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A MULTICRITERIA DECISION SUPPORT MODEL AND GEOGRAPHIC INFORMATION SYSTEM FOR SUSTAINABLE DEVELOPMENT PLANNING OF THE GREEK ISLANDS

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1 Introduction

The diffusion and acceptance of any new technology, including the new information technology products like geographic information systems (GIS), are not only depending on the technical quality of such new goods or services (the 'technology push' view), but also to a large extent on the user needs (the 'market pull' view). The rather low penetration rate of GIS among local or regional planning authorities in many countries is often co-determinated by the absence of a clear need for GIS in the planning process or by the lack of a tailor-made GIS for specific planning questions. It has to be added that GIS is both a research and a planning tool. And therefore any GIS has to fulfil at least two requirements:

- it should meet standards of **scientific credibility**; this means that GIS should allow for a linkage with existing analytical tools such as spatial statistics, spatial modelling and multicriteria evaluation (see Fischer and Nijkamp 1992).
- it should comply with the demands of planning agencies or even society at large, so that **socio-political desirability** of GIS tools is of critical importance; this also means that GIS should be able to provide recognizable and customized products of scientific analysis in the framework of decision support for spatial planning.

Thus the value of GIS is not only dependent on its indigenous merits, but also on the way it is positioned in a broader research and planning context.

This paper describes the use of multicriteria analysis (MCA) and geographic information systems (GIS) models as a decision support system (DSS) for sustainable development (SD) planning of the Greek Sporades Islands (see for full details also Van den Bergh 1991; Giaoutzi and Nijkamp 1992). One of the most intriguing and difficult dilemmas facing policy-makers is the often mentioned incompatibility between economic efficiency goals, socio-economic equity goals, and ecological sustainability goals.

The present paper serves to offer a framework for decision support regarding the wide spectrum of development options for one of the Sporades islands, viz. Alonnisos. It is organized as follows. First, in Section 2 an operational decision support system, DEFINITE, will be discussed and used to evaluate six development options for this area (see for further details on DEFINITE Van Herwijnen and Janssen 1989; Janssen 1991; Janssen and Van Herwijnen 1991). In this evaluation the attention will be focussed on ~~compound~~ development alternatives. Then the rankings of alternatives are determined for these six choice options on the basis of different sets of priorities for these developments by using multi-criteria methods. Finally, the various results are investigated with regard to their sensitivity regarding shifts in policy priorities and in the initial impact scores on the various policy or performance indicators.

In the second part of the paper (Section 3), the geographic information system SPANS (SPatial ANalysis System 1990) will be used as an illustration of the application of spatial evaluation of different land use alternatives for these development options. The resulting maps of this spatial evaluation are then used as input into DEFINITE for a compound evaluation of these different land use alternatives in order to offer a comprehensive decision support system.

2. A Multi-Criteria Evaluation of Development Alternatives

2.1 Development alternatives

In our GIS-SD framework, six distinct development alternatives for the Sporades to be evaluated from a policy perspective will be described. These six alternatives are:

D_1: **Steady growth:** a steady growth development path, based on extrapolation of present trends without any specific policy constraints on land or marine use. Tourist numbers continue to rise and tourists are allowed to visit the Marine Park area in the Sporades. This alternative may act as a zero or reference alternative.

D_2: **Marine Park:** a steady growth development path like alternative D_1, but now with a strict control on the tourist flows to the Marine Park. The fishing activity is held at a safe (sustainable) level, the waste management and sewage treatment activities are maximized, and tourism in the Marine Park area is restricted.

D_3: **Strong growth:** a steady growth development path with a controlled tourist flow to the Marine Park like in alternative D_2, but with a higher potential growth rate of tourism.

D_4: **Limited tourism growth:** a steady growth development path with a controlled tourism to the Marine Park (see alternative D_2), but with a strict limit on the growth of tourism on the islands.

D_5: **Sustainable fishing:** a steady growth development path with a controlled tourism flow to the Marine Park like in alternative D_2. The fishing ~~alternative~~ in this alternative is limited to such levels that the stocks of fish are not reduced.

D_6: **Agricultural incentive:** a steady growth development path with controlled tourism flows to the Marine Park like in alternative D_2. Employment in agriculture, especially cultivation of land, is strongly stimulated.

These development alternatives seem to be feasible, but certainly not equally desirable. In the next subsection, each of these development alternatives will be investigated in greater detail.

2.2 An effect table of development alternatives

A basic notion in any evaluation analysis is the **effect table**, which comprises for all development alternatives the foreseeable effects on a set of relevant policy criteria. The development alternatives mentioned in Subsection 2.1 have effects on the socio-economic and ecological development of Alonnisos. These multiple effects can be grouped into various categories. The classification of effects in socio-economic and ecological classes is shown in Table 1 and Figures 1a and 1b.

The scores of the effects for each of the six development alternatives are presented here in a visually attractive manner by means of computer graphics in the form of histograms (see Janssen and van Herwijnen 1991).

The six alternatives in the histograms are ranked in order of preference based on the ranking of the effects, where the most important effect is placed in the first row, the second best in the second row, and so on. In the histogram in Figure 1a the socio-economic development effects have been assumed to have a higher priority than the ecological development effects. In Figure 1b this order is just reversed. This way of graphically presenting and analyzing the effect table is very useful to get a first comprehensive overview of the weak and strong points of the various development alternatives. In the histograms presented in Figures 1a and 1b the highest bar for each effect indicates the best alternative. The first overall impression of this histogram is that a number of effects have a similar pattern. These effects concern import of water, disamenities, sewage, congestion, dust, land use and quality of sea water. The patterns of land use diversity and of natural vegetation are also very similar.

When we take a closer look at the histograms, some observations can be made. The development alternative 'limited tourism', for example, scores on the whole very good for all ecological development effects, but relatively poor for the socio-economic development effects. The alternative of 'strong growth', on the other hand, scores poor for all ecological effects, but rather favourably for socio-economic effects. From this information it can be easily deduced that the alternatives 'strong growth' and 'limited tourism' are essentially contrasting development options.

The effects which have a favourable score for the alternative Marine Park are related to both the ecological and the socio-economic development effects. The scores on the effects in the 'land use' category and the 'marine environment' category rank second after, of course, the 'tourism limit' option. Only fish is an exception, which of course scores best for the alternative 'sustainable fishing'. The emission effects for the Marine Park score about the same as those for 'agricultural incentive', 'steady growth' and 'sustainable fishing'. From these results it can be concluded that the Marine Park is a very good alternative if socio-economic development is regarded equally important as ecological development.

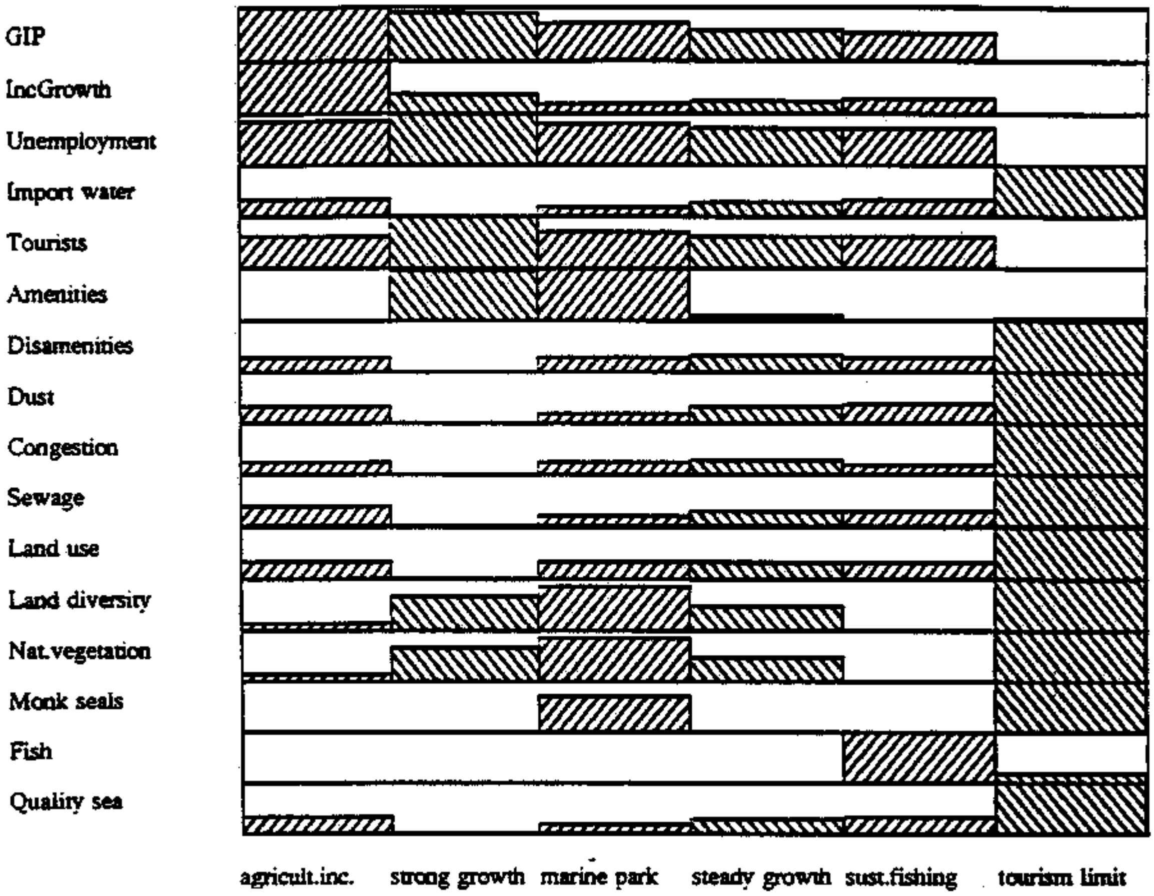

Figure 1a. Histogram of an effect table with socio-economic development effects more important than ecological development effects

