Incorporating Multiple Criteria into the Design of Conservation Area Networks

Sahotra Sarkar*,
Alexander Moffett*,
Rodrigo Sierra[†],
Trevon Fuller,*
Susan Cameron,[*,§]
and
Justin Garson*

* Biodiversity and Biocultural
Conservation Laboratory,
Section of Integrative
Biology,
University of Texas, Austin,
1 University Station, #C3500,
Austin, TX 78712 –1180

[†] Department of Geography,
University of Texas, Austin,
1 University Station, #A3100,
Austin, TX 78712 –1180

[§] Present Address: Graduate
Group in Ecology, Department of Environmental
Science and Policy,
One Shields Avenue,
University of California,
Davis, CA 95616 -8573

Abstract

A two-stage protocol for the design of conservation area networks which allows multiple constraint synchronization is described. During the first stage areas are selected to represent components of biodiversity up to specified targets as economically as possible. The principal heuristic used is complementarity. This process results in a set of conservation area networks which comprise the feasible alternatives for the subsequent analysis. During the second stage, multiple criteria (including spatial configuration criteria, vulnerability criteria, and socio-political criteria) are used, first to select the non-dominated feasible alternatives, and then to refine the non-dominated set further. This refinement is performed using a modification of the analytic hierarchy process.

Resumen

Describimos un protocolo de dos etapas para el diseño de una red de zonas que permita la sincronización de múltiples limitantes. En la primera etapa, se eligen zonas representativas de la biodiversidad hasta obtener en la manera más económica posible las metas especificadas. La complementación es la heurística usada. Este proceso genera una red de áreas de conservación que constituyen en alternativas viables para ser analizadas subsecuentemente. Durante la segunda etapa, usamos criterios múltiple (incluyendo criterios de configuración espacial, de vulnerabilidad, y político-social) primero para seleccionar alternativas viables no dominantes, y luego para refinar aun mas la selección del grupo no dominante. Para lograr la selección usamos una variación del proceso de jerarquía analítica.

Introduction

Conservation areas consist of sites at which biodiversity management plans are implemented (Sarkar 2003). Traditional conservation areas include national parks and wildlife reserves; more recent categories include biosphere reserves and community conservancies. The first stage in the design of a conservation area network (CAN) consists of ensuring the adequate representation of all surrogates for biodiversity (for instance, species, ecosystems, habitats, *etc.*) in a network of selected places. Adequacy of representation is measured by the satisfaction of an explicit quantitative target of representation for each surrogate, such as, 100% of occurrences for a critically endangered species, or 10% of occurrences for a common species. In principle, these targets are supposed to reflect the biological requirements for the indefinite persistence of each surrogate. In practice, these targets often only reflect socio-economic constraints and are established by planners, usually in consultation with scientists (Soulé and Sanjayan 1998). Since not all areas of biological interest can be set aside for conservation because of competing claims on land, it is often imperative that this representation be achieved as economically as possible, with as few sites as possible being set aside for conservation (Margules *et al.* 1988).

The representation problem comes in two versions: 1) achieve the specified targets of representation for biodiversity surrogates in as few sites as possible, and 2), given a maximum budget of sites that can be included in a CAN by satisfying the targets of representation for as many surrogates as possible (Sarkar *et al.* 2004b). Both of these problems can be formulated as constrained optimization problems in the formalism of mathematical programming, and solved using "branch-and-bound" algorithms, which are guaranteed to produce the best solutions (Nemhauser and Wolsey 1988). However, these optimal algorithms are computationally inefficient and cumbersome to use. Consequently, conservation biologists have devised a variety of heuristic algorithms which solve the problems rapidly and generally achieve almost as much economy as the optimal algorithms (Csuti *et al.* 1997; Pressey *et al*. 1997). Most of these algorithms are based on the principle of complementarity (Margules *et al*. 1988; Justus and Sarkar 2002): sites are added iteratively to a CAN on the basis of how much representation they provide for surrogates which have not yet met their targets in the sites that are already selected. Other iterative heuristic rules that have been commonly used include the prioritization of sites by the rarity of the surrogates present in them.

