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An Application of MOP and GP to Wildlife Management (Deer)

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The case study presented in this paper has been developed after several years of spreadsheet-based model and trial and error analysis for game management in Southern Spain. The experience gained in this applied planning permitted the authors to make a model for the average manager's criteria. This research proves that management models can be improved by using multicriteria approaches, especially when a satisfactory combination of methods is employed. First, an efficient set is generated for analysing the conflict between economic and ecological objectives. Second, a lèxicographical GP model obtains the management plan.

Keywords: wildlife management, goal programming, multi-objective dynamic programming, multi-criteria decision making.

1. Introduction

Natural resource management involves a search for ecological, economic and social objectives, usually in conflict when real systems are managed. Land-use planning is done at "macrolevel" by regional authorities on a large scale and with long-term planning, usually with a low level of detail. A recent example and review of heuristic methodology for land-use planning can be found in Christodoulou and Nakos (1991).

Land-use planning and natural resource management problems have been tackled by some authors during the last two decades with the use of multiple criteria decision making (MCDM) techniques. A complete review can be found in Romero and Rehman (1987). We want to focus this research on agricultural and forest systems management. In this field, we can cite the recent papers of Zadnik and Stirn (1990) in the field of dynamic programming of forest resources, and Romero (1989) applied MCDM to forest management.

The main definitions of MCDM in terms of objectives, criteria, goals, etc., can be found elsewhere; we recommend the book of Romero and Rehman (1989) as a complete review of MCDM techniques, approaches and examples of application to agricultural problems.

2. Basic review of MCDM techniques used in natural resource management

It is convenient to study briefly the different groups of MCDM techniques as applied

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to natural resource management. An excellent review is given by Romero and Rehman (1987).

The first technique is goal programming (GP). GP deals with decisions involving multiple goals. A *goal* combines an *objective* and a *target*. An objective is a measurable characteristic of a problem which can be related to the *decision variables*. A target is a desired level of achievement for any of the decision maker (DM) objectives.

2.1. GOAL PROGRAMMING

Goal programming (GP) methods try to minimize the deviations between targets and what is achievable. GP is specially adapted to decision processes with explicit environmental or social and economic goals. A variant of GP known as lexicographical GP, or weighted GP, is applied when deviations from the target for the different goals are weighted and added in an objective function.

2.2. MULTI-OBJECTIVE PROGRAMMING

Multi-objective programming (MOP) attempts to solve the simultaneous optimization of multiple objectives subject to a set of constraints. MOP seeks to find efficient solutions. The elements of the efficient set make an optimal, achievable solution for the given objectives. There are various approaches to generate the efficient set, including the weighting method, the constraint method, the NISE method and the simplex multicriteria method.

2.3. COMPROMISE PROGRAMMING

Compromise programming (CP), proposed by Zeleny (1973), is based on the notion of ideal, which is the point, usually unfeasible, defined by the independent optimum for every objective. CP was developed to help decision makers to choose an efficient solution; Romero *et al.* (1987) apply CP to agricultural planning.

2.4. INTERACTIVE MCDM

This approach consists of a progressive definition of decision maker's (DM) preferences through an interaction between it and the model. The process takes the form of a progressive analysis of trade-offs among objectives in an interactive and iterative way until the DM finds the best achievable solution. The general structure of the decision process involves two roles: the DM and the analyst with the help of a model.

Usually, the analyst obtains an initial solution from the model that is presented to the DM, which states preferences regarding this initial solution. The DM is required to state local preferences with respect to the solution presented by the analyst. This local preference serves as a guide for the analyst to look for a new solution. This new solution is generated and presented again to the DM. The process continues until a solution is considered good enough by the DM to stop the process.