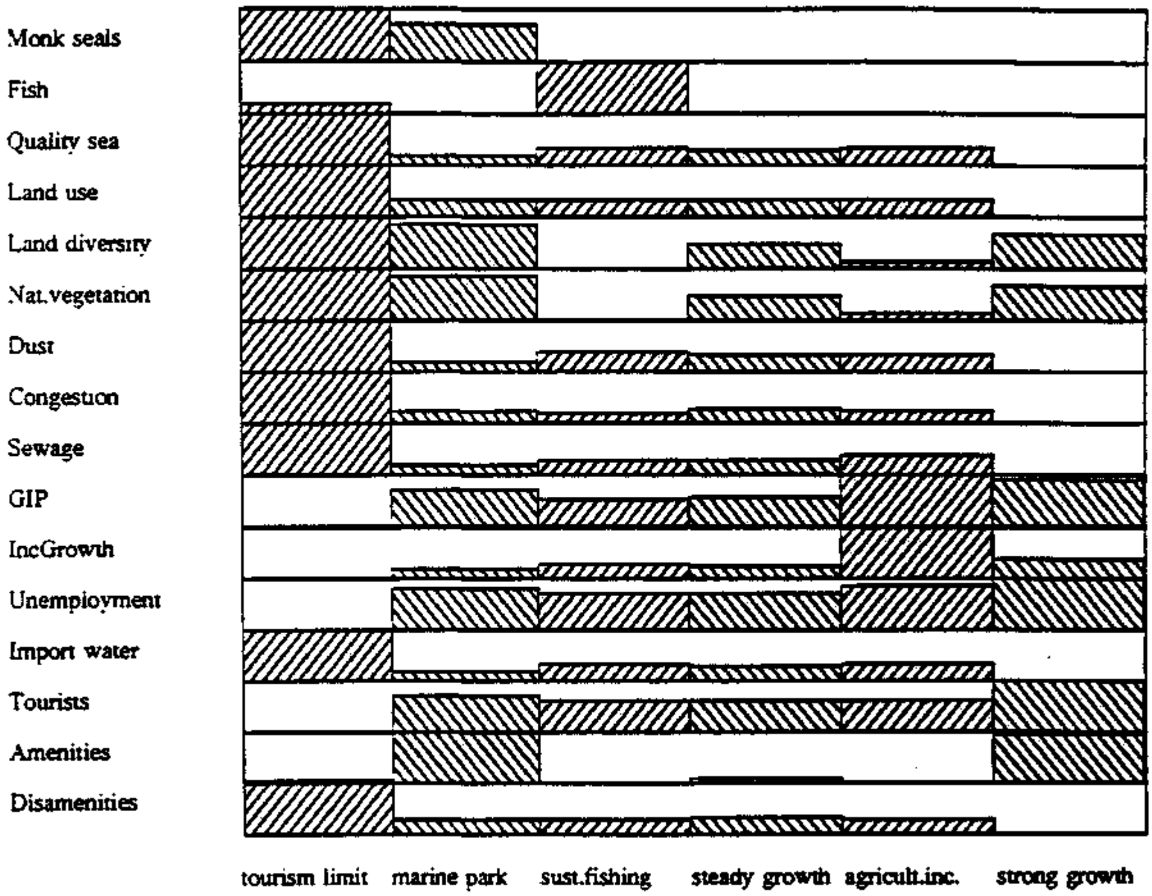

Figure 1b. Histogram of an effect table with ecological development effects more important than socio-economic effects

2.3 The use of weights

It is clear that the ordering of alternatives is dependent on policy weights for the successive criteria. By grouping the disaggregate effects (e.g., GIP, IncGrowth etc) into major categories (e.g., Economic welfare, Import of water etc.) and next the categories into main developments (e.g., Socio-economic development), compound indices can be created (Janssen and Hafkamp 1986). The compound indices for development alternatives are thus composed of indices of the various categories which are made up themselves by the scores on the individual effects. The degree of influence of the effects on each corresponding category is expressed by using percentages attached to the effects within that category. The degree of influence of the categories on their major development options is expressed in the same way. For example, from Table 1 we can derive that the influence of unemployment on economic welfare is 50%, while next the impact of economic welfare on socio-economic developments is 40%. The percentages which indicate the degree of influence of the effects on their corresponding category and of the categories on the two major development criteria are given in Table 1.

By using the percentages given in Table 1 and the original scores of the effect table, a compound development table can be created. This table is presented in the form of a histogram in Figure 2. In this histogram the alternatives are ranked, based on the assumption that socio-economic development is more important than ecological objectives. This histogram shows that the alternative Marine Park will always be better ranked than the alternatives 'sustainable fishing' and 'steady growth', whatever priority is given to the two compound development criteria. A look at the alternatives 'strong growth' and 'limited tourism' shows the contrast between these two alternatives with regard to the compound socio-economic and ecological development criteria.

Having now discussed these main ideas, we will in the next subsection deal with rankings of development alternatives in greater detail.

2.4 Rankings

The compound socio-economic and ecological development indicators discussed above can be compared for each of the six development alternatives by means of multicriteria analysis (see also Janssen 1991; Carver 1991; Nijkamp et al., 1991; Voogd 1983)

Socio-economic Development			
Economic welfare			40%
GIP	25%		
IncGrowth	25%		
Unemployment	50%		
	100%		
Import water			20%
Import water		100%	
	100%		
Tourism			40%
Tourists	50%		
Amenities	25%		
Disamenities	25%		
	100%		
			100%
Ecological Development			
Emissions			20%
Dust	20%		
Congestion	20%		
Sewage	60%		
	100%		
Land use			20%
Land use	60%		
Land diversity	20%		
Nat. vegetation	20%		
	100%		
Marine environment			60%
Monk Seals	60%		
Fish	20%		
Quality sea	20%		
	100%		
			100%

Table 1. Compound development indicators

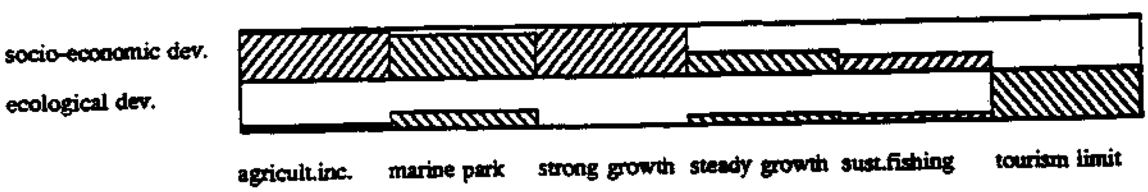

Figure 2. Histogram of compound development criteria

Application of the well-known summation method (see Nijkamp et al., 1991) gives a ranking of the alternatives in the same way. Results of a sensitivity analysis for three different weight vectors are shown in Table 2. The priorities of the compound developments are given by direct numerical weight values adding up to 1.

WEIGHTS		WEIGHTS		WEIGHTS	
1: ecological dev. 2: socio-econ. dev.	0.800 0.200	1: socio-econ. dev. ecological dev.	0.500 0.500	1: socio-econ. dev. 2: ecological dev.	0.800 0.200
RANKING		RANKING		RANKING	
1: lim tourism	0.80	1: marine park	0.66	1: strong growth	0.80
2: marine park	0.54	2: agriculture	0.54	2: marine park	0.78
3: agriculture	0.30	3: strong growth	0.50	3: agriculture	0.78
4: sustain fish	0.29	4: lim tourism	0.50	4: steady growth	0.44
5: steady growth	0.23	5: sustain fish	0.36	5: sustain fish	0.42
6: strong growth	0.28	6: steady growth	0.34	6: lim tourism	0.20

Table 2. Weighted summation results derived by direct numerical weights

2.5 Sensitivity analysis of results

In this section we will use a visual method for obtaining insight into the sensitivity of evaluation results; sensitivity of results regarding uncertainty in the **weights** used can best be shown graphically. In Figure 3 the results of the three different weight vectors of Table 2 are plotted. Here a weighted summation method (with cardinal weights) is used, so that the vertical axis ranges from 0 (low value) to 1 (high value). This graph clearly shows the turning points (break-even points) where a ranking of two alternatives suddenly changes. The alternative 'limited tourism', for example, will shift from the first to the second position in point X, in which the weight for the ecological development is about 0.6.

Next, the sensitivity of the **scores** can also be investigated. This is done using a Monte Carlo approach (Nijkamp 1979). Then the maximum percentage that the actual values can differ from the values included in the effect table has to be estimated. In this case all effects are given a maximum difference percentage of say 25%. By using a random generator this information is translated into a large number of effect tables around the original effect table. Rankings are then determined for all effect tables. The probability table of the results of the weighted summation technique in the first column of Table 2 is given in Table 3. This table shows that the probability that the alternative 'limited tourism' is selected as the best alternative equals 100%.

Next, the probability for the results from the third column of Table 2 is found in Table 4. While the probability that the best alternative in Table 3 (i.e., limited tourism) ranks first appears to be 100%, the probability that 'strong growth' is the best alternative in Table 4 is only 35%. The alternatives Marine Park and in particular 'agriculture' also score high on the first three places. The main conclusion which can be drawn from this probability table is that no best alternative can be selected - with sufficient reliability - for the given priorities and uncertainty percentage assumed here.

The final comprehensive rankings from the results in Table 2 with a given score uncertainty of 25% are shown in Table 5.

