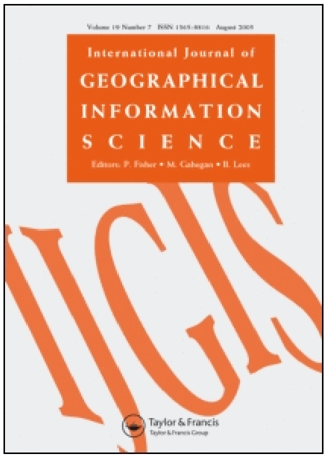

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Research Article

GIS-based approach for participatory decision making and land suitability assessment

LUIS A. BOJÓRQUEZ-TAPIA, SALOMÓN DÍAZ-MONDRAGÓN and EXEQUIEL EZCURRA

Instituto de Ecología, Universidad Nacional Autónoma de Mexico, Apartado Postal 70-275, México, D.F. 04510
e-mail:supremo@prodigy.net.mx; salo_diaz@yahoo-com

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Abstract. The objective of this paper is to present a GIS-based multivariate application for land suitability assessment with a public participation base. The approach takes into account the issues and concerns of the stakeholders, and employs a multivariate statistical procedure for classifying land units into land suitability groups, according to sectoral interests. Sets of spatial algorithms are incorporated into a GIS database to identify such groups. A participatory planning workshop was carried out to define the set of environmental attributes that determine the land-use pattern, in conformity with the interests, objectives, and values of the stakeholders. The approach allows experts to interpret the information generated by the stakeholders under methodologically rigorous conditions, with a minimum of spatial data, and with relatively low cognitive processing level demanded to the representatives of socioeconomic sectors, interest groups, and authorities.

1. Introduction

Land suitability is determined by both the fitness of the land for a particular use (Steiner 1983), and the values and interests of the stakeholders in a region (Bojórquez-Tapia *et al.* 1994). In fact, land-use decisions depend upon the socioeconomic activities and the character of the involved social organizations (Malczewski and Ogryczak 1995). However, environmental conflicts appear whenever different sectors with incompatible activities compete for available land (Bojórquez-Tapia *et al.* 1994).

Environmental conflicts over the allocation of land have resulted in laws and policies that require public participation in decision making. Since ideas, values, and attitudes over natural resources vary between social organizations and people (Smith *et al.* 1995), the goal is to provide the constituencies with an opportunity to collaborate and to attain consensual land-use decision making (Bojórquez-Tapia *et al.* 1994, Brown 1986).

Conflict resolution then implies making judgments about the stakeholders' goals and interests (Edwards and Newman 1986). It also entails the comparison of trade-offs among different decisions resulting from particular sectoral interest and land-use scenarios (Van Huylenbroeck and Coppens 1995). Hence, a critical issue in

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consensual decision making is the credibility of the conflict resolution process, particularly with respect to the unique demands of the stakeholders involved in participatory planning (Selin and Chávez 1995). From the technical point of view, credibility depends upon the availability of data, the internal structure of the analytical procedure, and the interactions and discussion among interest groups (OEA 1984, Crowfoot and Wondolleck 1990, Harashina 1995).

A land suitability assessment is a planning tool for the design of a land-use pattern that prevents environmental conflicts through the segregation of competing land-uses (Eastman *et al.* 1993). It is a decision problem under multiple criteria and multiple objectives that, when adapted into a geographical information system (GIS), produces a land-use pattern that minimizes conflicts and maximizes consensus among the stakeholders (Eastman *et al.* 1993, Malczewski *et al.* 1997).

Therefore, a successful land suitability assessment depends on how the activities and interactions of the relevant interest groups are included into the analysis (Malczewski *et al.* 1997), and how the decision rules are constructed in a way that all of the stakeholders' land-use criteria are satisfied (Eastman *et al.* 1993). Hence, GIS-based assessments have to include the three land-use decision elements at the regional scale (Smith *et al.* 1995): (1) the distribution of land cover, population, and human activities over the landscape, or infrastructure; (2) the social organizations present in a region, or structure, and (3) the ideas, values, and attitudes that people have about the particular uses of the land, or superstructure.

The objective of this paper is to present a GIS-based approach for land suitability assessment, which translate the infrastructure, structure, and superstructure of land-use decisions into a rigorous spatial analysis. It is presented by means of a case study: The regional land-use planning for Costa Norte of the state of Nayarit, Mexico.

Baseline data for the approach is obtained during participatory planning workshops. These allow both the stakeholders' representatives and the decision makers to produce a set of land-use criteria. Then, a multi-criteria assessment is used to determine suitability scores for each sector. In an analogous way to other approaches (Eastman *et al.* 1993, Pereira and Duckstein 1993), each grid cell in a raster GIS is valued according to its quality for a particular use, and each thematic layer represents an assessment criterion. Next, a multi-objective evaluation aggregates land parcels into suitability groups, based upon the multi-criteria evaluations for each sector. In essence, the aggregation is carried out by means of a multivariate numerical classification, through a divisive polythetic partitioning (Noy-Meir 1973, Pielou 1984). Finally, land suitability groups are associated to environmental conflicts by means of the relative suitability among groups, so that land-uses can be allocated in a pattern that minimize conflicts and maximize consensus among the stakeholders.

2. Study area

Costa Norte extended from San Blas, Nayarit (21°31′ N–105°23′ W) to Teacapán estuary (22°46′ N–105°46′ W), along the Southern portion of the alluvial Pacific Coastal Plain (figure 1). It encompasses a total of 3500 km^2, which includes the Teacapán-Agua Brava-Marismas Nacionales system.