The interactive methods can be classified mainly according to the way in which the dialogue between the DM and the model takes shape. STEM method (Benayoun *et al.*, 1971) starts from the ideal (the point that is defined by the independent optima for every objective, as in CP). The DM is presented the solution nearest to the ideal point (in a minimax sense); by comparing this solution with the ideal vector, the DM decides on its acceptability. If the DM is not satisfied, a decision on which attribute(s) of the solution can be worsened and which one(s) should be improved is made. The DM must also indicate the maximum degradation possible for the secondary objectives in this new iteration. The information imposes additional restraints to the problem, and new weights are attached to the objectives. The process finishes when the DM finds the best compromise solution.

Zionts and Wallenius (1980) proposed a method based on a local approximation of the DM's utility function which is a linear combination of the objectives being considered in the model. The weights that DM assigns to each objective are not known explicitly and the basis of this method is to process a different set of weights, changing their value until the DM is satisfied with a solution.

There are other methods such as interactive multiple goal programming (IMGP) proposed by Nijkamp and Spronk (1980) and by Spronk (1981). The general purpose of IMGP is to obtain the targets or aspiration levels from the DM interactively. There are other techniques included in the interactive MCDM approaches, such as surrogate worth trade-off (Haimes and Hall, 1974) method, widely applied to water resources planning, or the interactive weighted tchebycheff procedure (Steuer and Choo, 1983), among others. For a recent review and exposition of these techniques, see Romero and Rehman (1989), and for a critical assessment of the foundations of these approaches see White (1983) and French (1984).

The last of the approaches to MCDM in natural resource management is the multi-attribute utility function (MUF), which deals with discrete choices. Assuming a multi-attribute utility function, an ordering of the finite number of alternatives is made. The assumptions made by MUF regarding axioms of comparability of alternatives have led to the approach of ELECTRE (elimination and choice translating algorithm) (Roy, 1968). A critical description of discrete methods can be found in Romero (1993).

Romero and Rehman (1987) made an extensive survey on applications of MCDM methods to natural resources, updated in Berbel and Zamora (1991). Both surveys found that GP, MOP and discrete methods have a similar number of studies appearing in the literature, but that the interactive methods are less used. Water management is the most frequent field of application, followed by forestry and agriculture, with fisheries being the least frequent field of application.

3. Wildlife management

Wildlife management cannot be treated independently from other criteria in forest management such as timber yield sustainability, timber production maximization, outdoor recreation, and other economic and social factors. It is usual to find wildlife as a single criterion among others of an economic, social or ecological nature; then, the satisfaction of a certain level of the population is usually the main goal of the model. There are few examples in the literature dealing with wildlife populations as the main object of the model.

In wildlife management, it is possible to distinguish two different types of problems:

1. preservation of endangered species;
2. optimization of game uses of certain species.

This paper deals mainly with the second aspect but does consider ecological criteria and endangered species protection. The model focuses on wildlife management itself but does not take into account other forest management objectives.

Different authors deal with game management. For example, Davis (1967) proposes a dynamic linear program for deer population management in New Zealand and in a MCDM context Jordi and Peddie (1988) consider a game park in South Africa where twenty different species are simultaneously considered for commercial purposes, and different preservation goals are sought. A more comprehensive approach is used by Bare and Mendoza (1988) who proposed that the objective of the model should be the optimization of certain wildlife populations which are considered as an index for ecological wildlife quality, and simultaneously optimize timber yield as the other objective.

Our model is focused on medium-term planning of game resources by means of a set of criteria representing the game economic value and simultaneously maintaining an acceptable population level for two different species of deer. The use of game in forest Mediterranean ecosystems in Spain has become of great importance, exceeding by a large amount the economic value of the forest products themselves, the reason being the low productivity of lands under Mediterranean conditions and the protective characteristics of the Mediterranean forest. In these ecosystems, trees are planted and managed mainly to reduce soil loss, to maintain their capability and to prevent them from desertification processes.