2.6 Concluding remarks

It is clear from the above results that an overall evaluation of the six development alternatives for the Sporades can be carried out in several ways by means of the multi-criteria evaluation methods, as included in the DEFINITE software package. With the help of a graphical presentation a first insight into and a better understanding of the choice and policy problems at hand can be obtained. By grouping the effects into categories and next the categories in turn into compound developments, the problem is easier to handle. The influence of priorities for the socio-economic and ecological development options on the ranking of the alternatives becomes easier to analyze, if the influence of the different effects on their categories is held fixed. The different priorities appear to have a large effect on the ranking of the alternatives 'limited tourism' and 'strong growth'. These two alternatives appear to change position from best through middle to inferior. The alternative 'Marine Park', on the other hand, always ranks on the first two places, while the alternative 'agriculture' always ranks one position below 'Marine Park'.

Summarizing all results - given also the sensitivity analysis on the results - it seems plausible that the alternative Marine Park is the best alternative, except when the ecological development is deemed far more important for the Sporades Islands than the socio-economic development. In that case the alternative 'limited tourism' appears to be the best alternative.

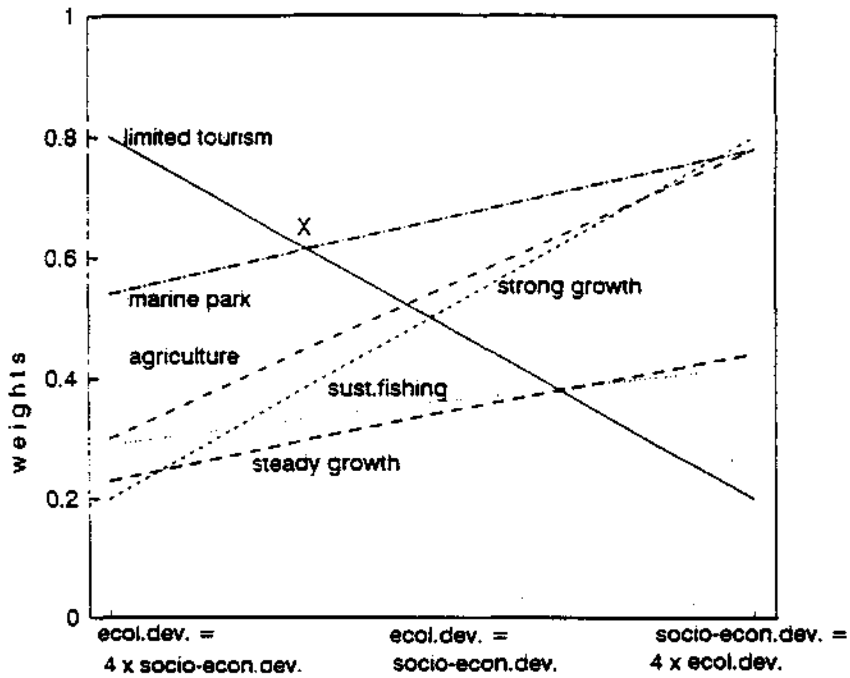

Figure 3. Weight uncertainty related to Table 2

Probabilities	first	second	third	fourth	fifth	sixth
lim tourism	1.00					
marine park		0.94	0.04		0.02	
agriculture		0.01	0.26	0.31	0.18	0.24
sustain fish		0.05	0.56	0.24	0.11	0.04
steady growth		0.08	0.36	0.34	0.22	
strong growth		0.06	0.09	0.35	0.50	

Table 3. Probability table of results from the first column of Table 2 with a score uncertainty percentage of 25%.

Probabilities	first	second	third	fourth	fifth	sixth
strong growth	0.35	0.20	0.28	0.14	0.05	
marine park	0.21	0.30	0.24	0.11	0.14	0.01
agriculture	0.37	0.37	0.15	0.09	0.03	
steady growth	0.03	0.07	0.16	0.31	0.30	0.13
sustain fish	0.05	0.08	0.18	0.29	0.29	0.12
lim tours				0.07	0.20	0.74

Table 4. Probability table of results from the third column of Table 2 with a score uncertainty percentage of 25%.

WEIGHTS	WEIGHTS	WEIGHTS
1: ecological dev. 0.800 2: socio-econ. dev. 0.200	1: socio-econ.dev.0.500 2: ecological dev.0.500	1: socio-econ. dev. 0.800 2: ecological dev. 0.200
RANKING	**RANKING**	**RANKING**
1: lim tourism	1: marine park	1: strong growth
2: marine park	2: agriculture	marine park
3: agriculture	strong growth	agriculture
sustain fishing	lim tourism	4: steady growth
5: steady growth	5: sustain fishing	sustain fishing
6: strong growth	6: steady growth	6: lim tourism

Table 5. **Conclusive ranking with a score uncertainty of 25%**

Park', on the other hand, always ranks on the first two places, while the alternative 'agriculture' always ranks one position below 'Marine Park'.
Summarizing all results - given also the sensitivity analysis on the results - it seems plausible that the alternative Marine Park is the best alternative, except when the ecological development is deemed far more important for the Sporades Islands than the socio-economic development. In that case the alternative 'limited tourism' appears to be the best alternative.

3. Spatial Evaluation

3.1 Land use alternatives

The six development alternatives described in the previous section did not (or hardly) discriminate in a geographical sense. A detailed spatial evaluation of these alternatives is therefore not possible. Nevertheless, it is clear that various development options may be judged in a different way if their geographical pattern differs significantly. To evaluate these alternatives from a geographical perspective, five spatially different policies (called land use alternatives) are here assumed and developed focussing on the growth of urban areas on the island of Alonnisos(see for details also Despotakis 1991). These distinct five policies can be combined with the above mentioned individual six development alternatives, which leads altogether to 30 different combined alternatives. For the sake of illustration but without loss of generality, in this section the development alternative 'Marine Park', D_2, is selected for further spatial evaluation. The method used here applies equally well to the other development alternatives.

The five different policies to control urban growth differ with respect to the place on the island where growth of the urban areas is encouraged. In the policies analysed here, urbanization on Alonnisos is assumed to be encouraged in certain areas and discouraged in other areas. The five land use policies distinguished here and denoted by LU are:

LU_1: encourage urbanization within 200m of the sea;

LU_2: encourage urbanization in the central part of the island;

LU_3: encourage urbanization in the south half of the island;

LU_4: encourage urbanization in the east half of the island;

LU_5: encourage urbanization in the city.

The five different policy scenarios are sketched in Figure 4. The symbols X indicate the places where urbanization is encouraged.

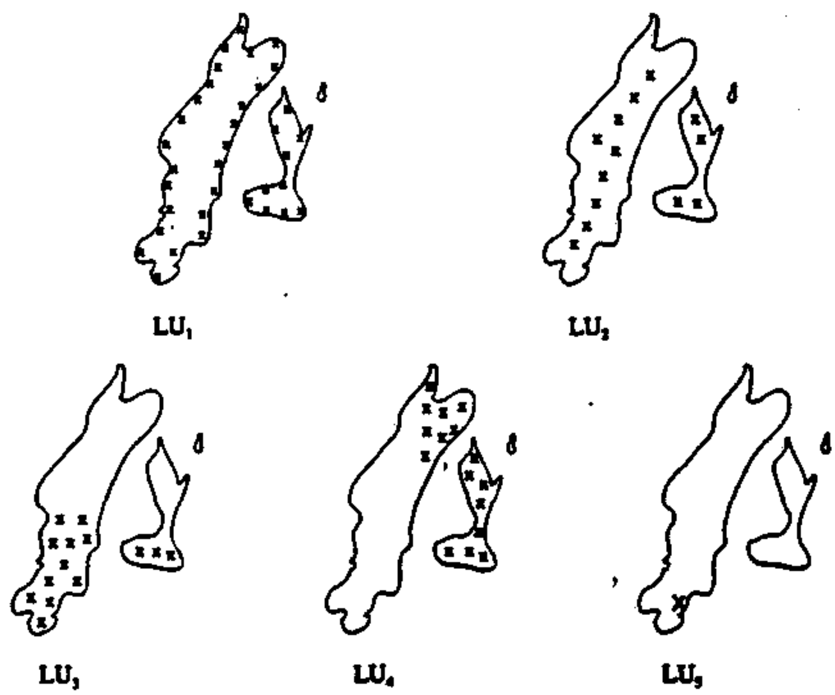

Figure 4. Land use alternatives for Alonnisos

It goes without saying that the previous sketches can also be represented in more professional GIS maps by making more specific assumptions regarding these policy alternatives. In order to offer a multi-dimensional evaluation, the following assumptions are made for each successive scenario.

Scenario LU_1: the first spatial scenario encourages urban growth within 200m of the sea. The beaches themselves fall then in the influence sphere of urban areas. This scenario is to be interpreted as a "sea-shore" development scenario, where the sea is considered as the major attraction force for tourism. Hotels, shops, public services, etc. are clustering in a zone between 0 and 200m from the sea.

Scenario LU_2: the second spatial scenario encourages urban growth in the central part of the island. The beaches and a zone of 500m from the sea may not be changed into urban areas. This scenario is to be interpreted as an "inner-land" development scenario. The old Alonnisos village and transportation in the centre of the island are the primary attraction poles for tourism. Sea plays a secondary role for tourism and, consequently, for urban activities. Beaches are fully protected.

Scenario LU_3: the third spatial scenario allows the urban area to expand only at the southern half of the island. Beaches are allowed to change into urban-dominated areas in the southern half of the island only. The north half of the island remains "untouched". This scenario is to be interpreted as a Marine Park laboratory protection scenario. The Marine Park laboratory resides at the northern gulf of the island and, under this scenario, no one is authorized to approach it.