The second stage of network design is the refinement of the set of CANs which satisfy the biodiversity representation targets in order to incorporate other criteria. These criteria generally fall under three categories: 1) spatial configuration criteria (such as, size, connectivity, and dispersion of the conservation areas.); 2) persistence criteria (such as population viabilities, measures of threat and vulnerability); and 3) socio-political criteria (such as economic and political costs). These criteria are not mutually exclusive. For instance some spatial configuration criteria, such as size and connectivity, are usually also persistence criteria.

Refinement using these criteria is often difficult because of two reasons: 1) not all of the criteria can be directly measured on the same quantitative scale; and 2) typically, not all of them can be optimized simultaneously, requiring the use of trade-offs between the alternatives. Methods for the incorporation of such criteria into CAN design are currently a topic of ongoing research. (In some protocols for CAN design, some of these criteria are incorporated into the basic site prioritization process)

We describe here a two-stage protocol for CAN design and illustrate its use by analyzing a data set from continental Ecuador. This protocol uses a modified version of the analytic hierarchy process (AHP) to avoid some well-known paradoxes of the original version while maintaining consistency with traditional multiple attribute utility theory (MAUT). It should be stressed that the results presented here are intended only as an illustration of these methods; they are not intended to guide policy choices in the field without further refinement. We will then describe how the data set from Ecuador must be treated for use in a planning protocol. Subsequent sec-

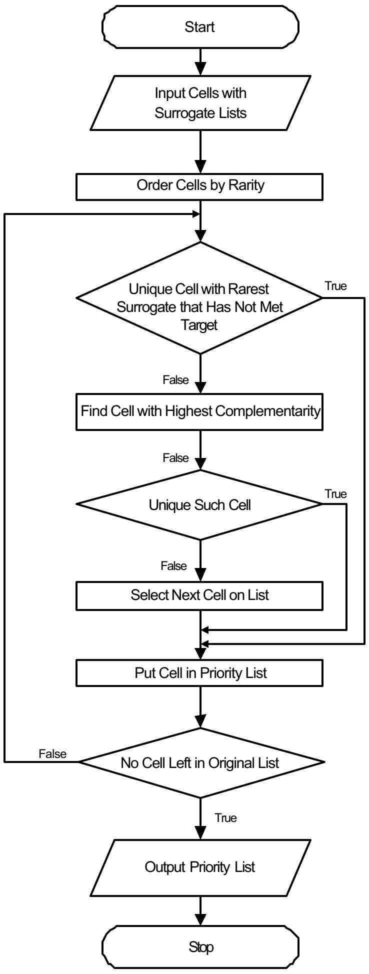

Figure 1. Rarity-Complementarity Algorithm for Site Prioritization. This algorithm belongs to the family of algorithms originally introduced by Margules *et al*. (1988). A rarity-complementarity algorithm is used because it is generally known to give economical solutions (Csuti *et al.* 1997; Pressey *et al.* 1997). However, Sarkar *et al.* (2004b) have recently observed that pure complementarity algorithms also perform as well when probabilistic data are used. The algorithm used to generate the results used in the text differs from this basic procedure in three ways: (i) there is a test for adjacency after the test for complementarity; and (ii) the exit condition is the satisfaction of targets for all surrogates—see the text for more detail.

tions will then show how these data can be used for biodiversity representation and subsequent multicriteria analysis. The software necessary to use this protocol can be freely downloaded from the web.