The case study area is a typical piece of land in a Mediterranean forest in southern Spain. The land consists of 3600 ha with mixed vegetation cover: pinewoods, groups of *Quercus* spp., *maqquia* and range lands under *Quercus* cover. Consequently, it has clear game potential. This land will support two main species for hunting purposes: roe deer (*Capreolus capreolus*), and red deer (*Cervus elaphus*).

A considerable effort was devoted to finding good models of the supply of nutrients by the natural cover and the demand of nutrients and energy by the population. A previous paper by Berbel and Zamora (1992) deals with the demographic evolution of red deer populations in southern Spain Mediterranean ecosystems (Sierra Morena area) while the main parameters of these species were taken from the works of López-Giménez (1972) and Zamora-Lozano *et al.* (1976).

Zamora-Lozano *et al.* (1979) published a simple linear program of red deer management in southern Spanish conditions. Berbel (1992) published a dynamic model of red deer management seeking to analyse the behaviour of the system as a function of the discount rate applied to evaluate the game product.

4. The case study

The management of hunting reserves needs tactical plans that take care of economic considerations and simultaneously assuring the population's sustainability and demographic equilibrium. These constraints imply that the planning period should not be a very short one because the population dynamics need longer periods for stabilization. On the other hand, a too lengthy planning period does not meet practical considerations. We have selected a planning period of 10 years; a complete description of the case study can be found in Zamora (1994).

The economic objectives of a hunting reserve imply maximizing the discounted value of captures. In the Mediterranean forest, the roe deer is considered as an endangered species, especially when it is in territorial competition with the red deer which behaves aggressively towards the roe deer which is smaller in size. Therefore, one ecological goal should be to increase the level of the roe deer population. However, the land competition between species has economic consequences: red deer is more profitable per unit of land than roe deer and thus, to increase the roe deer population would be in conflict with economic performance.

Financial considerations are treated as a goal in order to maintain the income level before increasing the number of roe deer. The ecological goal is to obtain a sustainable growth of the roe deer population, aiming to reach a level that assures the self-preservation of the endangered species. This goal is included in the model.

The constraints of the system imply, for both species, that nutritional requirements are satisfied by the vegetation cover every year. There is also a set of equations defining the dynamic relations between different ages and sexes for each species. The complete model is shown in the following sections.

5. Ecological vs. economic objectives

The model introduced in the last section has complex internal dynamics including, for each deer species, population variables divided into age and sex for each of the ten years in the period of analysis. As in any other system model, a crucial decision to be made is the selection of the relevant criteria to be optimized. In our case, we see quite clearly the need for an economic performance criterion and an ecological value criterion.

The economic criterion was assumed to be the capitalized value of all yearly income of hunted individuals. The price for each species and age is known from the local market, and the interest rate to use was 4%, which is quite usual in forest analysis, and is suggested by Berbel (1992) as a rate that does not produce population distortion. Therefore, the first criteria will be to maximize economic income, which is:

$$\text{Maximize } Z_1 \sum_{t=1,10} r_t V_t \tag{1}$$

where V_t is the value of income for each year from $t=1,10$ both for roe deer and red deer. The coefficient r_t will take the values from:

$$r_t = 1/(1+i)^t$$

$$Vt = \sum_{i=2,5} (V_i^{cc} HM_{ti}^{cc} + V_i^{ce} HM_{ti}^{ce}) \tag{2}$$

The V_t will be computed for years 1 to 10. The model allows only adults to be hunted (both sexes and older than 2 years). The variables used in the formula are:

V_i^{cc} = Value of roe deer (*Capreolus capreolus*) of age "i"

V_i^{ce} = Value of red deer (*Cervus elaphus*) of age "i"

HM_{ti}^{cc} = Hunted males of roe deer (age "i", year "t")

HM_{ti}^{ce} = Hunted males of red deer (age "i", year "t")

The ecological objective will be assumed to be the maximization of roe deer, which in southern Spain is an endangered species. The ecology of roe deer implies that it needs almost ten times more area for survival than the red deer although the value of hunted individuals is about the same. Obviously, when only economic performance is considered, the model will eliminate roe deer from the land (which is practically what happened in Spain before environmental laws protected the species).

