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Applying Multicriteria Decision Analysis to Managing Species at Risk and Other Critical Resources on Military Installations

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PURPOSE: When managing species at risk (SAR) and other critical resources (e.g. threatened and endangered species) on military installations, land managers are often faced with complex sets of land use objectives (warfighter training, installation operations, natural resource extraction, multiple SAR or threatened and endangered species, etc.), conflicting priorities among stakeholders (trainers, public works managers, natural resource managers, other federal agencies, environmental nonprofits, etc.), and limited resources (funds, manpower, time, etc.). Identifying optimal solutions or management actions, and effectively communicating concerns, probable outcomes of alternative actions, and reasons for decisions are some of the more difficult tasks faced by land managers. This technical note will describe how managers and stakeholders can resolve conflicting objectives, deal with the uncertainties, and optimize SAR management. The importance of "value trade-offs" in arriving at optimal decisions will be illustrated. Ultimately, this technical note will provide a general overview of a structured, transparent approach to decision-making that not only helps managers determine the best management alternatives, but also defend them.

INTRODUCTION: Species are defined as SAR on Department of Defense (DoD) installations if they are not yet official candidates for federal Endangered Species Act (ESA) listing, but are either designated as candidates for listing or classified by NatureServe as being critically imperiled or imperiled throughout their range, and have populations on or near DoD installations (NatureServe 2006). In 2004, 523 species spread across 224 military installations were considered by NatureServe to be classified as SAR. Of these species, 47 were identified as candidates for federal ESA listing and another 24 species were known to exist only on DoD installations (NatureServe 2004).

Active management of SAR on military installations can be an important part of maintaining healthy populations and can prevent SAR from being listed as threatened or endangered species (TES) under the ESA. A change in status of an installation SAR to a TES may result in increased regulatory encroachment on the installation, reduced training opportunities and flexibility, and, consequently, reduced military readiness. Such listings may also result in increased allocation of Army funds and manpower for studying and managing a species. Because of these concerns, the DoD has a goal of preventing the decline of such species on its lands and associated changes in SAR status to TES (MacDonald and Lozar 2006). To meet this goal, DoD must find management approaches that meet SAR needs without endangering priority DoD missions (e.g. training and operations). Existing tools and guidance documents for assessing and managing strategic actions (e.g. Integrated Natural Resource Management Plans (INRMP), DoD Biodiversity Handbook (Benton et al. 2008)) have given relatively little attention to developing the analytical decision-making structures necessary to compare alternative management actions and evaluate their likely end results.

Multicriteria Decision Analysis (MCDA) is a means by which managers can navigate the complexities of multiple land demands and stakeholder values, and is a method for explicitly dealing with alternative decisions or actions, multiple objectives, varying criteria, and multiple stakeholders (see Appendix A for definitions). MCDA helps managers to drill down and accurately identify core issues and concerns, and prevents the unwanted outcomes, wasted resources, and loss of goodwill that can accompany efforts that address symptoms instead of "true" problems. MCDA also helps managers prioritize concerns, quantify stakeholder and land manager preferences, and determine cost:benefit ratios associated with alternative actions (Anderson and Hobbs 2001). Finally, MCDA provides mechanisms for arriving at decisions when there is a lack of consensus among stakeholders and/or uncertainty about the likely outcomes of proposed alternative actions (Keeney and Raiffa 1976; Clemen 1995). The National Research Council (NRC) (2004) has recently emphasized the benefits that can be gained from confronting the uncertainty of outcomes and considering multiple objectives when developing ecosystem management plans.

This technical note provides a primer on MCDA and its potential use in managing natural resources. A hypothetical case study is used to illustrate how MCDA could be used to help arrive at effective management decisions for SAR.

MULTICRITERIA DECISION ANALYSIS (MCDA): Often, several different alternative strategies or management decisions are available when SAR management conflicts with training and operations on an installation. However, no alternative is likely to meet *all* the needs of either the SAR or training/operational activity. In such cases, making tradeoffs among SAR objectives and others will be required. As an example of potential tradeoffs, protecting a parcel of woodland habitat from training-associated soil erosion and logging could seem the best alternative for promoting a healthy population of an SAR frog, which requires ephemeral woodland pools for breeding, and for protecting adjacent stream and water quality. However, this approach could conflict with training on tracked vehicles, as well as with installation forestry management plans. Translocating individual SAR frogs to a different parcel on the installation where training demands might have less impact on the SAR could ameliorate the conflict with tracked vehicle training. However, the translocation could still conflict with forestry management, does not protect water quality, and has some likelihood of being unsuccessful and even severely damaging to the health of the SAR population. Finally, doing nothing and leaving the SAR unprotected from track wheel vehicle impacts would meet training and forestry management requirements, but could result in increased likelihood for transition of the SAR to TES and would not protect water quality. Additional complicating factors could come into play; for instance, the currently inhabited parcel might be adjacent to a live fire artillery impact area, making it much more susceptible to wildfire than the potential translocation site (or vice versa), or an endemic cryptic disease within the SAR might be spread by translocation. An additional complication might arise if there were a government partner (e.g. USFWS) willing to spend considerable funds to protect the SAR on refuge lands adjacent to the currently inhabited parcel (an important step in preventing status transition to TES), who might not be willing to pursue the effort should the installation proceed with translocation. Finally, each decision is flavored by the land manager's and other stakeholders' sometimes differing environmental values.