Scenario LU_4: the fourth spatial scenario allows urban activities to expand only in the eastern half of the island. Beach areas are allowed to change to urban in the eastern part of the island only. The western part of the island remains "untouched". This scenario is to be interpreted as an encouragement for exploiting the island Peristera for urban activities and tourism. In this way the main western part of Alonnisos island is relieved from any distortion by human activities.

Scenario LU_5: the fifth spatial scenario allows urban land to expand only within the existing urban areas of the islands. This means that any type of urban growth in a horizontal direction is strictly prohibited, so that only urban growth in a vertical direction is allowed. That is, any type of urban growth is to be accommodated by constructing more floors on the already

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Now the allocation of urban areas on Alonnisos can be depicted using the above GIS model. This model uses the current basic land use map (see Figure 5) and generates as a result of the above spatial development options five new land use maps in which urban area is spatially allocated (see Figures 6 - 10). A resulting land use map of one specific urban allocation, for example LU_2, in relation to a given development alternative D_2 is named here D_2LU_2. The land use allocation maps are the policy alternatives in a spatial evaluation context. The basic land use map, D_2, and the five allocation maps, D_2LU_1 to D_2LU_5, are thus presented in Figures 6 - 10. The areas in these maps show the places where urbanization will take place (unfortunately, the original colour maps cannot be printed here). The change of land use can be further investigated by comparing the basic map with the successive five urbanisation maps. The size of the land use classes in the basic land use map of development alternative D_2 and in the five land use allocation maps is shown in Table 6.

Class	Legend	D_2	D_2LU_1	D_2LU_2	D_2LU_3	D_2LU_4	D_2LU_5
1	Sea	272.074	269.932	269.932	269.932	269.932	269.932
2	Forest	5.813	6.000	6.000	6.000	6.000	6.000
3	Maquis	32.187	29.141	26.316	28.729	30.680	32.860
4	Low maquis	28.938	26.872	27.941	25.207	21.470	29.676
5	Valleys	2.180	2.109	1.924	1.951	2.239	2.268
6	Bare rocks	3.285	2.745	3.368	3.042	3.113	3.437
7	Trees	3.352	2.492	2.358	2.142	3.441	3.480
8	Agriculture	1.803	1.654	1.276	1.545	1.622	1.917
9	Urban	2.235	11.558	12.717	13.285	13.355	2.261
10	Beach	1.119	0.483	1.153	1.153	1.153	1.153
		352.985	352.985	352.985	352.985	352.985	352.985

Table 6. Area table of the basic land use map and the urban allocation maps

Clearly, the land use size from the basic map and the urban allocation maps D_2LU_1 - D_2LU_5 should be the same. Table 6 shows that the size of forest area in all allocation maps remains the same. The size of beach area remains the same, except for the allocation map in which the policy aim is to encourage urbanization within 200 meter of the sea, i.e. D_2LU_1. An important conclusion from this map is that the urban area appears to grow with a factor five to six for all allocation maps, except for the allocation map in which the urbanization is encouraged in the city.

The maps also show that Maquis and low maquis are best protected, of course, within the policy to encourage urbanization in the city (i.e. D_2LU_5). The worst policy for maquis is to encourage urbanization in the central parts of the island (i.e., D_2LU_4) and for low maquis to encourage urbanization in the eastern part of the island (i.e., D_2LU_4).

3.2 Evaluation criteria

Having identified now five spatial development scenarios in combination with a given base development alternative D_2 (i.e., Marine Park), we will next use four judgement criteria to evaluate the five alternative land use maps, D_2LU_1 - D_2LU_5, representing the land use options corresponding to the five different ways to allocate urban area on Alonnisos, and assuming the Marine Park development alternative as a given policy option. The relevant criteria to be used here are:

C_1: tourism

C_2: nature

C_3: landscape

C_4: transportation

These four criteria are measured on a 10-point scale and can of course be mapped separately as extreme policy choices. Thus we may have for each development alternative and each land use option a GIS map for each of the four individual criteria. Assuming for instance the second development alternative and the first land use option (i.e., D_2LU_1), the resulting maps are: tourism (Figure 11), landscape (Figure 12), transport (Figure 13) and nature (Figure 14).

On the basis of four evaluation criteria (i.e., tourism, nature, landscape and transport) and five land use options (LU_1 to LU_5) for a given base development alternative (i.e., Marine Park), the total number of resulting maps would be 20. By mapping also all six base development alternatives, the total number of combinations would even be 120. In the graphical presentation above (see Figures 11-14) we have made a cross-section of all four criteria for a given spatial development option, viz. D_2LU_1 (i.e., the policy to encourage urbanization within 200m distance from the sea). It is of course also possible to make a different cross-section, viz. a mapping of all five land use options for a given criterion. This is carried out in Figures 14-18 for the criterion 'nature' with respect to all land use development options D_2LU_1 to D_2LU_5.

The resulting maps of the criterion 'nature' are found in Figure 14 (nature 1) to Figure 18 (nature 5). For example, Figure 16 (nature 3) shows the value map of the criterion 'nature' for land use policy 3 (favouring urbanisation in the southern part of the island). In these maps, not only urban area is valued, but all areas that change as a result of the chosen policy. For example, if maquis changes to agriculture in a certain area, the area concerned is valued as bad for nature. The basic land use map and the map for alternative 1 is then needed to create the value map for the criterion 'nature'. It is clear that in this way a complete set of value maps can be created.

The GIS maps can of course also be translated into numerical information. The value areas of all maps will now be described in Subsection 3.3, so that the results of all alternatives can be compared for all criteria.

3.3 Evaluation maps and tables

To allow a numerical comparison of all alternatives for all criteria, in this subsection the island areas associated with the land use classes of all resulting maps are systematically listed in tables grouped for each of the four criteria. The classes represent the estimated values for each criterion and range from 1 to 10.

Each land use alternative is assessed for each criterion by calculating a weighted sum of the areas of each class. This compound valuation is found in the bottom row of each table. The valuation is carried out by multiplying the area of the worst class by 1, the class "very bad" by 2 etc., until the "best" class by 10. After adding up all multiplied values, a correction has to be made for the classified total areas; the total area which is classified from 1 to 10 is not equal for all alternatives, so that a standardization is needed. By dividing the weighted sum by the total classified area this problem is solved.

In this way each weighted sum gives an estimation of the value of each judgement criterion for a given land use alternative. The higher the criterion value, the higher the performance of that land use alternative for that criterion. These estimations can finally be included in an overall effect table which can be evaluated by means of the software program DEFINITE, as described before. The various criteria can separately be treated; for the sake of illustration we will only discuss in greater detail the tourism criterion C_1.

The successive land use options related to the performance classes of the tourist criterion in the basic land use map (i.e., D_2) and the five land use alternatives (i.e., D_2LU_1 to D_2LU_5) are listed in Table 7. For criterion 1 (i.e., tourism) each land use alternative is provided with a prefix C_1, so that we have six possibilities, viz. C_1D_2 and $C_1D_2LU_1$ to $C_1D_2LU_5$. The tourist criterion values only urban areas. Due to the fact that in alternative 5 urbanisation is encouraged in the city only, the total urban area is here smaller than in other alternatives. For this reason the unclassified area, which equals the non-uurbanised area, is everywhere larger for the fifth land use alternative. The calculation of the weighted estimations listed in the bottom row is corrected for this.

The bottom row of Table 7 shows that land use alternative 2 (i.e., $C_1D_2LU_2$), encouraging tourism in the central part of the island, scores worst. The other four alternatives are better and score roughly the same.

Class	Legend	C_1D_2	$C_1D_2LU_1$	$C_1D_2LU_2$	$C_1D_2LU_3$	$C_1D_2LU_4$	$C_1D_2LU_5$
1	Worst		0.159	0.493	0.303	0.024	
2	Very bad		1.171	3.131	1.042	0.874	
3	Bad	0.031	1.025	3.687	0.713	1.160	0.045
4	Rather bad	0.109	0.687	1.950	0.861	0.343	0.092
5	Rather fair	0.334	0.577	0.997	0.712	0.320	0.303
6	Fair	0.539	1.380	1.160	2.199	2.455	0.523
7	Rather good	0.743	3.392	0.729	4.506	4.687	0.729
8	Good						
9	Very good	0.397	3.027	0.537	2.831	3.226	0.537
10	Best	0.083	0.140	0.033	0.118	0.244	0.033
11	Unclassified	84.620	72.141	70.982	70.415	70.364	81.438
12	Sea	266.129	269.286	269.286	269.286	269.286	269.286

Total 12 classes	352.985	352.985	352.985	352.985	352.985	352.985
Weighted sum	6.725	6.219	3.761	6.242	6.543	6.818

Table 7. Area table of tourism criterion

3.4 An overall evaluation

After the computation of the 20 value maps, the compound effect table can be produced by extracting a single value from each evaluation map. This value is a weighted areal average of the value map. The weighted sums for each of the four criteria to be found in the bottom line of the corresponding criterion table from Section 3.3 are listed in Table 8. At this stage also the transformation from spatial (pixel level) to non-spatial (relative importance of each criterion per alternative) is carried out. These values give an indication of the quality of the criteria for the five land use alternatives. This table is evaluated with DEFINITE to find the ranking of the alternatives taking into account the outcomes of the criteria.

	ALTERNATIVES				
CRITERIA	LU_1	LU_2	LU_3	LU_4	LU_5
tourism	6.219	3.761	6.242	6.543	6.817
nature	4.128	3.841	3.906	3.879	5.516
landscape	4.663	5.742	4.575	4.427	4.353
transportation	6.299	5.635	6.945	5.168	8.691

Table 8. The effect table used for numerical application of the GIS-SD-DSS system in the test area

The following comments are in order for this effect table.

