP that facilitate the analysis of complex problems are: (1) the structuring of a problem into a hierarchy consisting of a goal and subordinate features of the problem and (2) pairwise comparisons between elements at each level. Subordinate features which are arranged into different levels of the hierarchy, may include such things as objectives, scenarios, events, actors, outcomes, and alternatives. The alternatives (i.e. final decision choices) to be considered are placed at the lowest level in the hierarchy. Pairwise comparisons are made among all elements at a particular level with respect to each element in the level above it. Comparisons can be made according to preference, importance, or likelihood-whichever is most appropriate for the elements considered. Saaty (1980) developed the mathematics necessary to combine pairwise comparisons made at different levels in order to produce a final priority value for each of the alternatives at the bottom of the hierarchy.

As a simple and easily understood example, consider the hierarchy in Figure 1, which is designed to enable one to select a "best" college to attend. The goal, *satisfying college,* appears at the top of the hierarchy. The criteria appear on the next level: *academic reputation, cost, campus beauty, local living climate,* and *social life.* The colleges to be considered are labeled A, B, and C at the lowest level. First, the criteria are compared pairwise with respect to their importance for producing a satisfying college experience. The scale of integers in the range 1-9 is used for comparison (Saaty 1990). One possible matrix resulting from these pairwise comparisons appears in Table 1. In this matrix, each value a_{ij} indicates how much more important, preferred, or likely row heading/is than column heading *j.* Corresponding matrix entries a_{ji} equal 1 /a_{ij}. Elements on the matrix diagonal are always unity. The normalized principal right eigenvector c' = [0.465, 0.326,0.085,0.097, 0.038] of this matrix represents the priority values of those criteria (Saaty 1980).

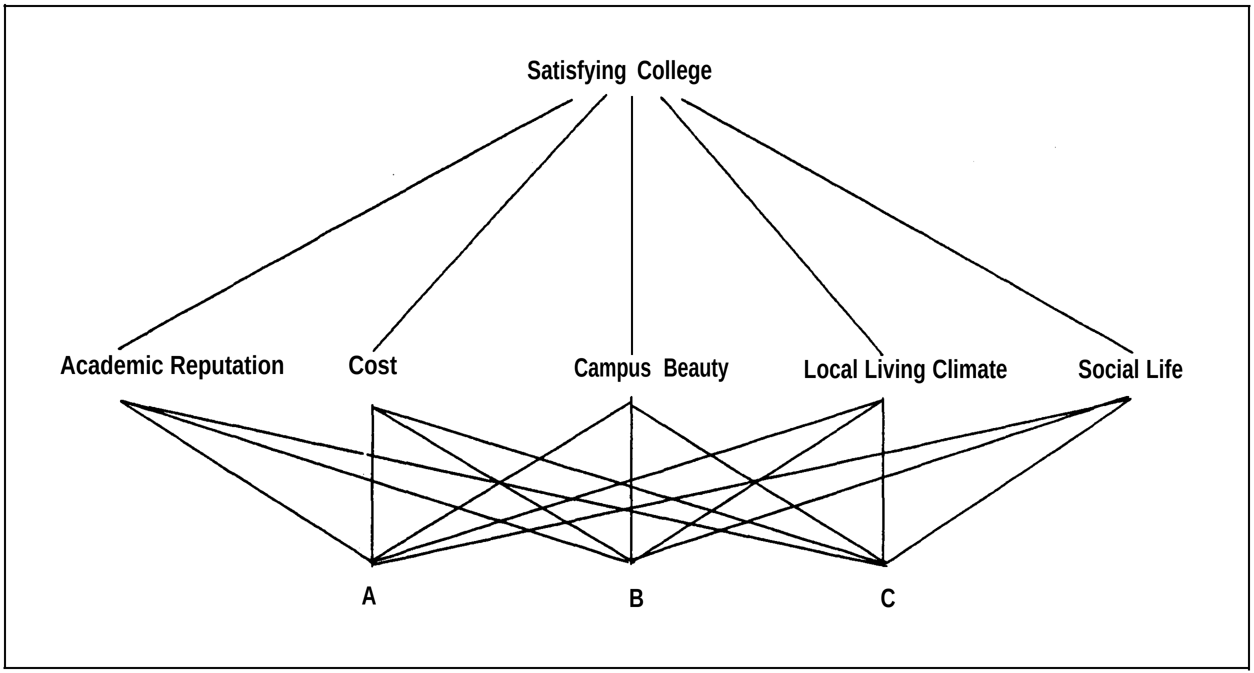


Figure 1. A simple analytic hierarchy for selecting a satisfying college from among three alternatives, A, B, and C, makes use of five criteria. Each of the alternative colleges is scored on each criteria. In general, however, a hierarchy need not be fully connected in this way.