As illustrated above, it is unlikely that any of the above management alternatives will outperform all other alternatives in meeting all objectives or in addressing each concern. Land managers that are tasked with deciding on a single alternative to implement are then, often, presented with a real and substantial dilemma. MCDA was designed to navigate such "sticky" and complex situations, to assist managers in assessing the likely overall effectiveness of various alternative actions, and to help them arrive at optimal decisions that *best* perform against such arrays of competing objectives and concerns.

One source of difficulty in making decisions that must incorporate multiple objectives is that the criteria – usually costs or impacts – by which the different alternative decisions are assessed often lack a common unit of measure (e.g. cost in dollars, change in number of individuals, change in likelihood of status transition to TES, change in available training hours, acceptability to installation leadership). For some objectives, cost and impact criteria can be monetized; however, many objectives have criteria that are difficult to translate into dollars gained or lost, and attempts to do so may be misguided (Keeney and Raiffa 1976). One of the several strengths of MCDA is the ability to integrate diverse objectives (e.g. environmental, social, and economic) in evaluating alternatives, typically through the conversion of different kinds of measurement units into a single class of measure known as a "utility score" (Clemen 1995).

MCDA structure and steps. The MCDA process involves the following steps and is illustrated in Figure 1:

- Step 1: Carefully and explicitly define the problem or issue at hand. Make sure that the core issue – the one that is the source of and influences the problem or situation to be addressed – is accurately identified. Carefully considering the objectives (next step) can help this process considerably. Addressing a secondary issue or symptom, instead of the core problem, can be a highly detrimental mistake, and remains a common pitfall for managers and decision-makers.

- Step 2: Define objectives associated with successfully addressing the problem or issue, and the criteria that will be used in evaluating success and failure of the final decision. In this step, the objectives are carefully described and considered to make sure they are truly tied to the core issue; this prevents managers from expending limited time and resources measuring impacts to objectives that are not actually related to the core issue or responsive to the alternative decisions. Criteria are carefully considered to make sure they are accurate indicators of whether objectives have been successfully met or not.

- Step 3: List and describe alternatives that can be undertaken to achieve the fundamental project objectives. When there are competing objectives, different alternatives will likely vary in their effectiveness across those objectives.

- Step 4: Collect data needed to develop measurable standards of success and failure in meeting different criteria and satisfying different objectives. Depending on the available information and resources, this can be accomplished through mining historical data, conducting targeted studies, running models and simulations, or eliciting expert opinion if inadequate data are available or uncertainties associated with existing data and models are substantial.

- Step 5: Populate a "decision matrix" where each entry corresponds to the expected performance of an alternative decision against one of the criteria for an objective. At this point, the expected impacts of alternative decisions on the varying objectives may be quantified or qualified using different units of measure.

- Step 6: Elicit appropriate weightings for criteria based on their relative importance in meeting the objective(s). This step accounts for the likelihood that different criteria will affect the success or failure of a decision differently, or, in other words, will have more or less influence on the objective(s).

- Step 7: Integrate criteria and predict overall performances of alternative decisions, assign weights to rank alternatives, and communicate results with stakeholders. The MCDA process uses a trade-off approach to integrate unlike criteria and derive a common metric, or "utility score," by which the expected overall impacts of alternative actions on objectives can be calculated. The utility score can then be used to rank alternative actions by their attractiveness (of likelihood of success).

- Step 8: Managers make decisions guided by stakeholder input and MCDA results.