The Teacapán-Agua Brava-Marismas Nacionales system covers 607 km^2 of tidal channels, seasonal flood plains, and coastal lagoons, and 705 km^2 of mangrove swamps and forests. It is under intense pressure from competing resource uses. On the one hand, major shrimp farming developments were being projected or undertaken in the region at the time of this study. Since shrimp farming has resulted in

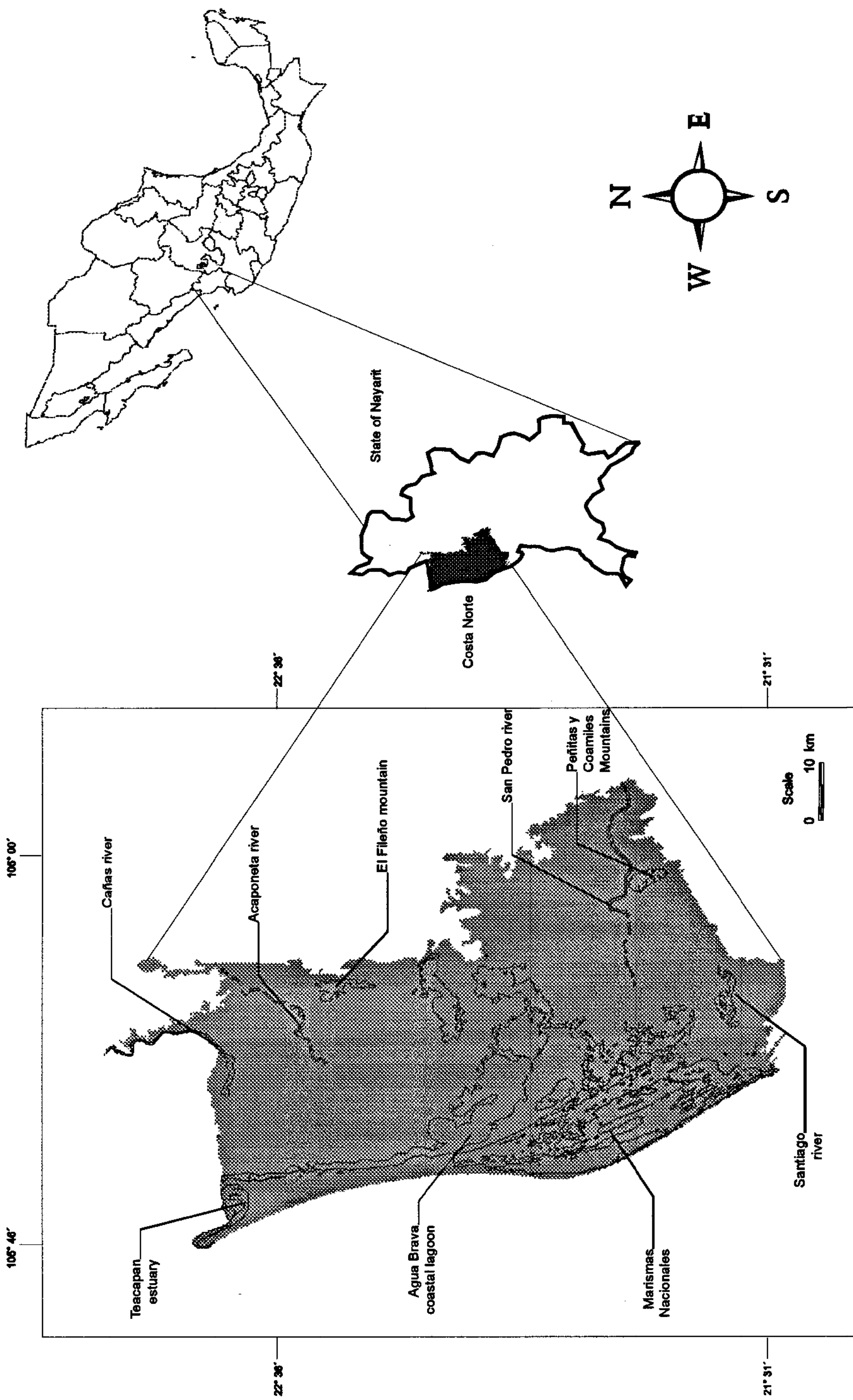

Figure 1. Study area.

the degradation of wetland ecosystems and threatens their biological diversity elsewhere (Snedaker *et al.* 1988, Larsson *et al.* 1994, Flaherty and Karnjanakesorn 1995), the Mexican government was responsible for designing strategies aimed at preventing further deterioration and reducing environmental conflicts (Bojórquez-Tapia *et al.* 1997). Fishing was the most important economic activity in coastal lagoons.

On the other hand, Teacapán-Agua Brava-Marismas Nacionales is important for biological conservation. The system contains the largest expanse of mangroves on the Pacific coast, and about 22% of the total mangrove cover in Mexico (Flores-Verdugo *et al.* 1992). It was a critical component of the Pacific migratory flyway, and the system provides important habitats for commercial, endemic and endangered species (Flores-Verdugo *et al.* 1990).

Along the coastal plain, the river deltas and alluvial soils allow the development of highly productive agriculture and cattle ranching on 1410 km^2. Likewise, terrestrial natural vegetation has been fragmented and reduced to a total of 782 km^2 of low deciduous forest and scrub lands.