Data Preparation

The type of data transformations that are required for systematic conservation planning will be illustrated using a data set for continental Ecuador (excluding the Galápagos Islands) which, with an area of 248 750 sq. km sq. km., is small in size but rich in biodiversity. Since geographical distributions of species are not currently available for a representative set of taxa, systematic conservation planning must be based either on abiotic environmental surrogates or modeled distributions of coarse biological surrogates. This analysis started with a 200 ´ 200m raster grid on which the modeled distributions of 46 major vegetation types were mapped. These vegetation types span the entire floral range of Ecuador. (See Sierra [1999] and Sierra *et al.* [2002] for details on the classification and modeling of the distribution of the vegetation types.) At this spatial scale, each data cell contains one vegetation type. This scale of resolution was reduced to a 2 ´ 2 km grid in which each new cell consisted of 100 of the original cells. The motivations for the scale change were to improve computational efficiency because of the reduced size of the data set and to use sites that are of appropriate size to be regarded as units of conservation.

The analysis kept track of the vegetation types in each of the original cells that were compounded to make a new cell. Each of the new cells can potentially contain at most 46 vegetation types. For each cell, for each vegetation type, the probabilistic expectation of the presence of that type in that cell was set equal to its proportion in the original 100 cells. Thus, if all the original cells contain exactly the same vegetation type, then that type has an expectation equal to 1 and each other type has an expectation of 0. Place prioritization algorithms have recently begun to use expectations because they can represent abundance data for surrogates (Sarkar *et al.* 2004b). Traditionally, these algorithms have only used data that are of surrogate presence (represented by 1) or absence (represented by 0).

The map of Ecuador was further modified by masking areas that were permanently transformed by anthropogenic modification as of 1996 (see Sierra *et al*. [2002]) and are, therefore, inappropriate for inclusion in a CAN. In this way 39% of the cells were excluded . The Ecuadorian national reserve system (NRS) was also represented on a 2 ´ 2km grid. The target of representation for each vegetation type was set to 10 % of the untransformed area in which that type occurred. Thirteen of the 46 vegetation types do not meet this target within the NRS. Any target of this type is a social choice reflecting a compromise between assessments of what is politically achievable and what is biologically desirable. The 10 % target is consistent with that proposed by the International Union for the Conservation of Nature (IUCN) (1994). A slightly higher target of 12% (though of the total land area and not for the habitat of each biodiversity surrogate) is currently being used for Canada (Hummel 1995), and much higher targets have occasionally been proposed (*e.g*., Ryti 1992). The protocol being discussed here can be carried out for any explicit target.

Site Prioritization

Given a list of cells (with each cell representing a site for potential inclusion in a CAN) and a list of the probabilistic expectations of biodiversity surrogates for each cell, a variety of algorithms can be used to select sites for inclusion in a CAN. The basic form of the algorithm used here is shown in Figure 1 (see also Sarkar *et al.* [2002]). Two additional steps were implemented. First, when ties remain after selecting cells on the basis of rarity and complementarity, cells that are adjacent to ones already selected are given preference. This preference for adjacency results in larger conservation areas. Second, the selection process terminated as soon as each vegetation type achieved its 10 % target of representation. The selection procedure was initiated using the existing NRS of Ecuador. Thus, the final solution records the minimum number of cells that must be added for the satisfaction of those targets according to this heuristic algorithm.

One-hundred different solutions were generated using randomized re-orderings of the data set. These re-orderings generated different solutions because they resulted in the selection of different cells when ties were broken by lexical order (that is, by selecting the next cell in the list of cells). All computations were carried out using the ResNet software package (Garson *et al.* 2002). Figures 2 and 3 show two of the solutions generated in this fashion.

In general, iterative procedures, such as the one used here, have the advantage that the biological reason for the selection of a cell in a CAN is explicitly known (for instance, whether it is selected because it contains more rare surrogates than other cells, has a higher complementarity value, or is adjacent to previously selected cells). Data of this sort facilitate the selection of alternative sites if, for unforeseen reasons, an initially selected site cannot be included in a CAN. However, less transparent procedures such as simulated annealing have also been successfully used for site prioritization (see Possingham *et al.* [2000]).

