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Identification of Potential Reforestation Sites Using Geographic Information System and Remote Sensing

Thomas Gumbricht, Camilla Mahlander and Jenny McCarthy

Royal Institute of Technology, Division of Land and Water Resources, S-100 44 Stockholm,
Tel: +46 8 790 86 12, Fax: +46 8 411 07 75

Abstract

Geographic Information System and Remote Sensing supported methods for identifying sites for regional reforestation in Cyprus are presented. The land cover was categorised combining statistical classification and expert rules, using multitemporal Landsat TM and MSS data and digitised maps of elevation and geology. Land needed for future technical infrastructure was allocated using multi criteria evaluation. Reforestation areas were identified for two different pine species based on two methods; a rule based expert approach, and multi criteria evaluation. The rule based approach is a forward chaining expert system with compact transparent rules. The multi criteria evaluation is a backward chaining goal seeking, decision support tool. Compared to traditional rigid Boolean output of overlay and statistical classification the result can be used for alternative reforestation strategies. The use of integrated landscape indicators for evaluating different strategies is outlined and presented as an example.

Key words: expert system, decision support system, multi criteria evaluation, landscape management, Cyprus.

Introduction

The loss of natural and semi-natural vegetation associated with urban expansion and agricultural intensification is widely recognised (Turner et al., 1990). Integrated landscape management for redevelopment of viable systems is an active field of research, where much interest has turned to dynamic feedback processes and the role of ecotones and other communicating interfaces (e.g. Turner and Gardner, 1990; Holland et al., 1991). Geographic Information Systems (GIS) and Remote Sensing (RS) are progressively used for processing and analysis of spatial data. The presently strong integration of models and multi data sources (e.g. Ehlers et al., 1991; Fedra, 1993; Johnsson, 1994) opens for more powerful tools in e.g. spatial allocation of human and natural activity in a dynamic landscape. Site search and evaluation of potential management alternatives have thus gained a strong interest in the GIS community. Many problems that are called to solve are ill-structured and require several steps before reaching a solution. Based on forward or backward chaining, statespace can be searched through a large number of alternative solutions. Multi criteria evaluation (MCE) and linear programming (LP) are examples of backward, goal chaining decision support systems widely applied for analysing complex trade-offs between multiple criteria and conflicting objectives (e.g. Carver, 1991; Chuvieco, 1993; Banai, 1993; Pereira and Duckstein, 1993). A number of standard methods have been developed for assigning criterion scores and rules structuring (*ibid.*). Expert systems (ES) can be both backward and forward (model and data) chaining, and have previously been rather complex in structure and designed for datasets with low noise. Recent development has been towards compact transparent rules and fuzzy membership functions (Fig. 1) (e.g. Leung and Leung, 1993; Dymond and Luckman, 1994). For more detailed treatment of GIS integration and application to regional planning and natural resources management see e.g. Scholten and Stillwell (1990), Goodchild et al. (1993) or Gumbricht (1995a).

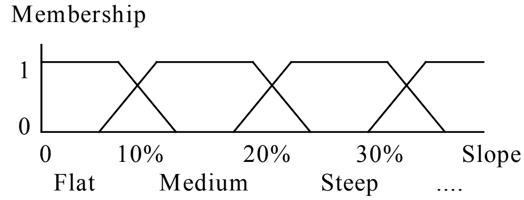

Fig. 1. Example of fuzzy membership function for slope profiles

The landscape pattern of tree-species' mosaics is attributed *inter alia* soil type, topographic and microclimatic conditions, slope, adjacent stands and the site history (e.g. Picket and White, 1985). Identification of the potential pattern of ecosystems can be based solely on probability density functions from combined RS and GIS data (e.g. Braun and Backhaus, 1993). However, site identification for integrated management is hypothesised to be superior with more advanced classification methods also considering ancillary data and contextual information (cf. Argialas and Harlow, 1990; Pastor and Broschart, 1990).