3. Methods

The land suitability assessment for Costa Norte was carried out through the method described by Bojórquez-Tapia *et al.* (1994), adapted for a spatial analysis in a GIS. We used the UNIX-based software Geographic Resource Analysis Support System, GRASS (USA CERL 1993) for generating the data layers and for carrying out all of the spatial analyses. The assessment involved three tasks: (1) development of decision rules, (2) database development, and (3) land suitability assessment.

3.1. *Development of decision rules*

3.1.1. *Participatory planning workshop*

Law in Mexico requires public participation in regional land use planning. Hence, a three-day participatory planning workshop was organized. In preparation for the workshop, consultations with federal, state and local policy makers, representatives of socioeconomic sectors, and spokespersons of non-governmental organizations were carried out to identify the relevant stakeholders in the region. These included shrimp farming associations, fishing cooperatives, agricultural and cattle ranching organizations, international conservation groups, academics, and state and municipal authorities. The stakeholders and the authorities were divided into four sectors to simplify the analysis: aquaculture, agriculture and cattle ranching, and conservation.

The activities in the workshop included a combination of lectures and group dynamic techniques (figure 2). The lectures were used to allow the representatives to present their goals, objectives, and concerns publicly, and to provide the participants with a basic understanding of the analytical tools to be used latter. Then, the stakeholders were divided into small groups of ten to fifteen people, according to their respective sector.

Through small-group involvement techniques (Steiner 1991), a facilitator guided group discussions to clarify the key issues, identify problems, and generate solutions. The specialists of the interdisciplinary team assisted the facilitators in the small-group dynamics; their role was to assist the stakeholders to generate criteria in a format usable for the spatial analysis. Thus, the representatives were able to: (1) declare the sectoral objectives and activities, (2) identify the physical, biological, and socioeconomic characteristics needed to carry out their activities, (3) establish the activities that could be in conflict with other sectors' goals, and (4) produce

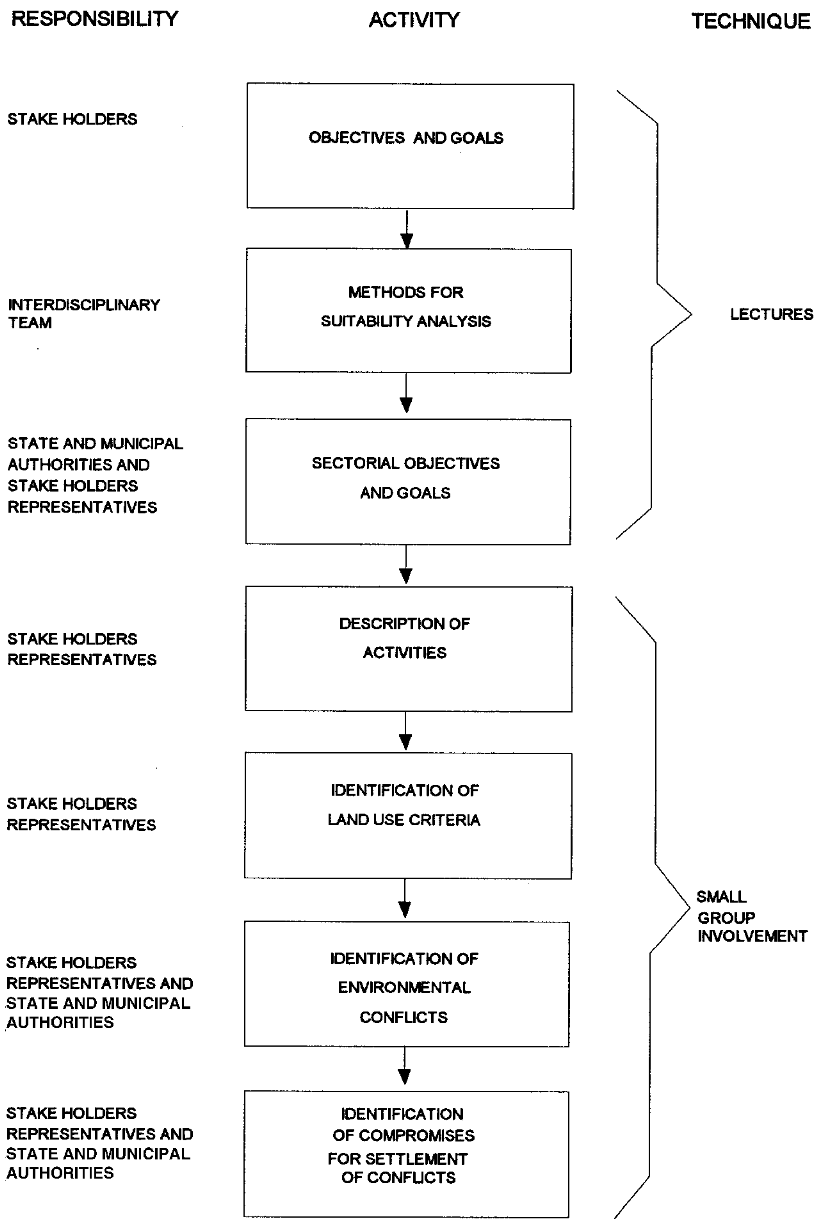

Figure 2. Flow chart of the participatory planning workshop for the land suitability assessment of Costa Norte de Nayarit, Mexico.

the specific compromises that would have to be assumed by each sector to prevent land-use conflicts.