Multiple Criteria

Because each potential CAN obtained from the site prioritization stage satisfied the surrogate representation targets, from the perspective of biodiversity representation, each such CAN is an appropriate solution: these are called alternative "feasible" solutions. The second stage of CAN design consists of incorporating other criteria to rank the feasible alternatives. This stage is critical to conservation planning for two reasons: 1) selecting CANs is of practical value only if these are implemented as a part of a conservation plan. Implementation always occurs in socio-political contexts in which biodiversity conservation and other potential uses of the land (including agricultural development, industrial development, biological resource extraction, mineral resource extraction, recreation) must be negotiated; and 2) mere representation of biodiversity does not ensure its persistence into the future. The vulnerability of biodiversity components due to both biological and non-biological features must be taken into account.

The second stage consists of three steps: 1) an identification of the relevant criteria and the ranking of the solutions or "alternatives" according to each criterion; 2) the determination of a set of "non-dominated" (or "efficient") alternatives; and 3), if the non-dominated set is too large, further refinement of this set to find a final set of preferred alternatives. Sometimes step 3) is carried out for the entire set of feasible alternatives without first finding the non-dominated set. The entire second stage falls within the scope of multiple criteria decision making (MCDM) which consists of a variety of heuristic optimization methods as well as the well-developed multiple attribute utility theory (MAUT) and closely related variants such as the analytic hierarchy process (AHP) (Dyer 2004).

As noted earlier, the criteria to be incorporated fall into three categories which are not mutually exclusive: spatial configuration criteria; persistence criteria; and socio-political criteria. For the Ecuador data set, six criteria were used:

(1) the aggregate number of conservation areas, which should be minimized to achieve spatial cohesiveness of CANs;

(2) the average area of each conservation area, which should be maximized to encourage larger conservation areas. (This aspect of CAN design was also encouraged by the use of the heuristic rule preferring adjacency during the first stage);

(3) the variance of the areas, which should be minimized to discourage further the selection of very small areas;

(4) the aggregate distance of the selected cells to existing units of the NRS, which should be minimized, again to increase cohesiveness (the distances being calculated between the centroids of the nearest cells);

(5) the aggregate distance to anthropologically transformed areas, which should be maximized to decrease the threat of habitat destruction (the distances once again being calculated from the centroids of the nearest cells);

(6) the total area of the selection cells, which should be minimized to decrease the cost of acquisition of the added cells.

Criteria (1) –(4) are spatial configuration criteria; criterion (5) is a persistence criterion. However, both criteria [2] and [3] are also persistence criteria. Criterion (6) is

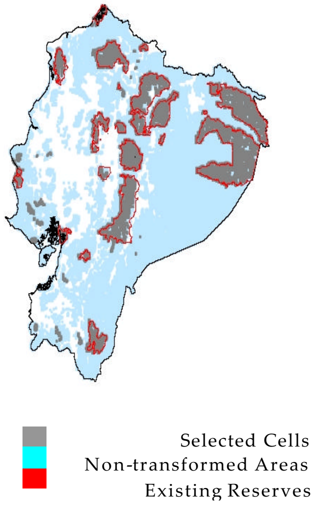

Figure 2. Best Solution for Ecuador Representing Biodiversity and Incorporating Six Additional Criteria. Because the runs were initialized with the cells belonging in the National Reserve System (NRS), the vast majority of the selected cells are within the NRS. Note that some cells within the NRS were anthropogenically transformed and were ignored by the selection procedure. The habitats that are most inadequately represented in the NRS are in the southwest of the country.

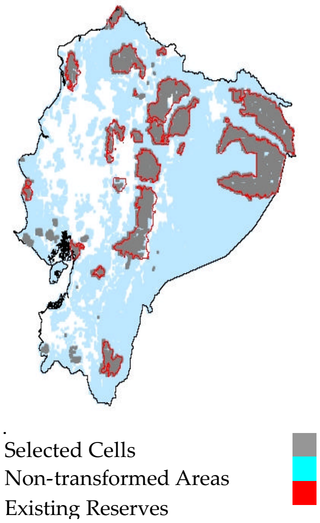

Figure 3. Second Best Solution for Ecuador Representing Biodiversity and Incorporating Six Additional Criteria. Because the runs were initialized with the cells belonging in the National Reserve System (NRS), the vast majority of the selected cells are within the NRS. Note that some cells within the NRS were anthropogenically transformed and were ignored by the selection procedure. The habitats that are most inadequately represented in the NRS are in the southwest of the country.