Therefore, the second objective will be to maximize the number of roe deer at the end of the planning period. This criterion will be defined as:

$$\text{Maximize } Z_2 = \sum_{i=2,5} LM^{cc}_{10,i} \tag{3}$$

where $LM^{cc}_{10,i}$ is the number of male roe deer adults at the end of the planning period (year $t=10$).

Sex ratio constraints are enforced during the planning period for each year, including the last one. Therefore, the maximization of males implies the maximization of the balanced population. The schema of the program is as follows.

$$\textit{Efficient } (Z_1, Z_2)$$

$$HM_{t,i} + LM_{t,i} = K1 \cdot LM_{t-1,i-1}; \quad i=2,5 \tag{4}$$

$$LM_{t,1} = K2(LF_{t-1,*} + HF_{t-1,*}); \quad i=2,5 \tag{5}$$

$$HF_{t,i} + LF_{t,i} = K3 \cdot LF_{t-1,i-1}. \tag{6}$$

$$LM_{t,1} = K4LM_{t-1,0} \tag{7}$$

$$LF_{t,1} = K5LF_{t-1,0} \tag{8}$$

$$LM_{t,0} = K6LF_{t-1,*} \tag{9}$$

$$LF_{t,0} = K7LF_{t-1,*} \tag{10}$$

Subscript "*" stands for years 2 to 5. Coefficient $K1$ to $K7$ defining population dynamics are taken from Zamora (1994) and they are different for roe deer and red deer. With equations (4) to (10) the system is defined perfectly. We have included some constraints for the sex ratio as suggested by Davis (1967).

The initial equations will be repeated for each species (roe and red deer) and HM stands for hunted male during the year, LM live male at the end of the year, HF is hunted female and LF, live female: the subscript stands for year t age i for each of the population classes. The initial population, year $t=1$ starts from the known values for $t=0$. The years $t=2,10$ population dynamic is modelled as follows.

The system is constrained by the nutritional requirements for age, sex and species that have to be smaller or equal to supply (computed from land cover ecosystems). We have included nutritional constraints for both the energy and nitrogen requirements. There are additional constraints to set minimum levels at the end of the planning period for both species and defined by adult males, being more than 5 for roe deer and 80 for red deer. The model was solved using an IBM-PC with HIPERLINDO©.

The model was first designed to be solved using multi-objective programming. The use of MOP allows the analyst to understand the conflicts and trade-offs between the

TABLE 1. Efficient set for MOP problem

Point	Income (Z_1)*	Population (Z_2)
A	110·7	5
B	103·0	61

* Million Spanish pesetas.

different objectives in conflict; the first step in analysing a system. The solution of this problem gives us a small efficient set defined only by two corner points.

The trade-off analysis shows that we can substantially increase the number of roe deer while giving up only a little income. On a purely theoretical basis, there is no way to induce us to adopt option B as the best solution because, by definition, the efficient set is formed by all non-dominated solutions, so that both solutions are efficient and non-dominated.

Nevertheless, we decided to analyse this system further, based on our previous experience of game management problems using spreadsheet analysis. Thus, the second step in the analysis of this problem was to redefine it as a lexicographical goal program described in the next section.

6. Goal program for wildlife management

The first phase of the system analysis showed that ecological and economic objectives have only a small conflict; this outcome is explained when we consider the following system characteristics:

(a) The red deer population is fully exploiting the resources; therefore, to avoid hunting some roe deer does not have a significant impact on economic performance.
(b) As the value of hunting red deer is equal to roe deer, the substitution of the endangered species for the commercial one has a scant influence on income.