(1) It appears that scenario 2 (urban growth in the middle of the island) has a very low relative score for the 'tourism' criterion, whereas scenario 5 (no urban expansion) has the highest score for the same criterion. This results from the fact that the urban distances to the sea - which determine the "happy tourists" in this scenario - are at a maximum for the case of scenario 2 and minimal for the case of scenario 5.

(2) The "best" sustainable scenario for the criterion 'nature', determined by the related land use changes, is scenario 5. This is due to the fact that for scenario 5, the natural area for the year 2005 remains almost equal to the natural area for the year 1985. The 'worst' scenario from the point of view of natural sustainability in this case is scenario 2; in this case the scarce natural areas in the central part of the island are destroyed and changed into urban areas. We also observe here that the third scenario (urban expansion in the southern half of the island) puts more environmental stress than the fourth scenario (urban expansion in the eastern half of the island). This is so because the existing urban area for the year 1985 is already located at the southern half of the island; therefore, a scenario according to which additional urban expansion at the eastern half of the island takes place, will place a heavier burden on the natural areas than on the southern (already congested) areas.

(3) Scenario 2 is the 'best' in terms of preserving the original landscape of the island: the urban expansion takes place in the middle of the island and therefore the urban areas are not visible from either the sea or other parts of the island (notably beaches). This non-visibility results in high scores for the landscape criterion.

(4) Scenario 5 is the 'best' in terms of road transportation; in other words, this scenario results in the minimum load of road transportation required for local people or tourists to move on the island. The 'worst' scenario in terms of road transportation load is scenario 4 (urban expansion only in the eastern half of the island). This is due to the fact that the distances from the harbour, located at the southern part of the island, are maximized and this is, in turn, taken into account for the computation of the road transportation burden.

The compound effect table is also graphically presented in Figure 19.

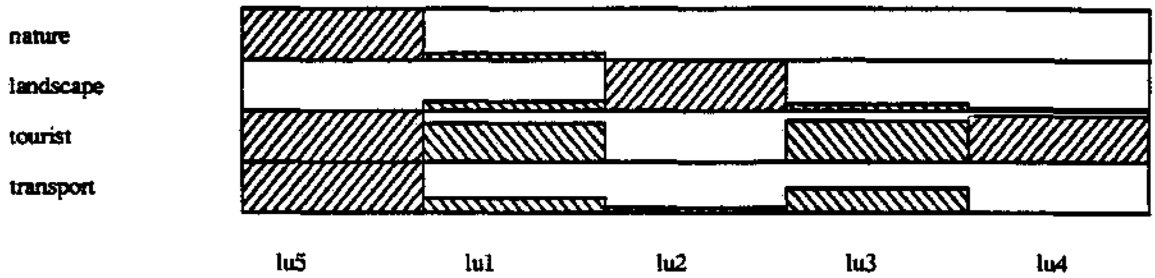

Figure 19. Histogram of effect table.

This effect table is then imported into DEFINITE (Van Herwijnen and Janssen 1989) in order to obtain a final ranking of alternatives. The choice of weights here was such that all criteria were considered equally important. The ranking results based on the four selected criteria are given in Table 8.

ALTERNATIVE	LU_1	LU_2	LU_3	LU_4	LU_5
RANK	3	5	2	4	1

Table 8. The ranking results for the five spatial (land use) alternatives on Alonnisos

We thus conclude that, based on the above assumptions and ranking methods, scenario 5 is to be selected as a stronger 'sustainable' scenario than the others. The term 'sustainable' here refers to a development (until the year 2005) which focusses simultaneously on four sustainability criteria selected: (1) touristic sector activities are favoured and enhanced, (2) natural areas are preserved as much as possible and/or changed into urban areas as little as possible, (3) landscape values are preserved, and (4) the road transport annoyance becomes minimal. However, such a conclusion is expected from development scenarios of the type of scenario 5: if the urban areas are to be restricted to their original locations, then this is the 'best' sustainable scenario, at least in an ecocentric sense. Since often such 'no expansion' policies tend to be unrealistic (and much more difficult to implement and control), we might, alternatively select scenario 3, i.e., the scenario which was ranked as the second best. According to this scenario, urban growth is encouraged in the southern part of the island, notably in areas surrounding the existing village of the island. This may also be interpreted as a 'Marine Park preservation' scenario, since the Marine Park laboratory is located in the northern part of the island. This scenario minimizes the road transportation load, but it is not a strong sustainable scenario for the natural ecosystem (like e.g. scenario 1). However, it may be easier and more realistically implemented in practice than scenario 5.

The next less strong sustainable scenario is scenario 1. This scenario however, seems to have a fair chance of actually being implemented, because: (1) urban expansion is allowed without too many restrictions and (2) the beach areas are exploited for the creation of touristic services. The only barriers to urban activities are natural conditions or existing policy regulations (high slopes, forest area restrictions, etc.). Therefore, it may happen that scenario 3 is fairly realistic, even though from a normative sustainable viewpoint it is less favourable.

Scenario 4 is the next 'worst' scenario. This is plausible since, according to this scenario, we force the population to move away from the existing urban areas toward the eastern half of the island. This in turn requires heavy road transport, destroys the natural areas and does not favour tourism.

The 'worst' scenario, according to our ranking results, is scenario 2. This was also expected, since (1) we 'move' the local population and tourists to the central part of the island and thus the access to the beaches is very difficult; this in turn creates "unhappy tourists"; (2) although the landscape is best preserved, transportation needs to be increased; (3) the natural ecosystem is mainly negatively affected, since urban activities destroy natural areas and disturb wild life.

4. Epilogue

The adoption of new information technology results depends on their scientific merits and political willingness. In the case study described above the most desirable development direction was very clear: much emphasis on protection of the marine environment and on restricting the negative externalities of tourism. In a geographical setting this would mean a concentrated land use pattern rather than a dispersion of tourist activities all over the island.

It is at the same time clear however, that any policy choice will affect the interest of various actors involved (e.g., fishermen, land owners, hotel owners, environmentalists etc.). The way the results were presented here, viz. in a conditional "what .... if" scenario form, makes the range of policy strategies and of citizen's interests more transparent. Whether or not policy recommendations will be accepted, depends on attitudes and perceptions of people. The methodology developed here is able to generate various best compromise solutions, but in case of rigid extreme interests by actors involved it may be difficult to pave the road to a SD-oriented future. At best one may claim that GIS-based DSS tools like the one presented above may increase awareness of current frictions and future incompatibilities in economic development, environmental sustainability and land use shifts. Whether or not a message from scientific analysis will be accepted, is at the end a matter of socio-political responsibility of actors in society characterized by conflicting interests.

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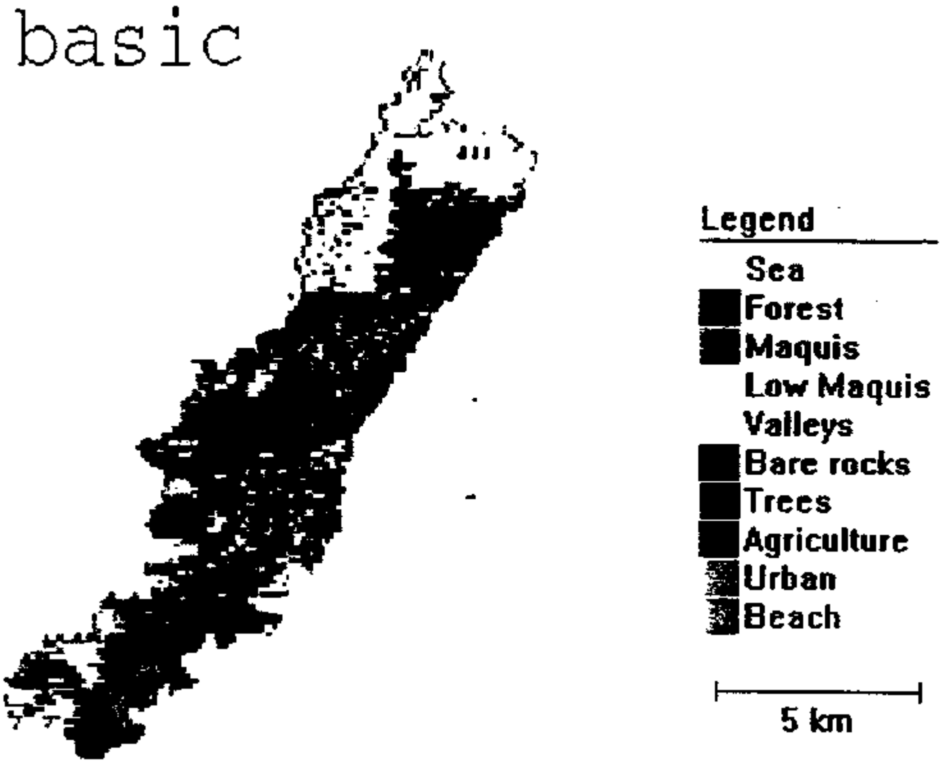
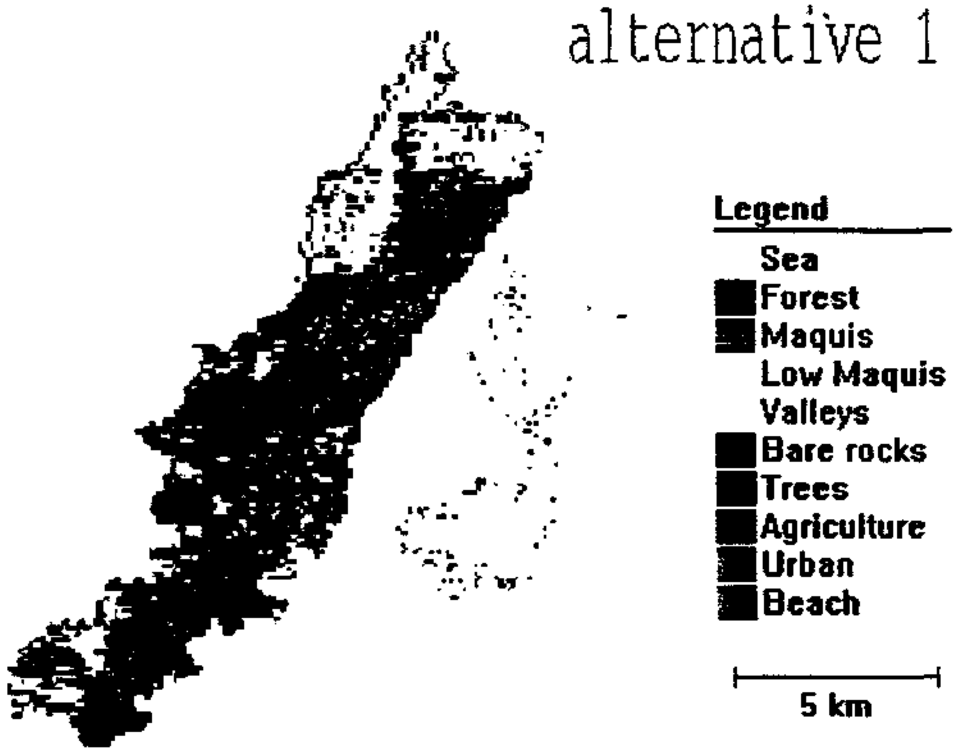