socio-political. In the protocol being described here it does not matter whether the criteria are independent of each other (Sarkar and Garson 2004). All 100 feasible alternatives were evaluated according to each of these criteria, which are such that a definite quantitative (numerical) value could be assigned to each alterative. For step 2 (though not for step 3 this is not essential: an ordinal ranking of each alternative according to each criterion is sufficient.

Turning to step 2, an alternative "dominates" another if: (a) it is no worse than the other according to any criterion; and (b) it is better than the other according to at least one criterion. A "non-dominated" alternative is one that is not dominated by any other alternative in the feasible set. Non-dominated alternatives correspond to the indifference curves of traditional economics. There is a natural sense in which non-dominated alternatives are special: each of these is an alternative that is uncontroversially better than all the dominated alternatives in the feasible set. Rothley (1999) advocated the use of non-dominated alternative sets in the selection of CANs; Sarkar and Garson (2004) provided a simple computationally efficient algorithm to find them. If the number of non-dominated alternatives is small, it makes sense to stop after finding them and turn over that set to political decision-makers who can then bring other non-modeled criteria to bear on them (Sarkar 2004). (Having more than one alternative enter the final political process of policy implementation is a virtue, not a limitation: it guards against the development of a biologically inferior plan should the plan originally proposed run into socio-political difficulties.)

Unfortunately, the number of non-dominated alternatives generally grows with the number of criteria. In practice, the non-dominated set must be further refined, which leads to step 3 of the second stage. For instance, in the case of Ecuador, using the six criteria listed above, 58 non-dominated alternatives were found which are clearly too many to be handed to political decision-makers in most contexts. (Figures 2 and 3 show two of these non-dominated solutions.) In step 3 each alternative must be numerically ranked according to each criterion, and the criteria themselves must be numerically ranked. However, the numerical ranking of the criteria are open to criticism as being arbitrary. This is why a CAN design process is usually regarded as more robust if it can stop at step 2 of the second stage (Sarkar 2004).

In standard MAUT a utility function is constructed to rank the non-dominated alternatives on the basis of their utility values (Keeney and Raiffa 1993; Dyer 2004). The AHP avoids the explicit construction of such a function. Instead, it elicits values on the users' implicit preference function by requiring a numerical pairwise comparison of the criteria on an increasing ratio scale, usually from 1 to 9 (Saaty 1980). This approach then generates weights, or scaling constants, for the criteria using the pairwise binary comparisons. A value of 1 indicates that the two criteria being compared have the same rank; a value of 9 indicates that changes over the range of values for the second is maximally preferred to changes over the range of values for the first. Thus, if criterion (*A*) has a ratio scale value of *X* compared to criterion (*B*), then criterion (*B*) has a ratio scale value of 1/*X* compared to criterion (*B*).

For the Ecuador data, the ratio scale ranking of the six criteria, taken in order, can be represented by the following matrix:

$$\begin{pmatrix} 1 & \tfrac{1}{2} & 9 & 3 & 6 & 7 \\ 2 & 1 & 9 & 9 & 4 & 9 \\ \tfrac{1}{9} & \tfrac{1}{9} & 1 & \tfrac{1}{5} & \tfrac{1}{6} & \tfrac{1}{2} \\ \tfrac{1}{3} & \tfrac{1}{9} & 5 & 1 & \tfrac{1}{3} & 4 \\ \tfrac{1}{6} & \tfrac{1}{4} & 6 & 3 & 1 & 2 \\ \tfrac{1}{7} & \tfrac{1}{9} & 2 & \tfrac{1}{4} & \tfrac{1}{2} & 1 \end{pmatrix}.$$

This means that changes over the range of values for criterion (2) was 1/2 as important as for criterion (1), while the changes for criterion (3) was 9 times as important as criterion (1), and so on. The eigenvector of this matrix with the highest eigenvalue provides the rankings of the criteria, which is essentially one approach to averaging the redundant comparisons. The rankings presented here were those that were found reasonable by one of the authors—they have no further claim of veridicality. The consistency of such elicited rankings can be checked, and the process iterated until an acceptable consistency level is found. The analysis of the Ecuador data set used the MultCSync software package to generate these rankings, test for consistency, and to support the subsequent analysis reported below.