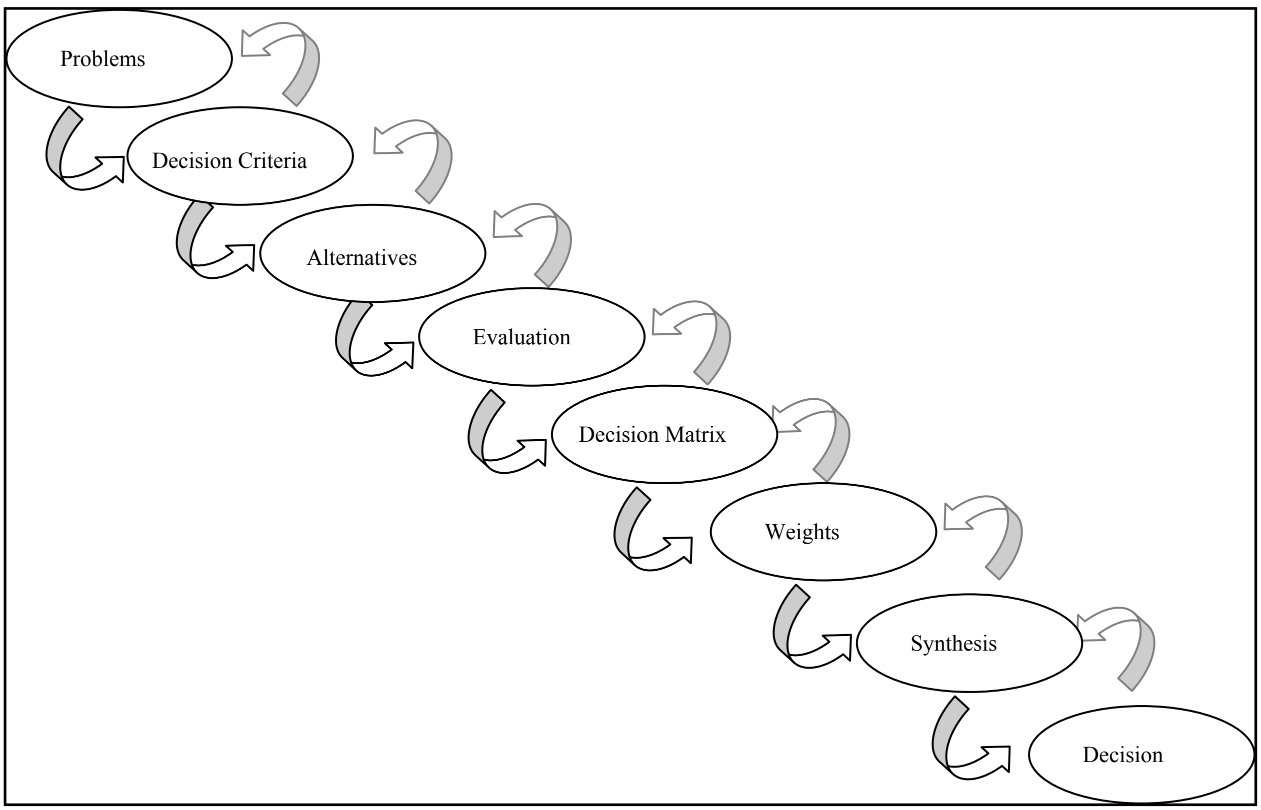

Figure 1. The iterative steps of MCDA.

The intent of MCDA is to improve the quality of decisions when multiple criteria are in play, and it does this by making complex decision processes more explicit, rational, and efficient. While these elements are presented in the form of a sequential list, *it is important to note* that iterations among these steps may be necessary and that subsequent steps may provide insights or information that require revision of preceding steps (Figure 1). For example, it may be difficult for a manager to arrive at precise judgments about the relative importance of different criteria. In such cases, a manager could make preliminary value judgments and follow the MCDA process to arrive at a potential optimal decision. The manager would then carefully consider that tentative decision. Should the decision appear to be counterintuitive or result in particularly negative impacts for some objectives, the manager would revisit and reassess the preliminary judgment, as well as decision steps made earlier in the process. The idea here is not to arrive at a predetermined decision, but to use an iterative process to more accurately understand the decision landscape and more effectively build the decision process.

As a part of this process, it is also critical to carefully and accurately identify stakeholders and other participants in the decision process, since MCDA depends on assessments of stakeholder preferences, values, beliefs, etc., relative to the fundamental objectives being addressed. A more in-depth definition and discussion of each of the above steps is provided below and some of the issues relative to SAR management are addressed.

Identify and define core issue or problem. Framing the problem to be solved is one of the most difficult and critical tasks in the decision-making process because it forces decision makers to clarify their objectives. Framing also helps to identify which attributes should be considered in judging decision outcomes and which criteria should be used in assessing progress toward objectives. Framing helps to establish the spatial and temporal scales that are needed for modeling decision outcomes. For example, the preferred alternative may change with the spatial resolution chosen for an analysis; therefore, factoring such spatial variation into how the framework is used should be considered. Similarly, the most preferred decision may vary as a function of the timeframe under consideration: a longer project timeframe may lead to a preference for alternatives with higher fixed costs and lower operational/maintenance costs.

Many of these points are best illustrated by exploring a hypothetical case. For example, different species or distinct populations of tortoises, some of which are SAR or TES, are found on numerous Army and Army National Guard installations. An important objective for SAR tortoise management could be to "minimize the negative effects of training on gopher tortoises while achieving military training goals." However, this objective is actually a second tier objective, and arises from the more fundamental objective of "preventing regulatory prohibitions relative to tortoises that might inhibit the training capabilities of the installation." Understanding the fundamental objective, then, might significantly modify the breadth and composition of the array of alternative actions facing the manager. For example, partnering with other agencies managing tortoise populations on other lands to significantly augment their effectiveness could ultimately relieve pressure on installations.