Figure 5



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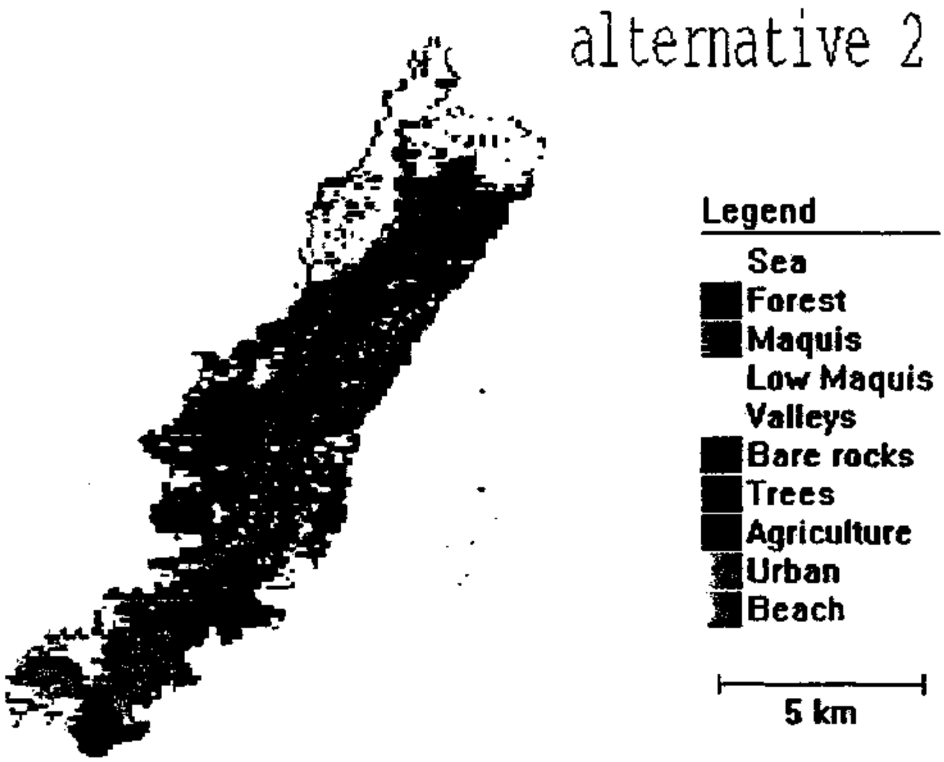


Figure 7

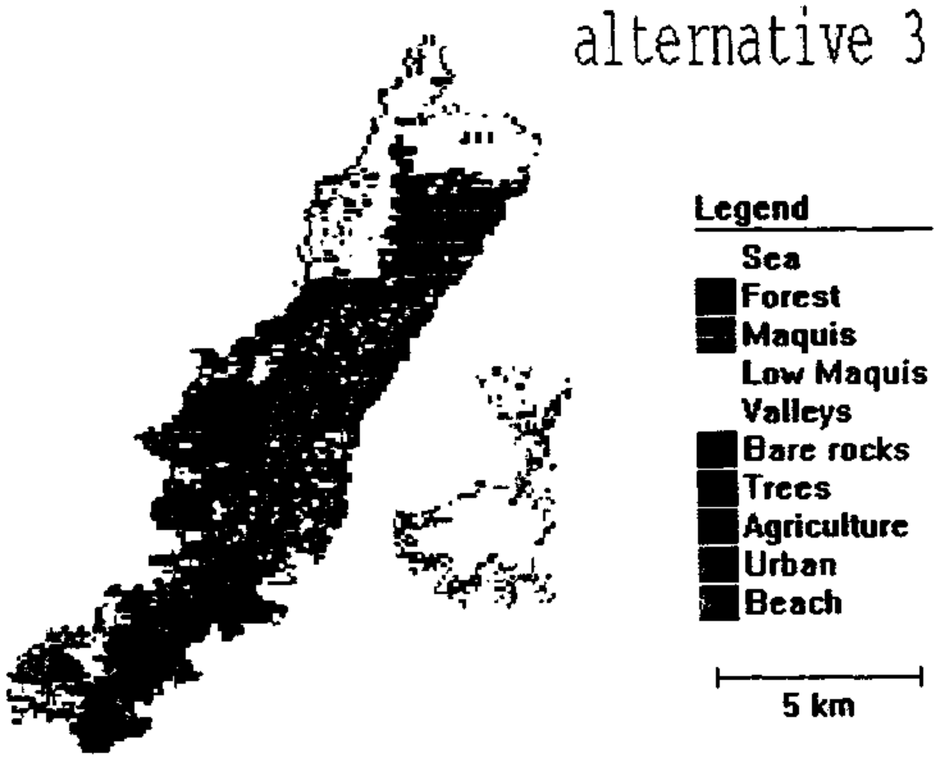
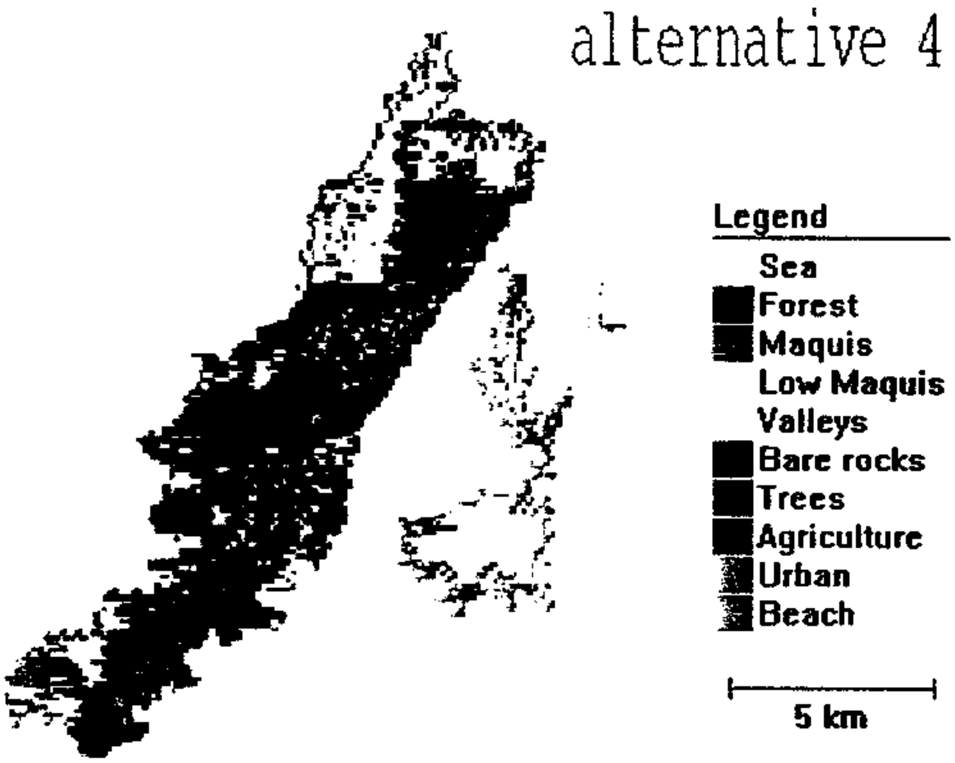