3.1.2. *Interdisciplinary team*

An interdisciplinary team of fifteen specialists was formed and organized in two groups (Holling 1978): specialist group and core group. The first included specialists of the following disciplines: geomorphology, hydrology, soils, vegetation, remote sensing, biological conservation, and human ecology. Team members were selected because of their experience, technical capacity, and knowledge of the stakeholders' interests.

The results of the participatory planning workshop were studied in detail by the specialists group. Each expert translated the physical, biological, and socioeconomic land attributes needed to perform a sectoral activity into specific spatial environmental criteria; this task was simplified by the participation of the specialists in the small-group dynamics. Next, the experts defined the conditions or states of favourability-unfavourability for each criterion, and ranked the importance of the attributes for each activity, as in Betters and Rubingh (1978). Disagreements among the specialist over definitions, and interpretations of the elements of the model, and importance weights were conciliated during brainstorming sessions.

The core group included specialists in GIS and regional planning. This group was responsible of applying multi-criteria/multi-objective techniques for the suitability assessment. Once the suitability assessment was completed, the whole interdisciplinary team conceived specific compromises to settle land-use conflicts, taking into account the information generated in the participatory planning workshop.

3.2. *Database development*

Results of the participatory planning workshop were transferred to a large scale (1:50 000) GIS database. Thus, the database included the following layers: vegetation and land cover, soil type, landforms, elevation, major roads, and urban areas. The vegetation and land cover layer was created by means of a supervised classification of Landsat TM satellite imagery, while the others were digitized into the GIS from corresponding thematic maps or, in the case of the elevation layer, derived from a digital elevation model.

The GIS layers for each land-use criterion were reviewed by the specialists group. This process was crucial for the conservation and aquaculture. For these sectors, wetlands were at first identified as a criterion in the workshop. After the revision by the specialists, however, the conservationists indicated that habitat requirement of shoreline birds and water fowl oblige the use of two separate criteria: salt marshes and coastal lagoons. Likewise, aquaculture specialists pointed out that flood prone areas would suffice as a criterion.

Therefore, the vegetation and land-cover, and the landform layers were adjusted to suit the conservation criteria. Since salt marshes were not separated by the initial satellite image classification, a second image interpretation was necessary. Aerial vertical videography techniques (Graham 1993) were used to support the second classification, whose results identified the salt marshes as a land-cover class. Meanwhile, flood prone areas and coastal lagoons were located from the landform layer. The specialists group suggested no additional changes.

3.3. *Land suitability assessment*

3.3.1. *Multi-criteria analysis*

The multicriteria analysis valued the landscape attributes with respect to specific land-uses or sectoral activities. As in Eastman *et al.* (1995) and Pereira and Duckstein (1993), each thematic layer represented an evaluation criterion and grid cells were valued according to their quality for a particular land-use through a weighted linear combination.

Formally, the set of all pixels in a given GIS database, X, with a total of K

pixels, is represented by (Pereira and Duckstein 1993):

$$X = \{x^1, x^2, \ldots, x^k\}, \qquad k = 1, 2, \ldots, K.$$

Each pixel is characterized by a set of criteria or decision variables, I, so the kth pixel takes a value x for criterion i, and the collection of all possible values in different map layers is defined as follows:

$$x^k = (x_1^k, x_2^k, \ldots, x_i^k); \qquad i = 1, 2, \ldots, I;\ x = (0, 1);\ \forall x_j^k \in X$$

where $x_i = 0$ if the state of a criterion is favourable for a sector, and $x_i = 1$ otherwise.

The suitability s_j at the kth pixel was computed by a weighted linear combination as follows (Eastman 1993):

$$s_j^k = \sum_i^I w_{ij} x_{ij}^k; \qquad \forall x_i^k \in X$$

where w_{ij} is the weight, and x_{ik} is the value of criteria i for sector or land-use j in the kth pixel.

The criteria weights, w_i, were computed on an ordinal scale as follows:

$$w_{ij} = n_j - r_{ij} + 1$$

where n is the total number of criteria, and r is the rank of criterion i for sector j.

The multi-criteria analysis was implemented in GRASS in two steps (figure 3). First, a set of binary layers was generated to locate the favourable state for each criterion. Thus, the appropriate variables, either numerical (e.g. distance to roads) or nominal (e.g. soil type), were reclassified to a category value of 1. Next, the *r.weight* program of GRASS was used to carry out a weighted linear combination of the data layers and obtain sectoral suitability scores for each pixel.

The multiplication of ordinal weights (w_{ij}) and binary criteria (c_{ij}) generated a complete ordering of the geographical regions with respect to their importance for a specific land-use j. Because of the properties of measurement scales, however, the ordinal map layers had to be transformed to an interval scale for their use in the weighted linear combination.

Nevertheless, the level of understanding and education of the stakeholders constrained us to employ a relatively low cognitive processing approach, which in practical terms implied that the generation of transformation functions was avoided. Hence, we made the following assumptions: (1) the unequal separation between ranked criteria could be accounted for, and (2) there was a transformation function that could convert the ranked criteria to values in an interval scale. To simplify the manipulation of map layers in GRASS (which is restricted to integer numbers), the values of the ranked map layers were assumed to be equal to those of the interval scale needed for the execution of *r. weight*. The resulting suitability scores, s_j, were then normalized to a 1 (minimum) to 10 (maximum) suitability scale to facilitate comparisons between sectors. Also, normalization avoided the 'range effect' generated by different number of criteria among land-uses.

An aftermath of the multi-criteria procedure presented here was that a partially compensatory decision-making was implicit in the analysis; that is, the addition of low ranking criteria could compensate the absence of high ranking criteria in a pixel (Malczewski *et al.* 1997). Consequently, the quality of pixels for a land-use could be overestimated in areas where high ranking criteria were not present.