Identify objectives and determine appropriate criteria. Management alternatives should be evaluated and ranked based on their ability to optimally satisfy multiple management objectives. Important questions to be considered at this step include:

- What are the important objectives that will be the basis for the success or failure of the decision or action?
- What are the criteria that will be measured in order to assess how the decision meets objectives?

- How will those criteria be measured? What are the temporal and spatial windows for those measurements?

It is important to acknowledge here that there will be "conflicts" among alternatives as measured by the criteria used, resulting in the need to make tradeoffs. For example, a tradeoff may exist between achieving any significant benefit from a project and minimizing cost. As a consequence of such "conflicts," a given alternative may not take clear precedence over other alternatives in respect to every criterion for evaluating performance. This may present a dilemma to decision-makers, who are trying to choose a single alternative for implementation. It is important to place development of criteria before formulating alternatives because the "hard thinking" that goes into developing the criteria can create an improved set of criteria from which to formulate alternatives; this in turn permits stakeholders to focus on thinking about the objectives rather than anchoring themselves to favored criteria (Keeney and Raiffa 1976).

In the hypothetical case, objectives can relate to a wide variety of factors, including potential impacts to land accessibility for training, ecological factors that favor SAR recovery or persistence, factors associated with relationships between stakeholders, costs in time or funds, public perception, impacts to other species, the manager's values regarding environmental stewardship ("environmental ethic"), etc. For example, the manager seeks a management action that will result in the following objectives:

1. No regulatory encroachment on lands available for training.

2. Adequate habitat for tortoise populations to maintain or expand in number.

3. Favorable reception by the general public, particularly non-profit tortoise advocacy groups.

4. Costs within annual budget allocation for nongame management on the installation.

5. Actions that do not violate the manager's strong professional sense of duty to protect the environment and the installation tortoise population.

Unfortunately, many of these objectives are likely to conflict and a solution that is *optimal*, not *maximal*, in meeting these objectives is likely to be required. In order to assess the impact of alternative actions on these objectives, the following criteria and initial measures against criteria, might be identified:

1. A requirement or recommendation from a permitting agency (e.g. USFWS) that track-vehicle training be limited on the select parcel (measured as hectares/day not available for training).

2. Requirement that a certain square acreage of suitable habitat is available for tortoises on the installation (measured as hectares of available habitat, with an ideal total area of 2 ha for 1.5x the current census number of tortoises on the installation).

3. No lawsuit. Measured as risk of lawsuit.

4. Cost no greater than 70 percent of available budget for nongame management (measured in dollars).

5. Decision must be ethically acceptable to the manager (measuring this acceptability will require some tools associated with MCDA).

Identification of alternatives decisions and actions. Identification of alternatives is the process of building alternatives that meet project objectives and account for project constraints. The likelihood of completing the alternatives formulation process successfully is increased if the knowledge, experience, and judgments from many professional disciplines, as well as the views of stakeholders, other agencies and non-governmental organizations (NGOs), and the public are utilized.

In the hypothetical example, the manager might be faced with several alternative management actions, including:

- A1. Relocating tortoises to little-utilized areas of the installation and modifying habitat (creating glades within a forested parcel) in those areas to better match tortoise habitat requirements.

- A2. Halting track-wheel training around burrows, as well as training in all areas of tortoise habitat during critical periods when gopher tortoises are dispersing.

- A3. Agreeing with USFWS to fund an "outside the fence" purchase of a large parcel of unprotected tortoise habitat from a private landowner whose property is adjacent to the wildlife refuge, in return for an agreement that no restrictions on installation training be recommended.

Alternative action A_1 raises a concern for the manager about impacts to important woodland species, namely turkeys, and the decision maker adds another objective to the decision process:

6. Action does not negatively impact turkey populations on the installation.

The manager is primarily concerned about forage availability and sets his criteria as:

7. No more than 10 percent reduction in mast trees in wooded parcels (measured as percent reduction in mast trees).

Of course, there will have to be tradeoffs in the degrees to which different objectives are satisfied, as none of the three alternative decisions will maximally satisfy all of them. For example, implementation of A_1 would allow for training to proceed unhindered, could provide enough habitat to maintain and grow tortoise populations if relocation is successful, is unlikely to be met with enthusiasm by USFWS and advocacy groups who are concerned about success of relocation, would be costly, would result in loss of mast trees, and may run contrary to the manager's environmental ethic. Alternative A_2 would meet all species management objectives, please regulatory and public stakeholders, and would not incur many direct costs. However, the military training mission would suffer. Likewise, the manager will likely be highly concerned about any reduction in training capabilities. Alternative A_3 would potentially result in no reduction in training, may be looked on positively by the regulatory agency and advocacy group, and could benefit the species as a whole, but would incur considerable cost and may be unpalatable to the manager's environmental ethic.