Table 1. The five criteria for selecting a college are compared in a pairwise fashion and assigned a relative importance score.

	Academic Reputation	Cost	Campus Beauty	Local Living Climate	Social Life
Academic	1	3	5	3	7
Cost	1/3	1	5	5	9
Campus Beauty	1/5	115	1	1	3
Local Living	1/3	1/5	1	1	3
Social Life	in	1/9	1/3	1/3	1

When all pair-wise comparisons in the judgment matrix A are absolutely consistent, i.e. $a_{ij}a_{jk}=a_{ik}$ for all $i \neq k$, then Eq. 1 holds, where w is the vector of priority values. This mathematical statement [1] also says that w is an eigenvector of A with associated eigenvalue *n.* Because the matrix multiplication occurs on the right, w is called a right eigenvector. In the consistent case, *n* is the only non-zero eigenvalue of A. As small changes are made to the a_{ij}, however, A becomes inconsistent and multiple eigenvector and eigenvalues exist. The largest (or principal) eigenvalue remains close to *n* as long as changes to the a_{ij} are small and A does not become too inconsistent. Therefore, the principal right eigenvector is still a good approximation to the consistent case eigenvector w.

$$Aw = n\,w \tag{1}$$

Then alternative colleges are compared regarding the extent to which each has these criteria. One matrix, such as Table 2, would be produced for each criterion. Similar to the first matrix (Table 1), a priority vector w,' = [0.637, 0.258, 0.105 can be calculated from Table 2. Priority vectors $w_2, \ldots, w_5$ can also be generated for each of the remaining criteria. The degree to which the colleges possess each criterion (stored in the w,) is weighted by the importance of that criterion c, and summed across all criteria to obtain a final priority value for that college. In matrix arithmetic, the final priority vector for the colleges is calculated as

$$w = [\,w_1 w_2 w_3 w_4 w_5\,]\,c \tag{2}$$

A more detailed example of the AHP process appears in Schmoldt and others (1994) with some of the mathematical derivations. Because the final result of the AHP is a numerical priority value for each alternative, the decision-maker may then select the highest scoring alternative as the "best." The decision process that has been made explicit in the hierarchy and in the comparisons determines this "best" alternative.

Table 2. The three colleges are compared with respect to the criterion, academic reputation.

Academic			
College A	1	3	5
Collage B	1/3	1	3
College C	1/5	1/3	1

RESOURCES MANAGEMENT PLANNING

Application Overview

We now introduce a more realistic example of the use of the AHP to prioritize inventory and monitoring programs. If adaptive ecosystem management is to be realized in practice, there will be an increasing need to continually monitor ecosystem components and processes. In 1993 we worked with the resource management staff of Olympic National Park in Washington state, USA, in order to determine the usefulness of the AHP in actual practice (Peterson et al. 1994). We selected this park because it is large (380,000 ha) and has a diverse array of natural resources. It also has a diversity of management issues, including several with prominent legal and political ramifications. The complexity of resources management at Olympic NP is evidenced by the fact that the resource management plan (RMP) is over 700 pages. This is not atypical for large national parks, because the RMP is generally a long-term, comprehensive document for planning and project development.

The planning process is not highly structured at the present time. As one member of the staff at Olympic NP put it, they use the "BOGSAT (Bunch of Guys/Gals Sing Around a Table) method of planning". In other words, the management staff compiles a wide range of topics, discusses them, prioritizes them, and develops the RMP with minimal quantitative evaluation and without formal decision-making tools. The result is a large and rather cumbersome document.

There is nearly always a huge gap between the management programs described in the RMP and the actual programs that are constrained by budget and personnel limitations. Park managers see many critical needs for information; but they also realize that many of those information gaps will never be filled. As a result, they are continually faced with the prospect of making decisions in the absence of adequate data. They are also faced with deciding whether to develop an extensive program (many projects at a low level of detail) or an intensive program (a few projects at a high level of detail). Finally, park managers are often faced with political and operational constraints that may override decisions based on scientific information and resources management expertise.