The scope of this article is to evaluate different techniques for identifying suitable areas for integrated spatial landscape management, with emphasis on reforestation. Two different methods, a backward chaining multi criteria technique and a forward chaining expert rule approach are compared and discussed. Object oriented identification of the landscape structure for integrated management based on synoptic indicators is outlined.

Cyprus and its forest history

Cyprus was selected as a study area due to its varying vegetation and geological structure, a governmental interest for the problems under study, and data availability. The history of Cyprus is intimately connected to management of the island's copper and forest resources. Experience in using GIS for land evaluation in the region is limited (Davidsson et al., 1994).

The island of Cyprus lies in the Northeast corner of the Mediterranean Sea and covers an area of 9 251 km^2. The island is broadly divided in four east-west trending geologically defined regions: the Kyrenia mountain Range (not included in the study due to inaccessibility), the Mesaorian plain, the Troodos mountain and its surrounding sediments, and the Mammonia complex (Panayiotou, 1987) (Fig. 3). The Troodos range is one of the world's best preserved ophiolite series. Through uplift and erosion the most basal part of the sea floor spreading zone can be found at the top, and the pillow lava at the mountain foot (Fig. 3). The pillow lava contains classic examples of ore bodies associated with the formation of the ocean crust through black smokers (cf. Brimhall, 1991). The orebodies contain mostly sulphur and iron, and has a copper content of 0.5-4.5 %. Early mining was bound to gossans found as weathered deposits associated with the ores. It has been suggested that the acid soils associated with the sulphur of the gossans promoted growth of *Pinus sp.,* thus forming thick organic layers where copper was reduced and precipitated as metallic copper. This copper was mined as early as 4000 BC (Muhly et al., 1981). The earliest sign of smelting to produce metallic copper from sulphite dates back to the third millennia B.C. Based on the composition of the ore bodies and the amount of slag produced, Constantinou (1981) estimated that 60 million tons of charcoal must have been used in Cyprus during ancient times for copper smelting alone. This is equivalent to 16 forest generations covering the whole island. He argues that this charcoal

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must have come from the islands forests, partly because Cyprus is recorded a net exporter of timber (for e.g. shipbuilding) in ancient sources. Constantinou (1981) concluded that forest regeneration is more favourable on Cyprus due to its geological setting; comparable copper deposits in other parts of the region has not been exploited to the same extent during ancient times. His thesis is supported by Strabo, who in his Geographica (23) writes:

”There are mines of copper in plenty at Tamassos, in which are produced sulphate of copper and copper-rust useful in the healing art. Eratosthenes talks of the plains as foremely full of wood run to riot, choked in fact with undergrowth and uncultivated. The mines were here of some little service, the trees being cut down for the melting of copper and silver; and of further help was shipbuilding, when men sailed over the sea without fear and with large fleets. But when even so they were not got under leave was given to those who would and could cut them down to keep the land they had cleared in full possession and free of tax.” (from Cobham, 1908).

Between approximately A.D. 400 and 1900 no copper was mined on Cyprus. But forests declined due to overgrazing, escalating after the Turkish annexation in 1570 (Kardell, 1991). It has been hypothesised that the deforestation in the region is of this rather late date, and associated with overpopulation and grazing (Meiggs, 1982, referred to in Kardell, 1991), also promoted by law and tax regulations.

When the British took over Cyprus in 1878 from the Ottoman empire, they found the forests in a terrible state (Kardell, 1991). They sent out foresters that found a valley of long forgotten Cedars with the help of monks from the Troodhitissa monastery. It was a sensation when they could report finding *Cedrus brevifolia* to the Linnean society in London 1891, and it yielded a lasting interest in forestry on Cyprus. The British administration banned cutting and burning, and later the Cypriots continued this tradition after the independence in 1960. Today much of the Troodos mountain range is reforested, with fires reoccurring on average every 31 years. During the Turkish war in 1974 much of Troodos burnt due to bombing. Management practices are reported to be viable (Kardell, 1991), even if the reforestation management is rather brusque with Swedish measures; horizontal ploughing on steep hills forming shelves is the usual practice . The dominating tree species are *Pinus brutia*, and the top of Troodos hosts a stand of *Pinus nigra* and single huge individuals of *Juniperus froeditissma. Cedrus brevifolia* is planted in the 600 hectare large Cedar valley on the south western slope at approximately 1400 m.a.s.l. The understory in all forests are dominated by *Arbutus andrachne* and the endemic species *Querqus alnifolia*. *Platanus orientalies* and *Alnus orientalis* can be found in ravines, together with *Rubus ulmifolius* in the understory.