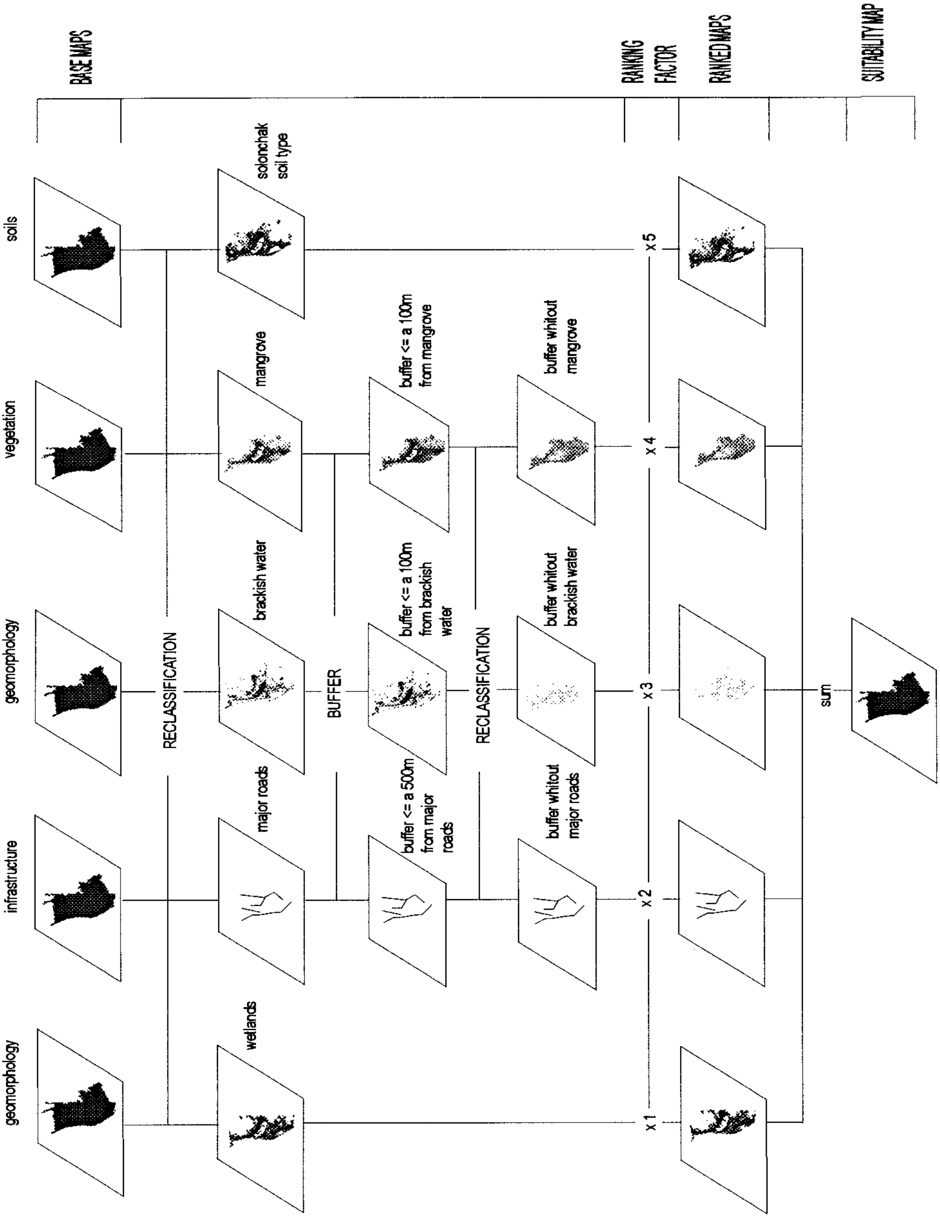

Figure 3. GIS-based multi-criteria model for aquaculture in Costa Norte de Nayarit, Mexico.

3.3.2. *Multi-objective analysis*

The multi-objective analysis aggregated land parcels into land suitability groups. These allowed the interdisciplinary team of experts to estimate the magnitude and likelihood of the environmental conflicts. The groups were formed by gathering the pixels in accordance to the similarities of their sectoral land suitability scores.

The GIS procedure consisted of a multivariate numerical classification, through a divisive polythetic partitioning (Noy-Meir 1973, Pielou 1984). The partitioning method required the application of principal component analyses (PCA) in successive steps. We used the *i.pca* program of GRASS to separate the suitability groups. At each step, the two resulting clusters were obtained by calculating the grouping of pixels that maximized the increment of homogeneity. This increment was computed by the following procedure: (1) The first-component-scores were divided in a frequency histogram; (2) the histogram classes were placed into a series of two sets (for example, class one of the histogram was placed in set *a*, and the other classes in set *b*; next, classes one and two were placed in set *a*, and the rest in set *b*; and so on); (3) the increment in homogeneity was calculated by the pairwise comparison of the sets. The formula used was the following:

$$\Delta\sigma = \sigma_t - (\sigma_a + \sigma_b)$$

where $\Delta\sigma$ is the increment in homogeneity; σ_t is the average variance of all the first-principal-component score classes; σ_a is the variance of set *a* of first-principal-component scores classes; and σ_b is the variance of set *b* of first-principal-component scores classes. Therefore, the resulting classified subsets of pixels were homogeneous with respect to their aptitude for the land-uses altogether.