Figure 8



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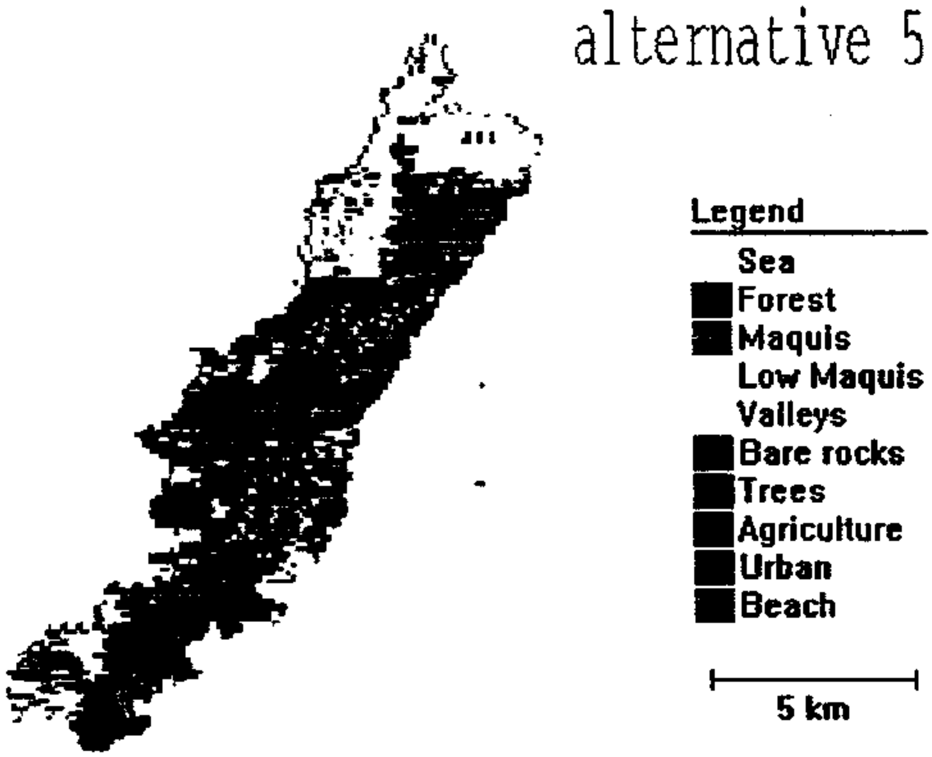