Reforestation today is multi-objective: to decrease erosion, to increase scenic (i.e. tourist) value, to create viable forest habitats for e.g. the mufflon sheep (*Ovis ammon orientalis*), and to increase productivity. Reforestation is however competing with other activities for land allocation. In the project three sets of criteria were primarily identified for excluding or including areas for consideration of reforestation. Sites should be ecologically suited regarding elevation, regolith, size and shape and adjacent pattern of ecosystems. The sites should not compete with technical infrastructure development, *inter alia* urban expansion, tourist activity, industry and irrigated agriculture. New technical infrastructure areas were limited to land cover categories of garigue, maquis and bare land. Suitability for new urban and agricultural areas was evaluated based on the factors slope, and proximity to infrastructure (including water supply) and urban centres. Additionally, for tourism beaches were graded as important, and soil conditions were used for identifying suitable areas for agriculture.

Material and methods

The study is based on a Landsat TM scene (resolution 30 metre) obtained in August 1984, and a Landsat MSS scene obtained in April 1987 (resolution 80 metre). The ancillary data made available for the study by the Cyprus authorities included a digital terrain model (Fig. 2), a geological map (Fig. 3), a soil map and a state forest map. They had all been manually digitised from maps in the scale 1: 250 000. Road and stream network were manually digitised by us (Fig. 4). Land cover classification was based on the original resolution of the data (Gumbricht et al., 1995). In this study data were reduced to a resolution of 300 meters.