The use of the AHP has been advocated in conservation planning many times (Anselin *et al.* 1989; Mendoza and Sprouse 1989; Kangas 1993; Peterson *et al.* 1994; Li *et al.* 1999; Mendoza and Prabhu 2000; Diaz-Balteiro and Romero 2001; Pesonen 2001; Reynolds 2001; Schmoldt and Peterson 2001; Clevenger *et al.* 2002; Villa *et al.* 2002; Ananda and Herath 2003), though, previously, only over the entire feasible set, without its initial refinement to a non-dominated set. Moreover, because the original AHP compounds the ranking of preferences and of the alternatives after normalizing both sets independently, this strategy leads to the paradox of rank reversal: the final ranking of two alternatives may change if new alternatives are added to the set (Belton and Gear 1982). Consequently, a modified algorithm, originally proposed by Dyer (1990), was used which avoids this problem. This modification is believed to help ensure consistency between the AHP and traditional MAUT (Kamenetzky 1982; Belton 1986; Dyer 1990; Salo and Hämäläinen 1997).

The two alternatives shown in Figures 2 and 3 are the two best alternatives found in this way, taking all six criteria into account. They select different areas in southwestern Ecuador thus potentially offering a range of alternative choices to political decision-makers. Since all non-dominated alternatives are ranked, a set of best alternatives can be presented to such decision-makers, with the number of alternatives to be presented determined by the decision-making context.

Final Remarks

The protocol described here is not the only option for incorporating multiple criteria into CAN design. An alternative strategy is to incorporate these criteria at the iterative step of selecting individual cells for inclusion of a CAN. Faith and Walker (1996) have developed such a protocol, based on complementarity, though only for two criteria (biodiversity representation and cost). Possingham et al. (1990) have developed a different such protocol, based on a simulated annealing algorithm (Kirkpatrick *et al.* 1983), but only for three criteria (biodiversity representation, area, and shaper). The main difference between the "global" strategy of the protocol described here and such a "local" strategy is that the former privileges biodiversity in the sense that every feasible alternative incorporates the representation of all biodiversity surrogates up to the specified target. In contrast, in the local strategy, some biodiversity surrogates may not achieve their target.

Acknowledgments

We thank Jim Dyer for helpful conversations and comments on an earlier version of this paper.

Software Availability

The initial prioritization of sites was carried out using the ResNet 1.2 software package (Garson *et al.* 2002). Multiple criterion synchronization used the MultCSync 1.0 software package (Sarkar *et al.* 2004a). Both software packages can be freely downloaded from http://uts.cc.utexas.edu/~consbio/Cons/ResNet.html.

Literature Cited

Ananda, J. and Herath, G. 2003. "The Use of the Analytic Hierarchy Process to Incorporate Stakeholder Preferences into Regional Forest Planning." *Forest Policy and Economics* 5: 13 -26.

Anselin, A., Miere, P., and Anselin, M. 1989. "Multicriteria Techniques in Ecological Evaluation: an Example Using the Analytic Hierarchy Process." *Biological Conservation* 49: 215 -229.

Belton, V. 1986. "A Comparison of the Analytic Hierarchy Process and a Simple Multi-Attribute Value Function." *European Journal of Operational Research* 26: 7 - 21.

Belton, V. and Gear, T. 1982. "On a Short-Coming of Saaty's Method of the Analytic Hierarchies." *Omega* 11: 228 -230.