Figure 10

tourist 1

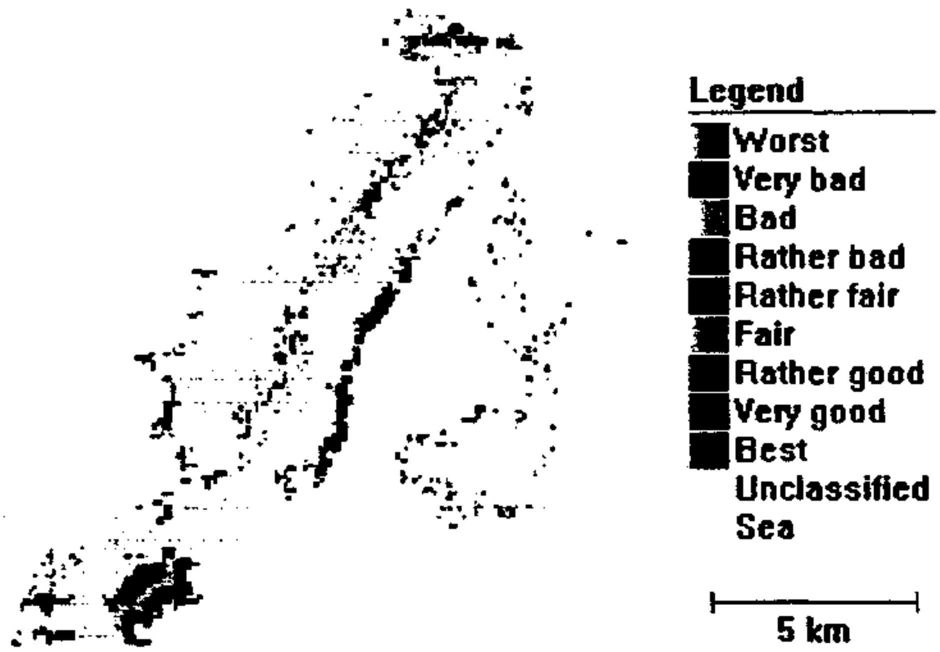

Figure 11

landscape 1

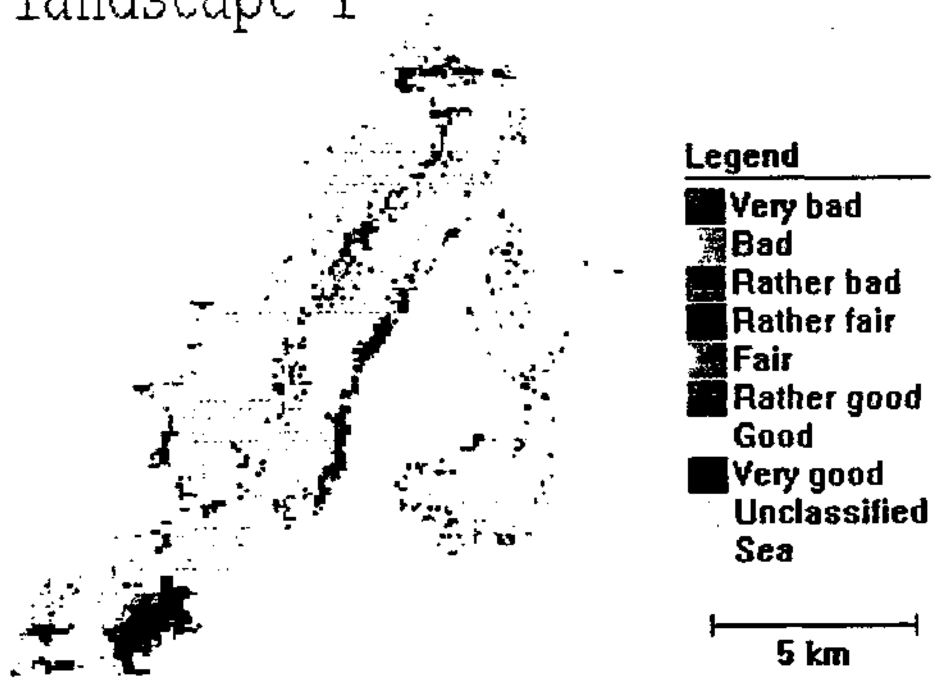

Figure 12

transport 1

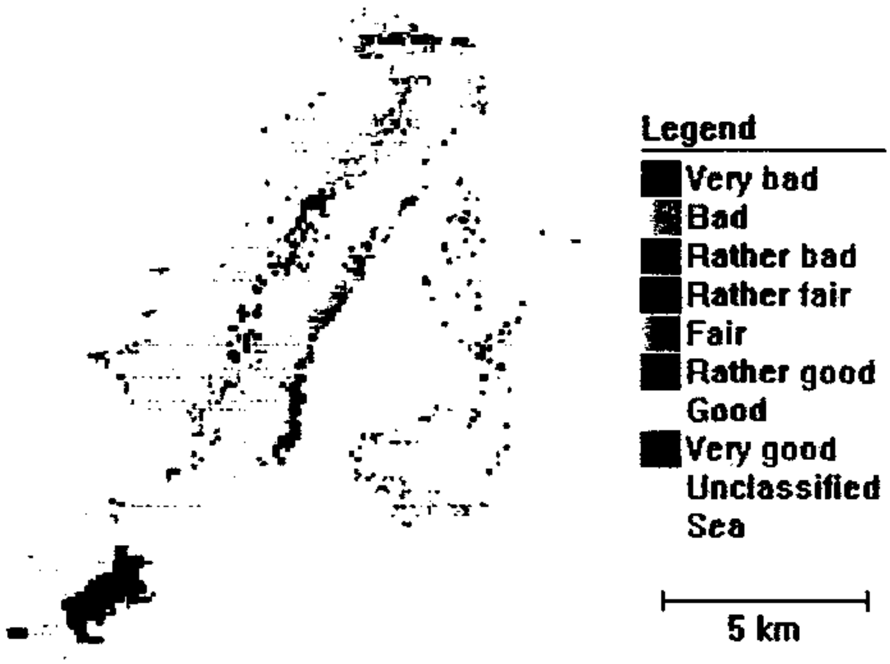

Figure 13

nature 1

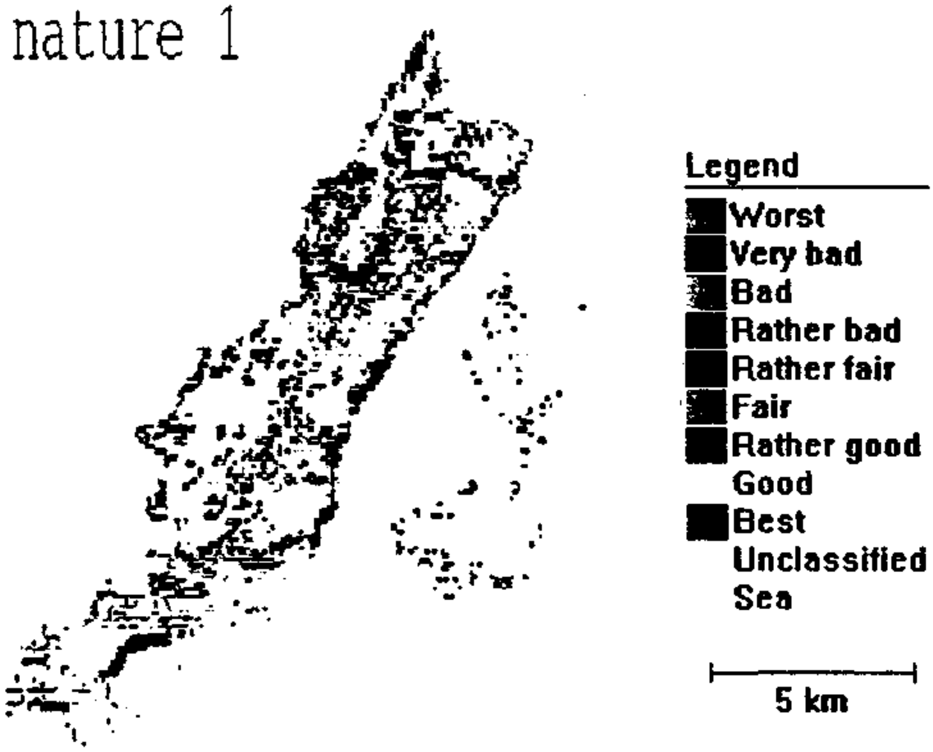

Figure 14

nature 2

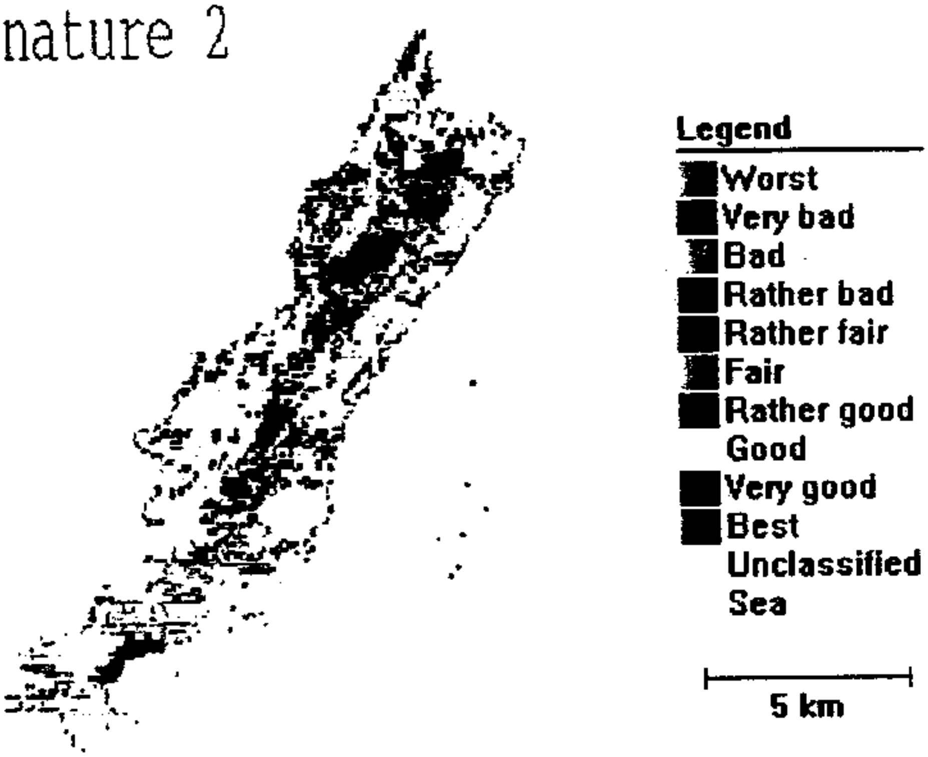

Figure 15

nature 3

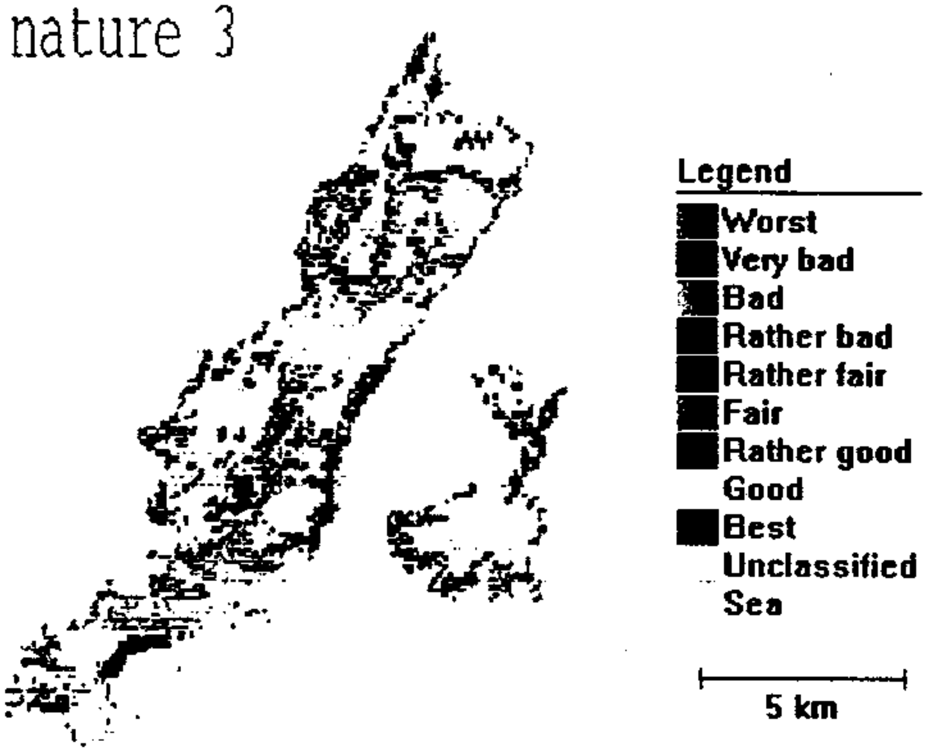

Figure 16

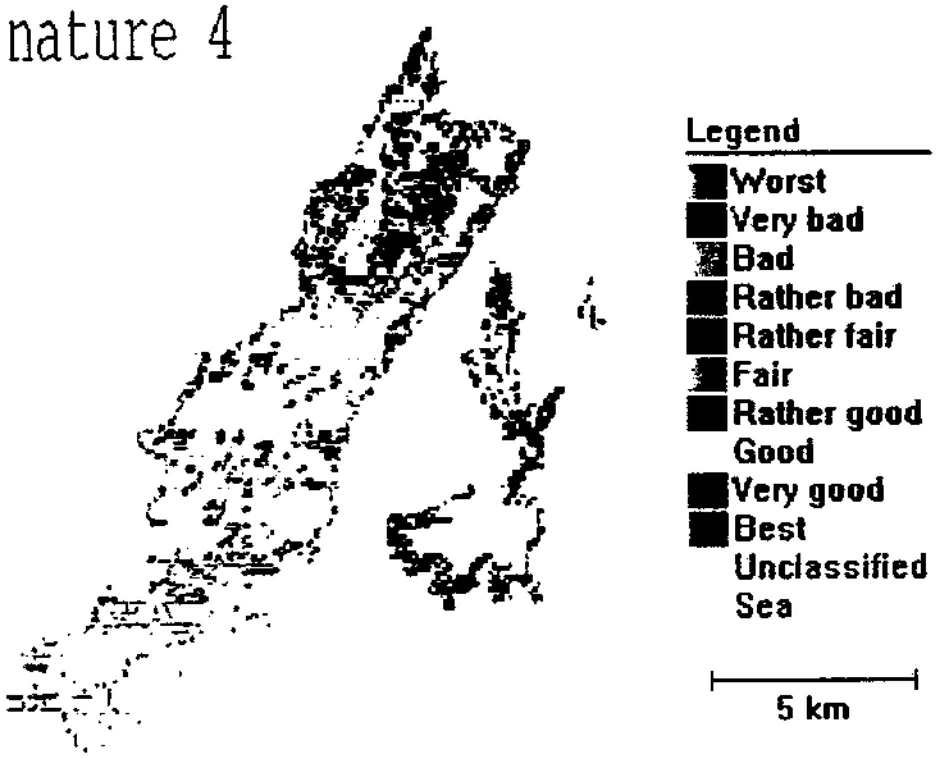

Figure 17

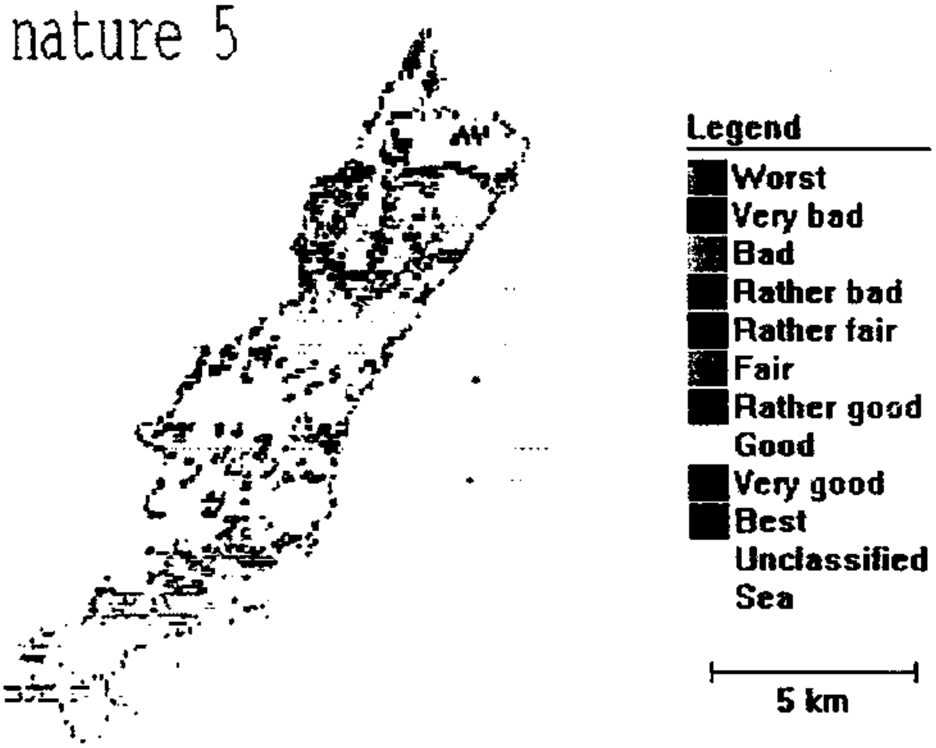

Figure 18