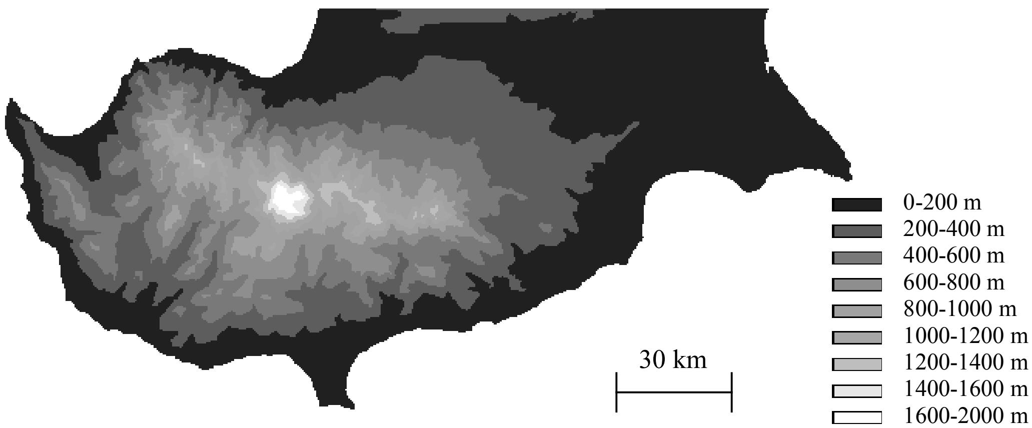

Fig. 2. Digital terrain model

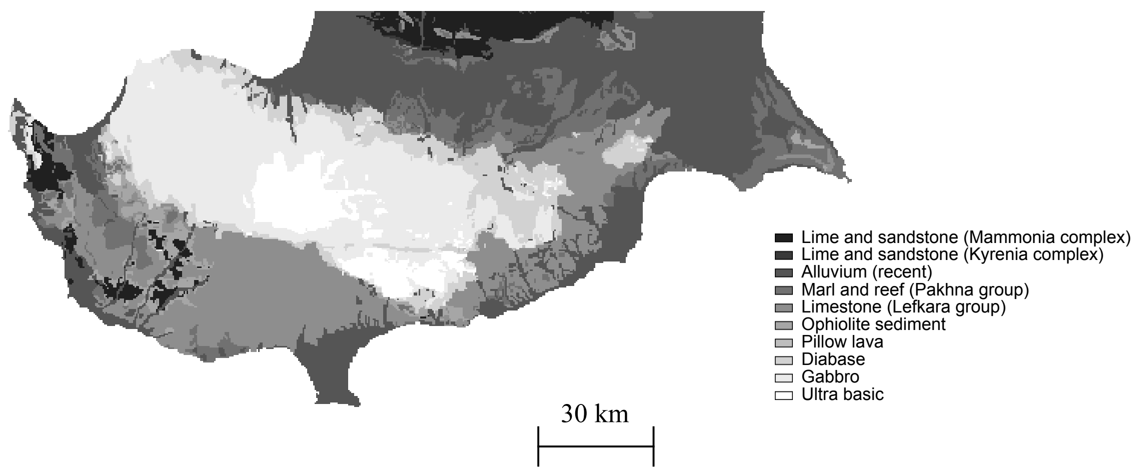

Fig. 3. Geological map

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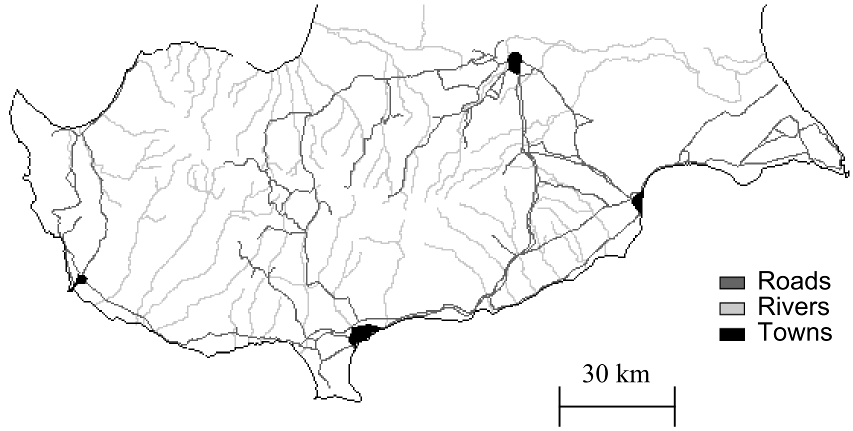


Fig. 4. Infrastructure map

A combined multispectral and rule based classification was used to categorise land cover (Fig. 5). Overall classification result was estimated to be 74 % (kappa index of 67 %). The classification is described in detail elsewhere (Gumbricht et al., 1995).

Based on the above information suitable areas for irrigated agriculture, urban development and tourism were identified based on the MCE (multi criteria evaluation) and MOLA (multi objective land allocation) modules in IDRISI. These areas were later omitted from the analysis of suitability for reforestation.

Reforestation sites were identified using MCE, and an expert rule based approach. The MCE was carried out in IDRISI, considering two kinds of criteria: Boolean constraints (excluded/included areas) and continuos (on a scale 1-255) factors (or decision variables) (Eastman, 1993). For both species of *Pinus* suitable areas were restricted to those classified as garigue, maquis or bare in the *a priori* classification, excluding areas allocated for technical infrastructure. Factors considered in the analysis were slope and distance to roads. Neither geology, nor soil seem to play any role for the success of reforestation at a regional scale (Pers communication, Forestry Department). However, fertile soils were indirectly excluded as they were given large weight for new agricultural areas.

Factors were combined into a decision rule evaluating suitability index (S) = $\Sigma(w_i x_i)$, where w_i is the weight of the ith factor (with $\Sigma w_i = 1$), and x_i the criterion score of factor i (1-255). The weighting was accomplished using pair wise comparison (i.e the weight function in IDRISI).