MCDA is a process that challenges the manager to select a preferred alternative among a range of competing alternatives, where the "preferred alternative" may or may not outperform other alternatives with respect to any single criterion, but balances its performance across multiple objectives and provides an optimal decision based on available information and current values. Furthermore, the MCDA approach can assist the manager to screen out clearly inferior alternatives so that the number of possible options is reduced.

Once objectives and criteria are defined, and alternative decisions are described, the expected or estimated performance of each alternative is assessed. The following section discusses how to quantify the performance of each alternative action or decision relative to the various objectives and criteria.

Quantification of impact. The quantification of impact should represent the expected performance of each alternative action against each objective. It can be predicted using historical data, expert judgment, models or simulations, and/or research projects.

When using models or simulations it is important to understand that they are, necessarily, simplified scenarios and are subject to different sets of assumptions and limitations. However, models can be very useful tools for exploring hypothesized cause-and-effect relationships associated with alternative decisions for SAR management, and may lead to insights about unexpected relationships among the decision objectives.

During the modeling process, interactions among scientists, managers, and stakeholders are essential. Although the function of these three groups can overlap or vary, managers spend much effort defining the problem and have responsibility for the final decision and policy implementation. Stakeholders may provide input to define the problem, but they also contribute by formulating criteria and contributing value judgments such as assigning the weights for management criteria. Scientists and engineers may act as stakeholders, but generally they have the most focused role in that they provide the measurements or estimations of success for the various alternatives on the desired criteria. Stakeholders and managers are required to provide input into the model or its interpretation. Such input may take the form of subjective judgments about the impacts of alternative decisions on criteria or about the importance (weight) of different criteria (described in the section titled "Value assessment and tradeoffs." Models may allow managers to conduct "what if" analyses to test different inputs from participants in the decision process.

An example of a decision-making problem related to the hypothetical SAR management scenario is demonstrated in Table 1, where no predictions of the performance of each alternative decision against each objective are tabulated. As one can see, no alternative dominates the other alternatives across all criteria. Nevertheless, a manager must select a management alternative that maximally meets professional values, protects the SAR from declines that might require future listing as TES, minimizes impacts to the military mission, turkey abundance, and biodiversity, and incurs the least cost (time and funds).

Table 1. Example of decision criteria for SAR management.

Alternative SAR Management Decisions	Estimated Impacts of Alternative Decisions Relative to Criteria for Multiple Objectives					
	Hectares/day *un*available for training	Relative amount of suitable habitat available	Risk of lawsuit	Cost relative to nongame budget	Acceptability of manager (environmental ethic)	Percent Reduction in mast trees
A1. Relocating the SAR	0	150%	60%	55%	Low-Moderate	9%
A2. Restricting training activities	600	100%	0%	0%	High	0%
A3. Funding outside the fence conservation actions	0	150%	30%	100%	Moderate	0%

Value-scaling. After predicting each alternative's performance against the various criteria, trade-off analyses can be used to quantify the relative degree to which the alternative actions satisfy each objective. Here, predicted performance of an alternative against a criterion can be translated into a measure of how well an objective is satisfied, and is measured on a "value scale" between 0 and 1, (0 = worst value, 1 = best value, respectively). Value scaling can take the form of a single value function or a "utility function," and reflect a manager's or stakeholder's preferences regarding different values within each objective's criterion. In each case, the combined measure and relative value are transformed into a relative measure on a 0 to 1 scale of preferability (with an increasing score representing increasing preference). Each objective will require its own value or utility function and each function can take one of three shapes: linear, nonlinear, or stepwise.

In the hypothetical example, for instance, the manager may feel that any amount of suitable tortoise habitat less than that needed to support 100 tortoises is equally unattractive, that any amount over that needed to support 250 tortoises is equally attractive, and that as values in between increase, attractiveness increases. Such a value curve would be sigmoidal (S-shaped). The manager might also decide that a loss in mast trees from 0-3 percent would be equally attractive, that a loss of mast trees from 4-7 percent would be equally attractive, but less attractive than the lower 1-3 percent range, and the loss of mast trees from 8-10 percent would be equally unattractive and a worst-case scenario. This value function would describe a step-wise relationship. And, as a final example, the manager may decide that any loss of access to tortoise habitat for training purposes is equally unattractive. This value function would describe a linear relationship.

The "value-scaling" approach can provide a quick check where any alternative actions that are clearly superior or unacceptable (for instance, any alternative that clearly outperforms or under-performs all other alternatives for all objectives) can be identified. In the hypothetical case (Table 2; Figure 2), however, no alternative is a clear winner or loser.

Table 2. Example of the value-scaling approach in decision criteria for SAR management.