The subsets of pixels or groups units formed by the numerical classification were transferred to a nominal map, which showed their spatial distribution. Finally, a matrix of mean group suitability $\boldsymbol{Z}$ was generated to compare the relative aptitudes amongst clusters. Matrix $\boldsymbol{Z}$ was adjusted following the Gower's residuals by a double centring procedure (Gower 1966, Digby and Kempton 1987, Bojórquez-Tapia *et al.* 1994):

$$z_{gj} = m_{gj} + m_{g.} + m_{.j} - m_{..}$$

where z_{gj} is the adjusted mean land suitability, m_{gj} is the mean land suitability of group *g* and sector *j*, respectively, $m_{j.}$ is the mean land suitability of group *g* for all sectors, $m_{.j}$ is the mean land suitability of sector *j* for all groups, and $m_{..}$ is the mean of the whole matrix. A positive value of z_{gj} indicates a high mean suitability of group *g* for land-use *j*, while a negative value denotes the opposite.

In conformity with multi-objective theory (Szidarovszky *et al.* 1986) and the area multiple use concept (Brooks *et al.* 1991), conflicts were located by examining which suitability groups presented positive Gower's residuals for competitive land uses (these occur whenever accomplishing a sectoral objective contravenes other sectoral objectives). Hence, the identification of land uses that minimized conflicts at each land unit was achieved by maximizing the Gower's residuals through an integer programming procedure; formally (Dykstra 1984):

$$\mathit{Maximize} \sum_{i}^{J} z_{gi} y_{gj}$$

Subject to:

$$z_{gj} \in Z \tag{1}$$

$$y_{gj} + y_{gk} \leq 1 \qquad \forall i \neq h \tag{2}$$

$$y_{gj} = 0, 1 \tag{3}$$

where: z_{gj} = Gower residual for land unit g and land-use j; g = Index of land suitability groups; j, h = Index of sectors or land-uses; $y_{gj} = 0$ if land-use j in suitability group g is not selected, or 1 otherwise; $y_{gh} = 0$ if land-use h in suitability group g is not selected, or 1 otherwise.

Constraint (1) ensures that all the Gower's residual values are considered, constraint (2) avoids the inclusion of mutually excluding decision variables (reflecting competing land uses), and constraint (3) is the binary restriction for the decision variable.

It should be noted that the range effect did not influence the multi-objective analysis because the land suitability map layers were normalized into the 1 to 10 suitability scale, and an intrinsic assumption in the numerical classification was that all the sectors had the same importance. For example, a numerical classification might generate a land unit A by gathering pixels with high s_j scores for two sectors ($j = 1, 2$) and low s_j scores for one sector ($j = 3$), and a land unit B by gathering pixels with the opposite s_j values for those same sectors.

The accuracy of the multi-objective model was computed by means of an error matrix (Jensen 1996). This contrasted the land suitability groups with the land cover categories used as decision criteria in the sectoral suitability analysis. Land cover data was obtained by interpretation of 3707 georeferenced images that were derived from vertical airborne videography (Graham 1993, Bojórquez-Tapia *et al.* 1997). Both the errors of commission and the errors of omission were computed for each land suitability group and each land cover class.

4. Results

The outcome of the participatory planning workshop resulted in nine environmental criteria (table 1(*a*, *b*)). The combination of these criteria by means of the GIS revealed the spatial distribution of the suitability scores for each land-use (figure 4(*a–d*)). The largest extension of high land suitability scores were obtained for conservation (48% of the study area), followed by agriculture and cattle ranching (40%), fishing (14%), and aquaculture (5%). The high land suitability scores were located as follows: for conservation, along the wetlands (coastal lagoons, estuaries, and swamps), and on areas with remnants of natural cover on the coastal plain; for agriculture and cattle ranching, on the coastal plain; for fishing on the coastal lagoons; and for aquaculture, on the wetlands (estuaries, and swamps), and on beach ridges and barrier islands.

The numerical classification for Costa Norte required seven PCA iterations to obtain eight groups (figures 5 and 6). The first PCA separated highlands from lowlands. The second PCA was applied to the highlands cluster and separated two sets of pixels, which were related to the elevation. One of those sets was subjected to the third PCA. It resulted in Group I, clearly associated with the higher lands on the coastal plain and the barrier islands (29% of the study area), and Group II, which was related mainly to the flood prone areas close to riparian zones in the coastal plain (11% of the study area). The other set was subjected to the fourth PCA

Table 1(*a*). Land use and environmental criteria used in the Costa Norte de Nayarit suitability assessment.

Variable	Sector							
	Aquaculture		Agriculture and cattle ranching		Fisheries		Biological conservation	
	Favourable	Unfavourable	Favourable	Unfavourable	Favourable	Unfavourable	Favourable	Unfavourable
Brackish water	50 m	> 50 m	NR	NR	100 m from mangrove	> 100 m from mangrove	NR	NR
Distance to major roads	500 m	> 500 m	3 km	> 3 km	NR	NR	500 m	< 500 m
Distance to agriculture and cattle ranching land	NR	NR	NR	NR	NR	NR	300 m	< 300 m
Coastal lagoons	NR	NR	NR	NR	NR	NR	Presence	Absence
Mangrove	100 m	> 100 m	NR	NR	NR	NR	Presence	Absence
Deciduous forest and scrubland	NR	NR	NR	NR	NR	NR	Presence	Absence
Soil type	Solonchak	Rest	Feozem Vertisol Regosol Luvisol Fluvisol and Cambisol	Solonchak and Litosol	Solonchak	Rest	NR	NR
Flood prone zones	Presence	Absence	Absence	Presence	NR	NR	Salt marsh	Rest
Riparian zones	NR	NR	Presence	Absence	NR	NR	NR	NR

NR: Not required.