The rule based identification uses compact rules of the form ”if condition1 ... (and condition2, and ..) then conclusion ... certainty ...”. Conditions are in the form of operators (=x, <x, >x, <x<), <), where x is the observation vector. Each rule condition can consist of several columns of numeric values associated with the operator (Gumbricht et al., 1995). Certainty is given in %. The program for the rule based classification was developed in PASCAL and uses IDRISI images as input and output. The program can handle different resolutions and longitudinal /latitudinal segmentation.

Based on the output images different strategies for reforestation can be adopted. Adopting a strategy emphasising jurisdictional and scenic objectives was done as illustration.

Results

The combined statistical and rule based land cover classification is shown in Fig. 5.

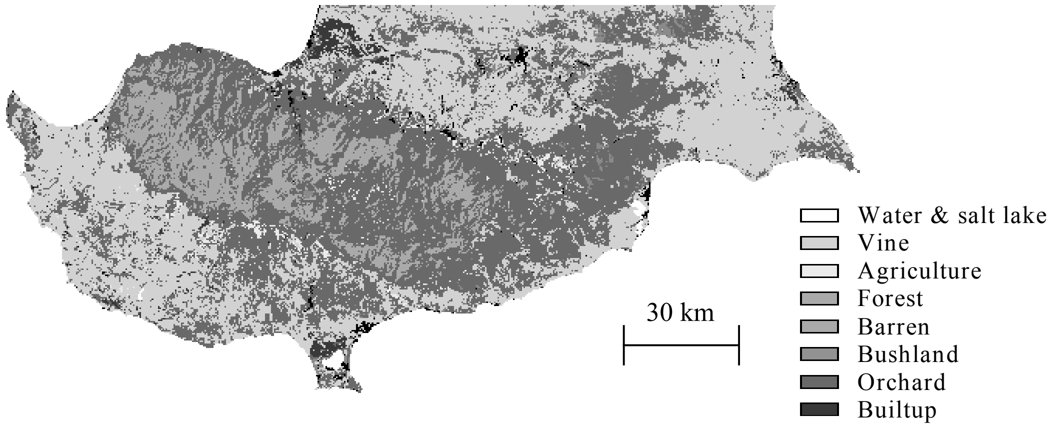


Fig. 5. Land cover classification based on a combined expert rule based and statistical methodology. Overall accuracy = 74 %.

Land identified for new technical infrastructure development is shown in Fig 6.

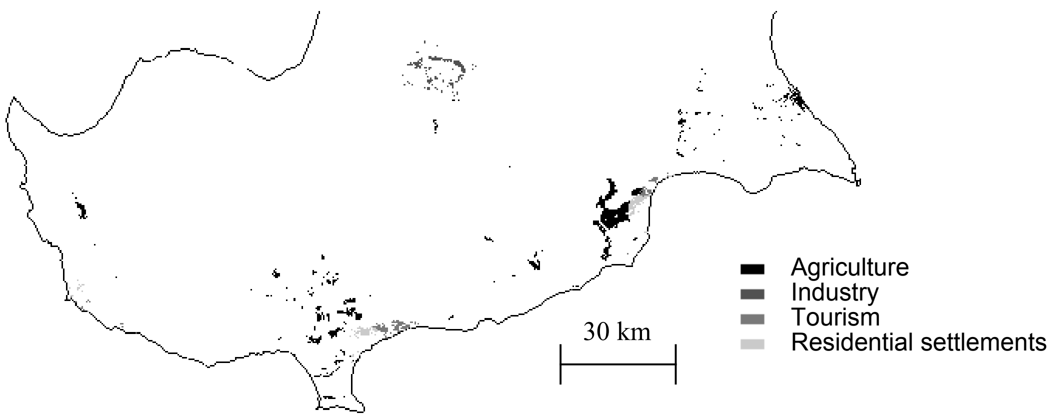
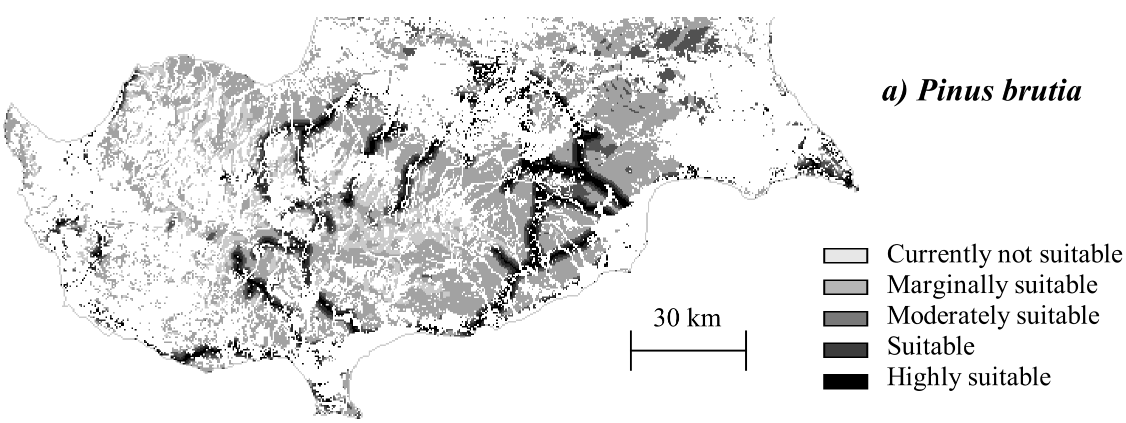