Alternative SAR Management Decisions	Estimated Impacts of Alternative Decisions Relative to Criteria for Multiple Objectives					
	Hectares/day *un*available for training	Relative amount of suitable habitat available	Risk of lawsuit	Cost relative to nongame budget	Acceptability of manager (environmental ethic)	Percent Reduction in mast trees
A1. Relocating the SAR	1	1	0	0.5	0	0
A2. Restricting Training Activities	0	0	1	1	1	1
A3. Funding outside the fence conservation actions	1	1	0.5	0	0.5	1

Figure 2 is a "value path" visualization of the predicted performance data (Table 2). The vertical axis represents the rescaled performance (i.e. between 0 and 1, representing the worst and best values, respectively) for each criterion. In this example, no alternative decision absolutely dominates all criteria, nor does any alternative clearly underperform the others. Therefore, in this example, no alternatives can be screened out. To reach an optimal solution (since there is no maximal solution), trade-offs (sacrificing desired outcomes in some criteria in order to satisfy desired outcomes in other criteria) will have to be explored to select one of the alternatives. An approach referred to as "value-elicitation" can be used to help identify the desired trade-offs and best alternative (described below).

Utility functions, while applicable for SAR management, have also been used in various other ecological applications including fisheries management (McDaniels 1995), management of an endangered species (Maguire and Boiney 1994), nuclear power plant siting (Keeney and Robilliard 1977), utility conservation planning (Hobbs and Horn 1997), forest management (Levy et al. 2000; Bertrand and Martel 2002; Van Elegem et al. 2002), reserve selection for biodiversity (Reyers et al. 2002), and the location of industrial-waste plants (Maniezzo et al. 1998).

Value assessment and tradeoffs. If no alternative is clearly superior to all others following value-scaling, the next step would be to explore trade-offs among objectives (sacrificing desired outcomes for some objectives in order to better satisfy desired outcomes in others). Trade-offs provide additional weighting to the predicted performances of various alternatives and, hopefully, improve the manager's ability to discern an optimal decision. One approach that can be used to weigh and quantify the importance of each objective relative to solving the identified problem or issue is "value-elicitation." Two steps are commonly used in the value-elicitation process: weighting and amalgamation (Hobbs and Meier 2000).

Weighting reflects the different levels of importance assigned to each objective and is based on the degree to which the manager and other stakeholders are willing to trade off different levels of performance between objectives. If they feel that objective A is just as important as objective B, then the weights for both objectives would be equal. However, if the manager and other stakeholders feel that improving objective A would be more important than improving objective B, they can develop a ratio expressing that preference. An example from the hypothetical scenario is how much of an increase in financial cost is the installation willing to absorb in order to increase area of protected habitat by 20 ha, or how many training hours is the installation willing to sacrifice within the tortoise habitat to reduce the risk of regulatory encroachment by 50 percent?