Clevenger, A. Wierzchowski, J., Chruszcz, B., and Gunson, K. 2002. "GIS-Generated, Expert-Based Models for Identifying Wildlife Habitat Linkages and Planning Mitigation Passages." *Conservation Biology* 16: 503 -514.

Csuti, B., Polasky, S., Williams, P. H., Pressey, R. L., Camm, J. D., Kershaw, M., Kiester, A. R., Downs, B., Hamilton, R., Huso, M., and Sahr, K. 1997. "A Comparison of Reserve Selection Algorithms Using Data on Terrestrial Vertebrates in Oregon." *Biological Conservation* 80: 83 -97.

Diaz-Balteiro, L. and Romero, C. 2001. "Combined use of Goal Programming and the Analytic Hierarchy Process in Forest Management." In Schmoldt, D., Kangas, J., Mendoza, G., and Pesonen, M. Eds. *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making*. Boston: Kluwer Academic Publishers, pp. 81 -95.

Dyer, J. 1990. "Remarks on the Analytic Hierarchy Process." *Management Science* 36: 249 -258.

Dyer, J. 2004. "MAUT-Multiattribute Utility Theory." In Figueira, J.,Greco, S. and Ehrgott, M. Eds. Sate of the Art in Multiple Criteria Decision Analysis. Dordrecht: Kluwer.

Faith, D. P. and Walker, P. A. 1996. "Integrating Conservation and Development: Effective trade-Offs between Biodiversity and Cost in the Selection of Protected Areas." *Biodiversity and Conservation* 5: 417 -429.

Garson, J., Aggarwal, A., and Sarkar, S. 2002. *ResNet Ver 1.2 Manual*. Austin: Biodiversity and Biocultural Conservation Laboratory, University of Texas.

Hummel, M. Ed. 1995. *Protecting Canada's Endangered Spaces*. Toronto: Key Porter Books.

Kamenetzky, R. 1982. "The Relationship between the Analytic Hierarchy Process and the Additive Value Function. *Decision Sciences* 13: 702 -713.

Kirkpatrick, S., Gelatt, J., C. D., and Vecchi, M. P. 1983. "Optimization by Simulated Annealing." *Science* 220: 671-220.

IUCN (International Union for the Conservation of Nature).1994. *World Conservation Strategy: Conservation for Sustainable Development*. Gland: Worldwide Fund for Nature.

Justus, J. and Sarkar, S. 2002. "The Principle of Complementarity in the Design of Reserve Networks to Conserve Biodiversity: A Preliminary History." *Journal of Biosciences* 27(S2): 421 -435.

Kangas, J. 1993. "A Multi-Attribute Preference Model for Evaluating the Reforestation Chain Alternatives of a Forest Stand." *Forest Ecology and Management* 59: 271 -288.

Keeney, R. and Raiffa, H. 1993. *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. New York: Cambridge University Press.

Li, W., Wang, Z., and Tang, H. 1999. "Designing the Buffer Zone of a Nature Reserve: A Case Study in Yancheng Biosphere Reserve, China." *Biological Conservation* 90: 159 -165.

Margules, C. R., Nicholls, A. O., and Pressey, R. L. 1988. "Selecting Networks of Reserves to Maximize Biological Diversity." *Biological Conservation* 43: 63 -76.

Mendoza G. and Sprouse, W. 1989. "Forest Planning and Decision Making under Fuzzy Environments: An Overview and Illustration." *Forest Science* 35: 481 -502.

Mendoza, G. and Prabhu, R. 2000. "Multiple Criteria Decision Making Approaches to Assessing Forest Sustainability Using Criteria and Indicators: A Case Study." *Forest Ecology and Management* 131: 107 -126.

Nemhauser, G. L., and Wolsey, L. A. 1988. *Integer and Combinatorial Optimization.* New York: Wiley.

Pesonen, M. 2001. "Potential Allowable Cut of Finland Using the AHP to Model Landowners' Strategic Decision Making." In Schmoldt, D., Kangas, J., Mendoza, G., and Pesonen, M. Eds. *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making*. Boston: Kluwer Academic Publishers, pp. 219 -233.