Table 1(*b*). Ranking of environmental criteria for the Costa Norte de Nayarit suitability assessment.

Variable	Sector	Rank
	Aquaculture	
Soil type		1
Distance to mangrove		2
Brackish water		3
Distance to mayor roads		4
Riparian zones		5
	Agriculture and cattle ranching	
Flood free zones		1
Soil type		2
Riparian zones		3
Distance to mayor roads		4
	Biological conservation	
Natural cover, coastal lagoons and flood prone zones		1
Distance to mayor roads		2
Distance to agriculture and cattle ranching		3
	Fisheries	
Brackish water		1
Soil type		2

that produced two clusters. From one of these, the fifth PCA segregated groups Groups III and IV, while the other cluster formed Group V. Group III included pixels located on flood prone areas of brackish water, near to mangroves (3% of the study area). Group IV gathered a heterogeneous collection of pixels located within estuaries or in flood prone areas near to mangrove swamps (2% of the study area). Group V was distributed along the riparian areas in highlands (1% of the study area).

The lowlands were subjected to the sixth PCA, which produced Group VI, the coastal lagoons and estuaries (8% of the study area), and a collection of pixels that was divided by the seventh PCA. This generated Group VII, associated with mangrove forests and natural cover in the coastal plain (33% of the study area), and Group VIII, related to the natural cover on the coastal plain and salt marshes (13% of the study area).

The maximization of the Gower's residuals (figure 7) depicted the potential for conflict among the four sectors, in contrast with the average suitability scores for each sector (table 2). Groups I and II presented a clear land suitability for agriculture and cattle ranching. Group III exhibited a high relative suitability for aquaculture, while Group IV showed a moderate relative suitability for aquaculture.

The suitability of Group V was not clearly defined because it obtained low suitability scores for the four sectors (table 2) and, as an aftermath, the Gower residuals were close to zero (figure 7). Nonetheless, the positive residuals indicated that there existed potential for conflict among agriculture and cattle ranching and aquaculture. Note that conservation obtained a negative residual value (figure 7) in spite of having the highest average suitability score among the four sectors (table 2). The explanation of this result was that the average suitability score in Group VII was among the lowest for the sector.