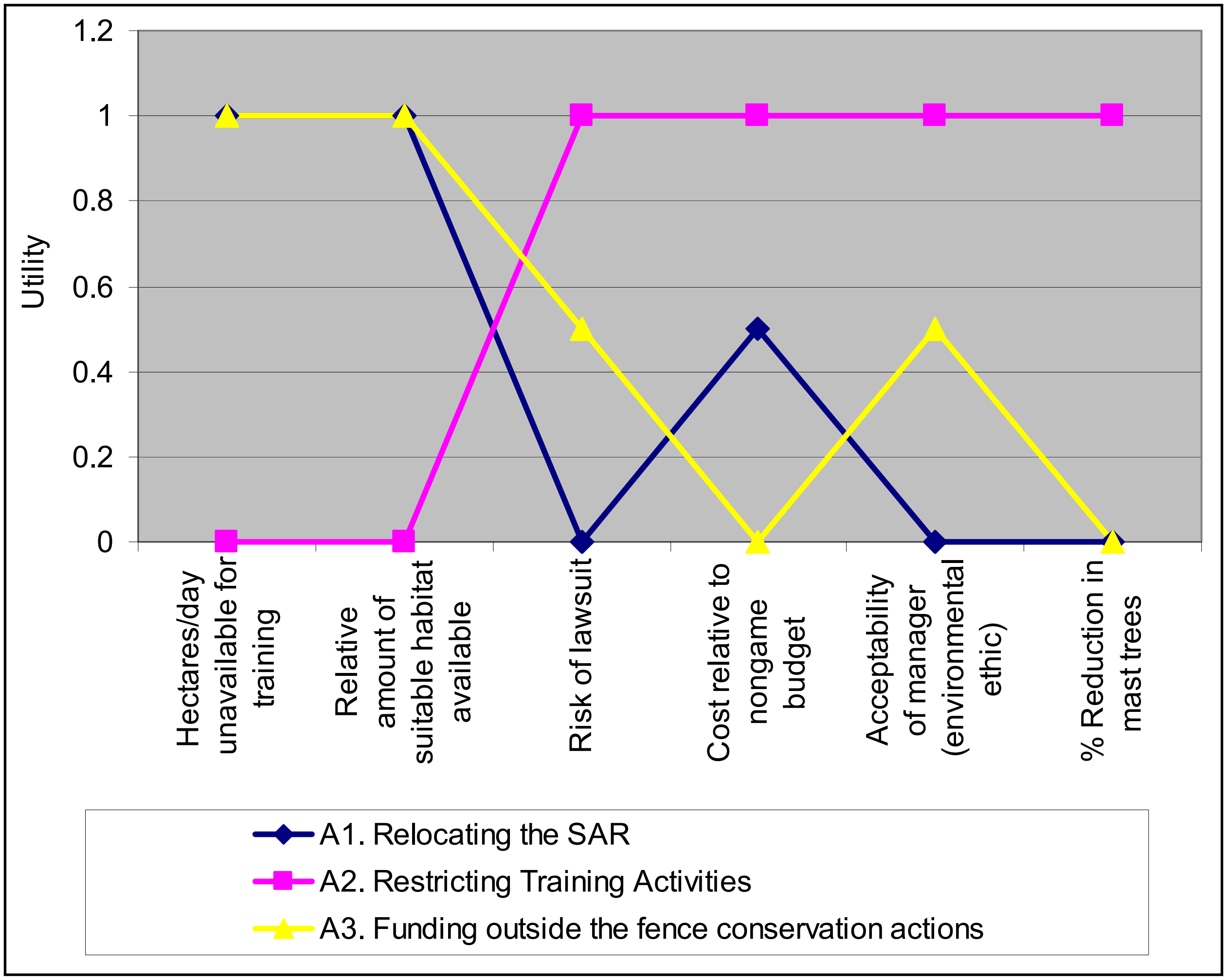

Figure 2. An Example Value Path Diagram for SAR Management.

Several techniques for determining trade-off values and assigning weights can be employed, including the analytic-hierarchy process and the gamble, swing, and trade-off methods (Watson and Buede 1987). For example, in the commonly used swing weight method, the participants (manager and other stakeholders) start with a hypothetical alternative decision that comprises all the least acceptable criteria values for all objectives that would be equally rejected by all participants as their least-preferred alternative. The participants are then asked to select which objective and criteria value they would most support changing from the least favored value to the most favored value. This objective is then removed from consideration and participants are asked to select the next objective they would most support changing from a least-favored criterion value to most-favored criterion value, and so on until no objectives are remaining. Then, for each objective, participants are asked to rate their overall satisfaction (on a 1-100 scale) for a hypothetical alternative where all objectives are at their worst criterion value, except the focal objective, which is at the best criterion value. The satisfaction rating for the alternative where the most favored objective has the one best criterion value is automatically assigned a 100 value and all other ratings are relative to this hypothetical alternative. In this fashion, participants provide a weight reflective of perceived "importance" to each objective. It should be noted that research (e.g. Hobbs 1986) has shown that different weighting methods can result in different weights for the same objectives and that two or more methods can be used to ensure accuracy and consistency of weightings.

Once the utility weights have been determined for each objective, an aggregate utility score can be calculated for each alternative decision. This aggregate score can be calculated as follows:

$$U\left(\underline{X}\right)=\sum_i w_i u_i\left(x_i\right)$$

where w_i represents the value scale weighting within that objective i ($\Sigma_i w_i = 1$), $u_i(x_i)$ is the performance level of the objective, and $U(\underline{X})$ is the overall utility of an alternative. In other words, the overall utility score for an alternative is based on the sum, across objectives, of that alternative's impact on each objective and the relative importance of each objective. After calculating the final aggregate score for each alternative, the competing management actions can be ranked according to their respective overall utility scores and the optimal decision can be tentatively identified (Keeney and Raiffa 1976).

For example, if, in the hypothetical SAR tortoise management scenario, the manager and other stakeholders decide that keeping costs low is much more important than any other objective, then restricting training within tortoise habitat could be the preferred alternative, although it underperforms the other alternatives for nearly every other objective. However, if maintaining land access for training is the foremost priority, then relocation of tortoises or funding "outside the fence" conservation may be attractive and the optimal decision would be more difficult to determine and would be strongly influenced by the relative importance of the other objectives. For example, if perception by non-profit groups that are tortoise conservation advocates, and reduced risk of being sued, is, by a large margin, the second-most important objective, then option A_3, funding outside-the-fence conservation and permitting track vehicle training on installation tortoise habitat, would be the optimal decision. In most cases, though, the decision process will be complicated by many factors with more closely valued levels of importance. In the hypothetical case, the manager and stakeholders rank access to training as the most important objective, followed by the others until the least important objective, reduction in mast trees, is identified (Table 3).

Table 3. Ranking and weighting of objectives in hypothetical SAR tortoise management scenario. Numbers in parentheses indicate the normalized weight.