Budget allocation among different resource areas within a national park is a difficult process because of the wide range of resources, personnel, and issues involved in implementation of RMP projects. Despite potential advocacy baffles ("pet projects") associated with specific projects in the RMP, the park staff must establish priorities for which projects can actually be conducted. Olympic NP currently has no formal process for prioritizing projects and allocating budget and personnel among projects. Park staff indicated that this is a frustrating situation, particularly because of unpredictable annual budgets. The two-step process of prioritization and allocation (Peterson, et al. 1994, Schmoldt et al. 1994) proposed by the authors makes decision-making more explicit and allows plans to be reexamined and more easily modified.

Interviewing with the AHP

We worked with five members of the Olympic NP staff (Resource Assistant, Resources Management Specialist, Wildlife Biologist, Fishery Biologist, GIS Specialist) to determine how the AHP could be used to prioritize RMP projects. Eight projects were selected for the priority-setting exercise, one from each of the resource disciplines in the natural resources section of the current RMP.

Pairwise comparisons and project ratings within the AHP were developed interactively using commercially available software[6]. Ail subjective judgments were reached by consensus within the resources management team. After the Olympic NP team became more comfortable with the format of the AHP procedure, decisions could generally be reached with a minimum of discussion. Although there was often disagreement about subjective assessments, there were few cases in which staff members' judgments were more than one score different from each other.

In addition to rating individual projects with respect to each objective and sub-objective, the Olympic NP team also developed relative weights for the objectives themselves. Specific objectives and their organization (i.e., the decision hierarchy) had been developed previously by the authors (Schmoldt, et al. 1994). We expected the Olympic NP team would create their own hierarchy for this exercise, but instead, they opted to use the existing structure for park objectives (Figure 2). Two other priority vectors for the objectives were used as part of the final analysis, these included: (1) all objectives have equal weight, (2) *management decision-making* has exclusive priority.

AHP Results

The final project ratings and their associated ranks indicate that the five highest ranked priority projects all had relatively high priority scores, while the three lowest ranked priority projects had considerably lower scores (Table 3). A different scenario in which all objectives in the model were ranked equally produced only minor changes in the order of project priorities; the highest and lowest ranked projects maintain their positions, while the middle four projects are reordered. However, a scenario in which "management decision-making" was the only important objective caused a considerable shift in priorities. Results for a scenario in which rankings were based on 1990 RMP expenditures for projects differed markedly from each of the previous sets of rankings. This indicates that allocations using the "BOGSAT process" followed a non-explicit set of objectives which diverge from those of the other explicit resource management planning scenarios.

---

[6] Expert Choice, inc., Pittsburgh PA. The senior author has also developed as Excel™ Add-in to generate matrices and calculate priority vectors. Tradenames are used for informational purposes only. No endorsement by the U.S. Dept. of Agriculture or the U.S.D.A. Forest Service is implied.

In the case study conducted for the Olympic NP, we found that the resource managers were receptive to alternative approaches for the evaluation of resource management planning. The complexity of multiple objective planning and project prioritization was simplified by the use of the AHP. Furthermore, resource management staff felt that they could present the RMP to other park staff and the general public with greater confidence if it were grounded in quantifiable decisions. Although this case study assessed only a few projects and objectives, there was considerable support for integrating the AHP approach into other aspects of resource management planning.