Peterson, D., Silsbee, D., and Schmoldt, D. 1994. "A Case Study of Resources Management Planning with Multiple Objectives and Projects." *Environmental Management* 18: 729- 742.

Possingham, H. P., Ball I. R., and Andelman, S. 2000. "Mathematical Methods for Identifying Representative Reserve Networks." In Ferson, S. and Burgman, M. Eds. *Quantitative Methods for Conservation Biology*. Berlin: Springer-Verlag, pp. 291-305.

Pressey, R. L., Possingham, H. P., and Day, J. R. 1997. "Effectiveness of Alternative Heuristic Algorithms for Approximating Minimum Requirements for Conservation Reserves." *Biological Conservation* 80: 207 -219.

Reynolds, K. 2001. "Prioritizing Salmon Habitat Restoration with the AHP, SMART, and Uncertain Data." In

Schmoldt, D., Kangas, J., Mendoza, G., and Pesonen, M. Eds. *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making*. Boston: Kluwer Academic Publishers, pp. 199 -217.

Rothley, K. D. 1999. "Designing Bioreserve Networks to Satisfy Multiple, Conflicting Demands." *Ecological Applications* 9: 741 –750.

Ryti, R. 1992. "Effect of the Focal Taxon on the Selection of Nature Reserves." *Ecological Applications* 2: 404 –410.

Saaty, T. L. 1980. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation.* New York: McGraw-Hill.

Salo, A. and Hämäläinen, R. 1997. "On the Measurement of Preferences in the Analytic Hierarchy Process." *Journal of Multi-Criteria Decision Analysis* 6: 309 -319.

Sarkar, S. 2003. "Conservation Area Networks." *Conservation and Society* 1(2): v -vii.

Sarkar, S. 2004. *Biodiversity and Environmental Philosophy*. New York: Cambridge University Press.

Sarkar, S. and Garson, J. 2004. Multiple Criterion Synchronization (MCS) for Conservation Area Network Design: The Use of Non-Dominated Alternative Sets. *Conservation and Society* :

Sarkar, S., Aggarwal, A., Garson, J., Margules, C. R., and Zeidler, J. 2002. "Place Prioritization for Biodiversity Content." *Journal of Biosciences* 27(S2): 339 -346.

Sarkar, S., Garson, J., and Moffett, A. 2004a. *MultCSync Ver 1.0 Manual*. Austin: Biodiversity and Biocultural Conservation Laboratory, University of Texas.

Sarkar, S., Pappas, C., Garson, J., Aggarwal, A., and Cameron, S. 2004b. "Place Prioritization for Biodiversity Conservation Using Probabilistic Surrogate Distribution Data." *Diversity and Distributions* 10: 125 -133.

Schmoldt, D. and Peterson, D. 2001. "Strategic and Tactical Planning for Managing National Park Resources." In Schmoldt, D., Kangas, J., Mendoza, G., and Pesonen, M. Eds. *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making*. Boston: Kluwer Academic Publishers, pp. 67 -69.

Sierra, R. Ed. 1999. *Propuesta Preliminar de un Sistema de Clasificacion de Vegetacion para el Ecuador Continental.* Quito: Proyecto INEFAN/GEF-BIRF y EcoCienca.

Sierra, R., Campos, F. and Chamberlin, J. 2002. "Assessing Biodiversity Conservation Priorities: Ecosystem Risk and Representativeness in Continental Ecuador." *Landscape and Urban Planning* 59: 95 -110.

Soulé, M. E. and Sanjayan, M. A. 1998. "Conservation Targets: Do They Help?" *Science* 279: 2060 -2061.

Villa, F., Tunesi, L., and Agardy, T. 2002. "Zoning Marine Protected Areas through Spatial Multiple-Criteria Analysis: the Case of the Asinara Island National Marine Reserve of Italy." *Conservation Biology* 16: 515 -526.