1.	Hectares/day *un*available for training	100 (0.22)
2.	Relative amount of suitable habitat available	90 (0.20)
3.	Risk of lawsuit	90 (0.20)
4.	Cost relative to nongame budget	70 (0.15)
5.	Acceptability of manager (environmental ethic)	60 (0.13)
6.	Percent Reduction in mast trees	30 (0.06)

With these trade-off weightings in hand, the alternative decisions are accordingly ranked (Table 4):

Table. 4 Aggregate score and ranking for alternative decisions in hypothetical SAR tortoise management scenario.

A1. Relocating the SAR	51.1
A2. Restricting Training Activities	56.8
A3. Funding outside the fence conservation actions	60.2

In this case, as in all other MCDA efforts, ranking alternatives based on their aggregate scores is not the final step of the process.

In the end, the manager and stakeholders must reflect on the outcome of the rankings and consider the degree to which they address the issue or problem, and meet the requirements of the stated objectives – in essence, conducting a reality check. Because the MCDA process is potentially complex and involves numerous steps, this is an important validation point to make sure that critical concerns have not been lost or forgotten along the way. Thus, it should be noted that the purpose of decision analysis is not to calculate a right answer that should be automatically acted upon, but rather to increase manager and stakeholder understanding of the nature of the decision that must be made and the value conflicts and tradeoffs that must be confronted. MCDA thus provides a transparent, defensible approach to arriving at decisions and making important compromises.

In the hypothetical case, complicated trade-offs were required among competing objectives (see Figure 2 and Tables 2 and 3). If the manager and stakeholders carefully and honestly follow the MCDA process shown in the example, the result should be recommendations and valuations about tortoise management that can be made with confidence.

Examples of applications of trade-offs in managing real-world natural resource issues include comparing alternatives for fisheries management and eutrophication mitigation (Reckhow 1994; McDaniels 1995; Anderson and Hobbs 2001), water conservation (Kindler 1998), natural reserve selection (Rothley 1999), and water quality improvement (Ridgley and Rijsberman 1992).

CONCLUSION: Multicriteria decision analysis has been shown to be an effective tool for SAR management when management decisions are confounded by multiple competing objectives. Achieving consensus in complex natural resource management problems represents a considerable challenge because people often have differing and sometimes irreconcilable views, differing priorities, differing objectives, and differing beliefs about outcomes. MCDA and its associated tools provide a means to identify the basis for disagreements that hinder cooperation and negotiation. Through interviews and group discussions within the MCDA process, the stakeholders and managers can facilitate a reexamination of their values, reflect on implications, and resolve inconsistencies. Decision analysis can help address SAR management because MCDA provides a formal and transparent structure within which stakeholders and managers can review and apply management criteria, effectively communicate those criteria, and thoroughly document the decision-making process.

A number of different MCDA techniques are available to address SAR management issues, making it difficult to select a technique that is 'most suitable' for a given situation. Several commercially available software products may be suitable.[1] Each software product uses a different technique to develop a decision model, so each has its inherent strengths and weaknesses. As discussed below, users should consider using more than one technique for a given SAR management issue. Users are encouraged to seek expert advice on the use and application of such tools when applying them to SAR management problems to ensure that the appropriate decision-making techniques are applied to a given situation.

The ranking of alternative management decisions may change somewhat depending on the MCDA method employed, and it is often recommended that decision makers employ "multiple platform analysis" (i.e. analysis of the same problem using more than one MCDA technique simultaneously). Multiple platform analysis can result in an increased depth of understanding of the problem and help managers think harder about a problem, develop a more consistent set of preferences, increase confidence in their judgments, and reduce scrutiny of the SAR management decision-making process. And, finally, it must be noted that there is no such thing as a foolproof "right answer," even when applying multiple approaches. MCDA has the objective of providing optimal answers within the limits of available information, but will work best within an adaptive management framework where new information can lead to new alternatives and decisions.

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> Suedel, B. C., J. B. Kim, and R. F. Lance. 2010. Applying multicriteria decision analysis to managing species at risk and other critical resources on military installations. ERDC TN-EQT-10-2. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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[1] Examples of decision analysis software include *Decision Lab, Expert Choice,* and *Criterium DecisionPlus*. There are other packages, and the authors do not officially endorse any particular package.

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Appendix A. Definitions

Alternative: Any detailed scheme, program, or method worked out beforehand to accomplish an objective.

Criterion: A parameter or attribute that can be used for measuring the performance of alternative decisions in respect to stated objectives.

Multicriteria Decision Analysis (MCDA): A set of techniques for structuring and analyzing complex decisions.

Objective: A statement that describes what a decision-maker wants to achieve.

Species at Risk (SAR): Species that are rare but are not protected under the Endangered Species Act.

Value-scaling: Normalizing process for each criterion which has different units and assigning relative importance between criteria.

Stakeholder: Any organization, governmental entity, or individual that has a stake in or may be impacted by a given alternative.

Utility Function: A combination of values with perceptions of risk or uncertainty relative to the impacts of alternative decisions on decision criteria.

Value Function: A reflection of personal preferences that does not incorporate any uncertainty about the impacts of alternatives on decision criteria.