RESOURCE MANAGEMENT OBJECTIVES IN MODEL

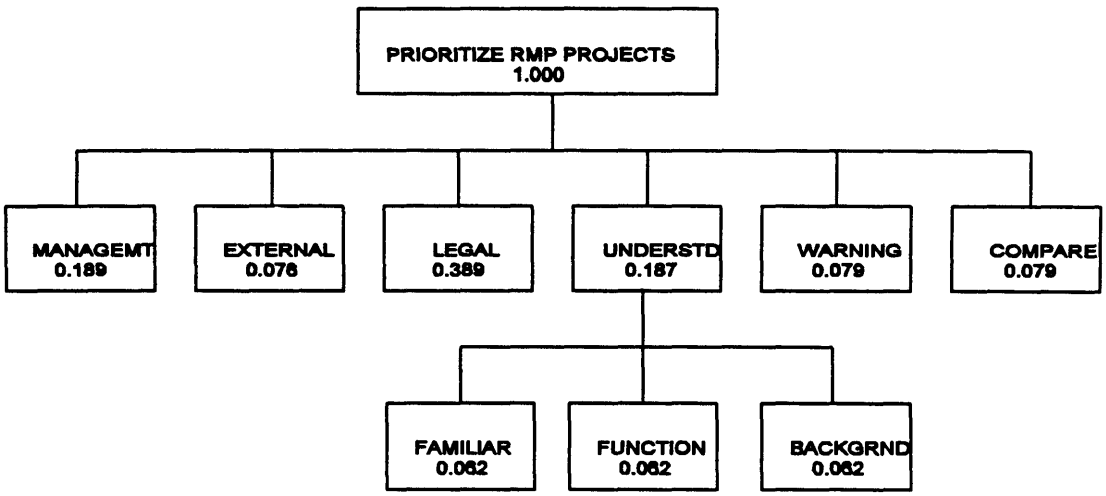


Figure 2. The hierarchy for RMP includes the primary goal and the objectives. Each of the 8 alternative projects were compared with respect to these 8 objectives.

Conclusion

The structured approach offered by the AHP allows different individuals and institutions to participate equally in a process that is quantitative and non-biased, rather than subjective and value-laden. If individuals can work around a table to quantify their input to decision-making, then an analytical process can provide a critical link in developing trust and true group participation. The AHP allows diverse viewpoints to be considered and integrated, without the requirement of consensus. The important thing is that all participants have input to, and ownership of, the final evaluation.

Literature Cited

Peterson, D. L., D. L. Schmoldt, and D. G. Silsbee. 1994. A case study of resource management planning with multiple objectives and projects. *Environmental Management* 18(5): 729-742.

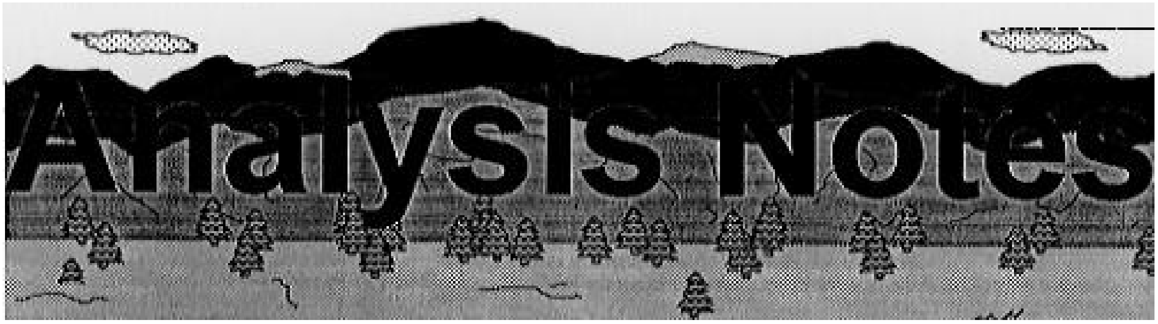
Saaty, T. L. 1980. *The analytic hierarchy process. New* York: McGraw-Hill.

Schmoldt, D. L., D. L. Peterson, and D. G. Silsbee. 1994. Developing inventory and monitoring programs based on multiple objectives. *Environmental Management* 18(5): 707-727.

Zahedi, F. 1986. The analytic hierarchy process-A survey of the method and its applications. *Interfaces* 16:96-108.

Table 3. Priority ratings and rankings for each project under different management objective priorities are listed. Staff ratings for each project, along with the relative importance of management objectives under each scenario, produced the final priority values in this table.

Project	Objective importance assigned by park staff		All objectives ranked equally		"Management decision-making" has highest priority		Actual funding level in the 1990 RMP implicitly determines rankings	
	Priority	Ranking	Priority	Ranking	Priority	Ranking	Priority	Ranking
Air quality	.137	5	.130	6	.099	7	-	3
Avalanche monitoring	.069	8	.057	8	.111	6	-	2
Water quality	.140	4	.146	3	.122	5	-	5
Goat impacts	.141	3	.135	5	.179	1	-	1
Sensitive wildlife	.143	2	.149	2	.134	4	-	5
Anadromous fish	.128	6	.143	4	.145	3	-	4
Elwha watershed	.148	1	.163	1	.168	2	-	5
IPM program	.095	7	.077	7	.042	8	-	5



WO/Ecosystem Management Analysis Center Fort Collins, Colorado | **January 1997** | **Volume 7, Issue 1**