Fig. 6. Land allocated for new technical infrastructure using multi criteria methodology

The result of applying MCE and expert rules for identifying suitable land for reforestation in Cyprus is shown in Figs 7 and 8, respectively.



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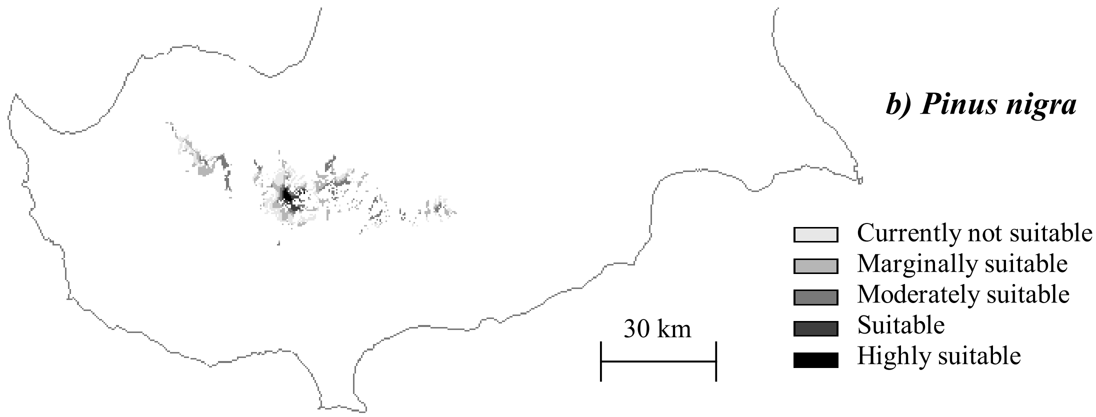

Fig. 7 Suitability index for reforestation using multi criteria methodology for a) Pinus brutia, and b) Pinus nigra