We decided to use lexicographical goal programming as follows:

$$\text{Lex}\{(n1,n2); (\Sigma\, n_t+p_t)\} \tag{11}$$

subject to:

$$Z_1+n_1-p_1=100 \tag{12}$$

$$Z_2+n_2-p_2=60 \tag{13}$$

$$LM^t_{ce2}+LM^t_{ce3}+LM^t_{ce4}+LM^t_{ce5}+n_t-p_t=400;\ t=1,10 \tag{14}$$

rest of constraints

Equation (11) is the objective function, (12) sets the economic goal (in million Spanish Pesetas), (13) is the number of roe deer adults living at the end of year 10.

The second level of goals (equation 14) attempted to obtain a scheme in which

TABLE 2. Population parameters for different solutions

	Solution A		GP solution		Solution B	
Year	Red deer	Roe deer	Red deer	Roe deer	Red deer	Roe deer
1	424	20	400	20	425	20
2	426	15	400	26	426	26
3	465	11	400	29	465	32
4	470	6	400	34	460	39
5	400	9	400	41	381	45
6	437	16	400	49	406	52
7	450	23	400	57	411	59
8	443	30	400	66	405	68
9	324	26	400	75	298	76
10	199	19	212	84	190	86

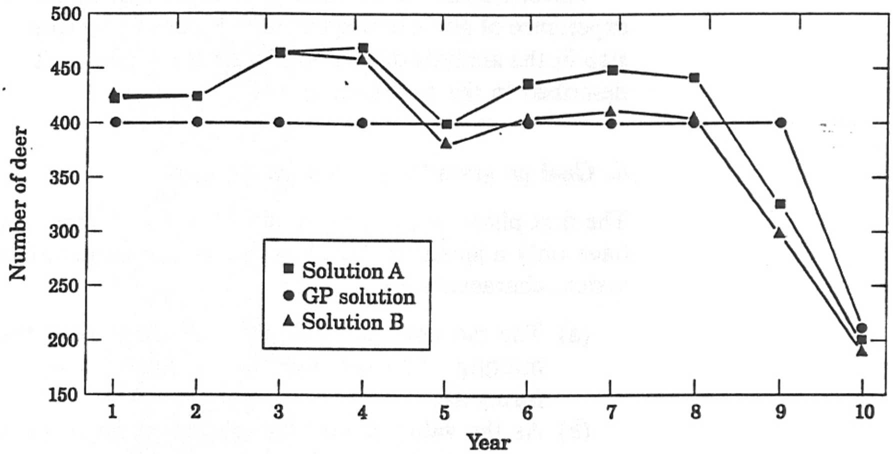

Figure 1. Population of deer for different solutions.

every year the number of adult red deer males is as close as possible to 400 (which is the average obtained in the MOP program explained in the previous section). This kind of formulation is similar to the seasonality criteria treated in Romero *et al.*

A solution to the first problem achieved the fulfilment of the first set of goals (i.e. $n_1=0$; $n_2=0$). Therefore, there are alternatives and we went on to minimize the second level of goals that gave us an unique solution. The analysis of the solution is of interest (Table 2 and Figure 1). We can see how this solution has achieved a steady level of population satisfying the first level of goals.

7. Concluding remarks

The aim of this paper is to illustrate the possibilities of MOP and GP in the management of natural resources. We analyse a case study of wildlife management in Southern Spain where commercial and endangered species compete for the land. The model includes an analysis of conflict between economic and ecological objectives and suggests criteria to measure both dimensions of the managed system.

As the MOP analysis shows, by means of the pay-off matrix, there is only a small conflict between both objectives. Lexicographical GP is thus used to improve the acceptability of a solution by including the stabilization of species during the planning period. Population stability is achieved by a set of goals similar to those used for the minimization of seasonality.

Results show the potential of combining the perspective of analysis given by the generation of the efficient set with the practical solutions given by GP formulations. Both approaches of MCDM are of interest for the management of resources and they may help managers to understand better the internal relationships among the different criteria involved in the system. We can expect more applications of MCDM to different natural resources and agricultural management as the cooperation between ecosystem experts and MCDM practitioners extends.

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