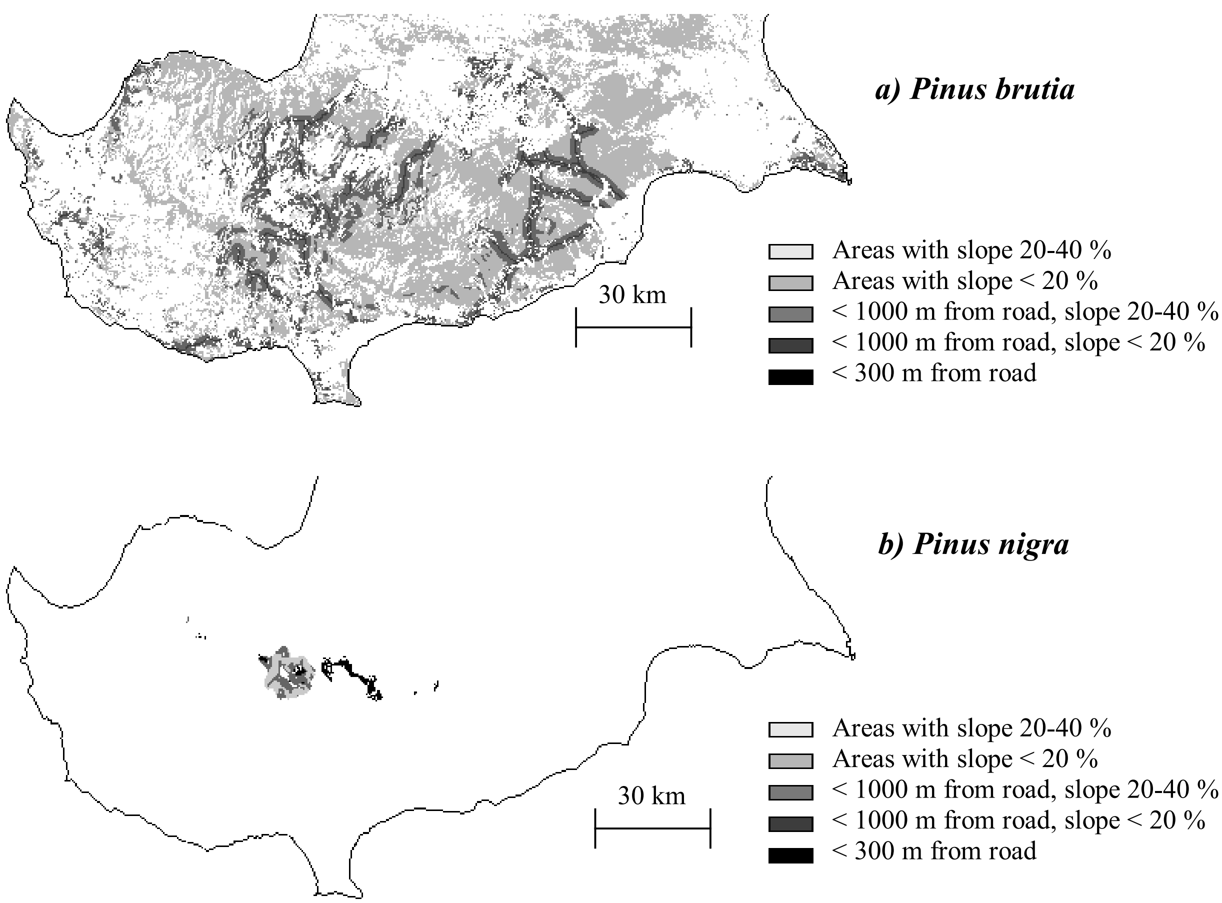

Fig. 8. Areas of different character identified for reforestation by using an expert rule approach for a) Pinus brutia, and b) Pinus nigra.

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Adopting a strategy emphasising jurisdictional and scenic values could be to prioritise state land, and management along highways (Fig. 9). The change in integrated landscape indicators following this strategy was evaluated using measures of total forested area, average forest stand size and perimeter (i.e. ecotone) length (table 1).

Fig. 9. Sites identified for reforestation with Pinus brutia adopting a jurisdictional and scenic strategy.

TABLE 1 Change in landscape integrated indicators following reforestation shown in Fig. 9.

Indicator	Presently	Suggested strategy	Total
Forest area (km2)	814	32	846
Forest patches (nr)	497	93	558
Perimeter length (km)	3143	255	3335

Discussion and conclusion

Compared to traditional Boolean logic of map overlay or statistical classification, there is no doubt that the adoption of expert rules and fuzzy set logic provides a more satisfactory methodology for land evaluation (cf. Davidson et al. 1994). This is emphasised by the multi objective nature of e.g. reforestation, seeking to improve productivity, biodiversity, scenic value, closure of nutrient cycles etc. (cf. Johnston, 1987). The MCE and rule based image outputs are suitable for determining final selection, either directly or applying a new set of rules. This is illustrated by the adoption of a jurisdictional and scenic reforestation strategy (Fig. 9), where the effects on landscape ecology is indicated by the regional measures of forested area, average forest size and forest ecosystem perimeter (i.e. ecotone length). Definition and evaluation of physically interpretable, synoptic indicators for holistic landscape management is presently evaluated in parallel studies (Gumbricht 1995b). For indicators to be powerful links between landscape structure and function, an object oriented view in landscape feature identification should be adopted (Gumbricht et al., 1995).

A critical issue in fuzzy logic is the scoring of criteria and the choice of membership definition. Thus sensitivity analysis for reaching a robust solution is of major importance. Knowledge acquisition and rule inference is the bottleneck for expert system development (Robinson and Frank). However, in many cases a few simple rules can describe the variation in datasets (cf. Dymond and Luckman, 1994). The system presented herein could thus be further improved in different directions, including artificial intelligence, improved interface for rule structuring and simplification (cf. Gumbricht et al., 1995), and multimedia visualisation tools for presentation of outcomes (e.g. Bishop and Hull, 1991).

Synergistic effects can not be portrayed in the MCE approach, but in the rule based expert approach. The transparency of the latter is also greater. However, the rule structuring is far more difficult than is the MCE analysis. The criterion scores in the MCE are linear membership functions over the considered criteria interval (e.g. slope, distance to road). Principally any membership function could have been chosen. The output of the MCE is a ranked image where the totally allowed statespace (i.e. unconstrained) has been searched and graded for reforestation. By defining a goal of reforestation in e.g. area, the highest ranked cells can be identified. The approach is thus goal driven or backward chaining; the area to be reforested is often known in forehand. The expert system output is an image with reforestation sites of identified characters; only land which fulfil the rule statements are identified; the approach is thus said to be forward, or model chaining. Both approaches have their advantages. Building the necessary rule-sets, however is not a trivial task, particularly if there is reason to believe that the attributes being mapped depend on a significant amount of variables (cf. Dymond and Luckman, 1994

Nijkamp and Scholten (1993) identified three conditions to be fulfilled for effective implementation of GIS centred tools in regional planning: user friendliness and robustness under different conditions; data and model integration; and a flexible decision support framework. Such developments have been fuelled by a technology push from builders of hardware, software and models, rather than demand pull for knowledge structuring and reflections of natural processes. The transparency and modularity of the rule inference program facilitates coding and model modification, and in ES applications, as here, it can be used to deliver simple explanations of the system's conclusions. GIS can be used for "Design with Nature" (McHarg, 1969) but our conclusion is that development towards a fuller integration of data, knowledge and models (cf. Ehlers et al., 1991; Fedra et al., 1992) is needed before it can be used by domain experts for learning and training, planning and management.

Reforestation in Cyprus has been successfully carried out for 80 years. Scenic value has been prioritised since the boom in tourism. Interest is now turning from site identification to dynamic modelling of integrated landscape functions, e.g. forest productivity and, most important, erosion and hydrological processes. The fact that landscapes are dynamic requires that time, or temporal changes, be considered in landscape management. The development in landscape ecology and system science suggests GIS and RS as strong candidates for finding synoptic indicators for transparency between (managerial) structure and desired integrated landscape functions (cf. Grossmann, 1991; Leibowitz et al., 1992; Gumbricht, 1995b). The inclusion of distributed models of e.g. forest growth, erosion and hydrology (e.g. Band et al., 1991) will enhance the understanding of outcomes of different management alternatives. The future work on Cyprus will thus be towards a semi-distributed hydrological dynamic modelling based on integrated landscape indicators derived from GIS and RS (Gumbricht, 1995b).

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