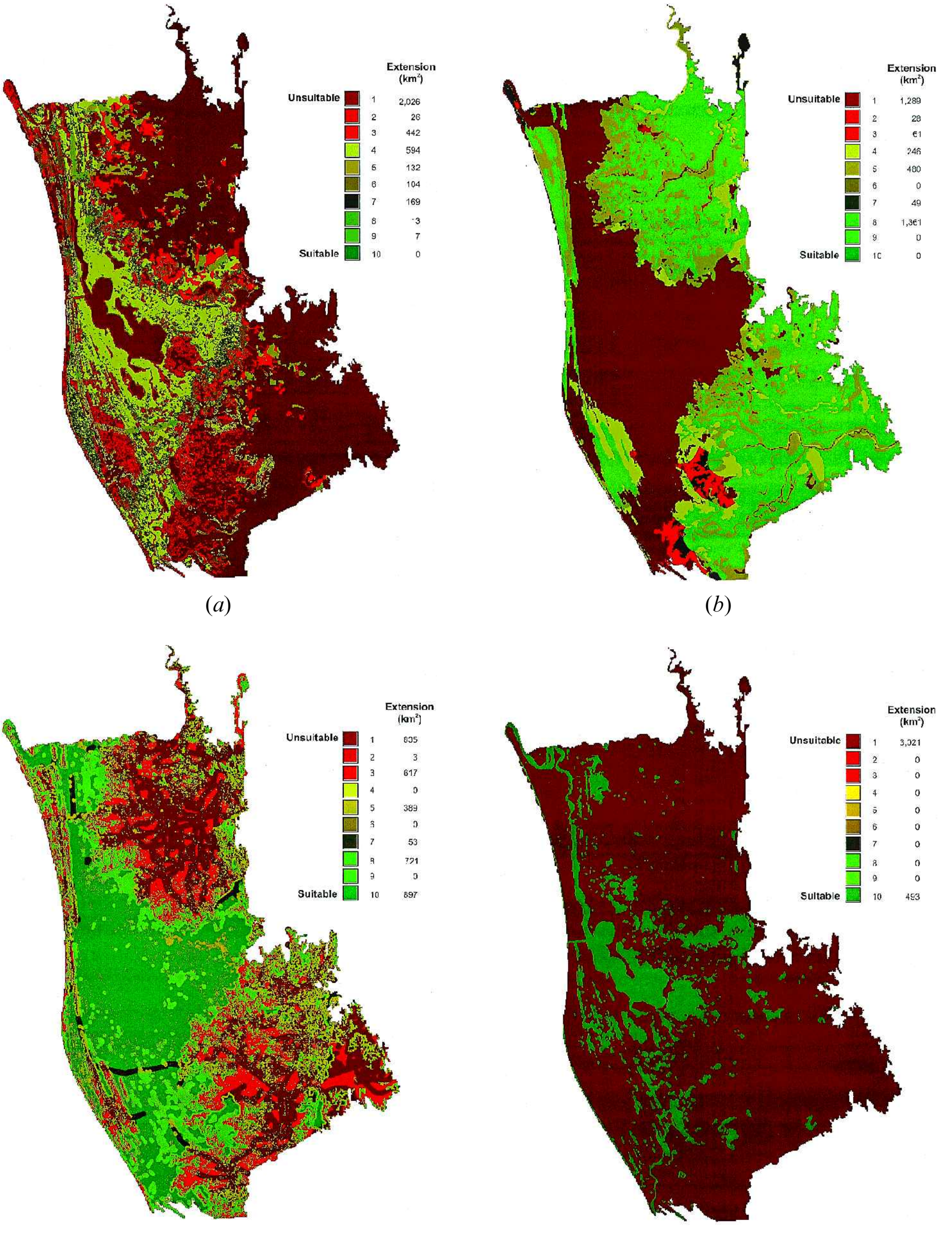

Figure 4. Land suitability maps for Costa Norte de Nayarit, Mexico, derived from sectoral multi-criteria models: (*a*) aquaculture, (*b*) agriculture and cattle ranching, (*c*) biological conservation, and (*d*) fisheries.

Groups VI and VII had a high relative suitability for conservation, although Group VI was also suitable for fisheries. Conflict was not expected among these Groups because the activities of these two sectors were considered compatible. Finally, the suitability of Group VIII was related to conservation and agriculture and cattle ranching, so conflicts among these sectors were predicted (figure 7).

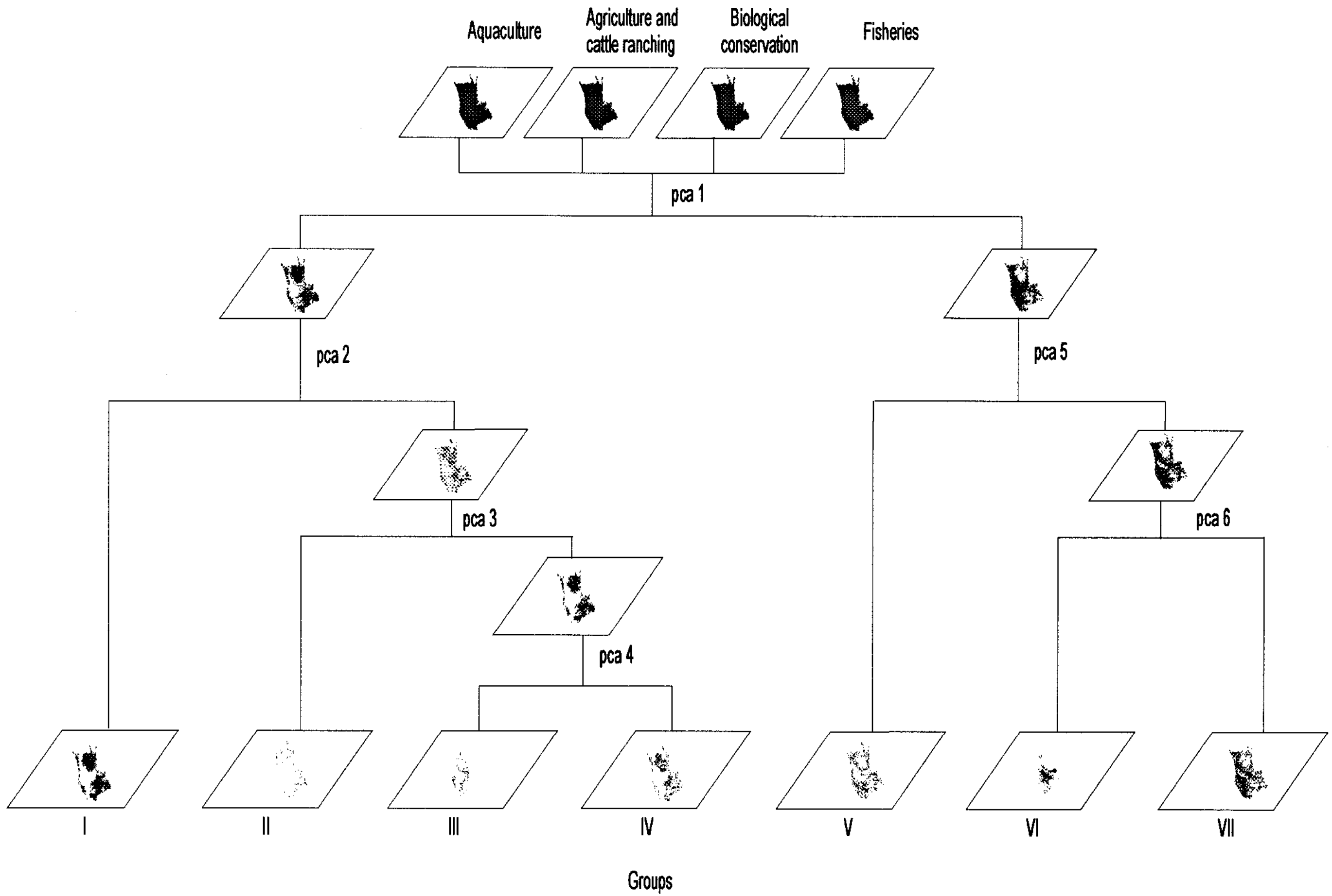

Figure 5. Multi-objective model for the Costa Norte de Nayarit land suitability assessments. A numerical classification of the four sectoral multi-criteria layers (see figure 4) was applied by means of the divisive polythetic partitioning, using seven iteration of principal component analysis (PCA).

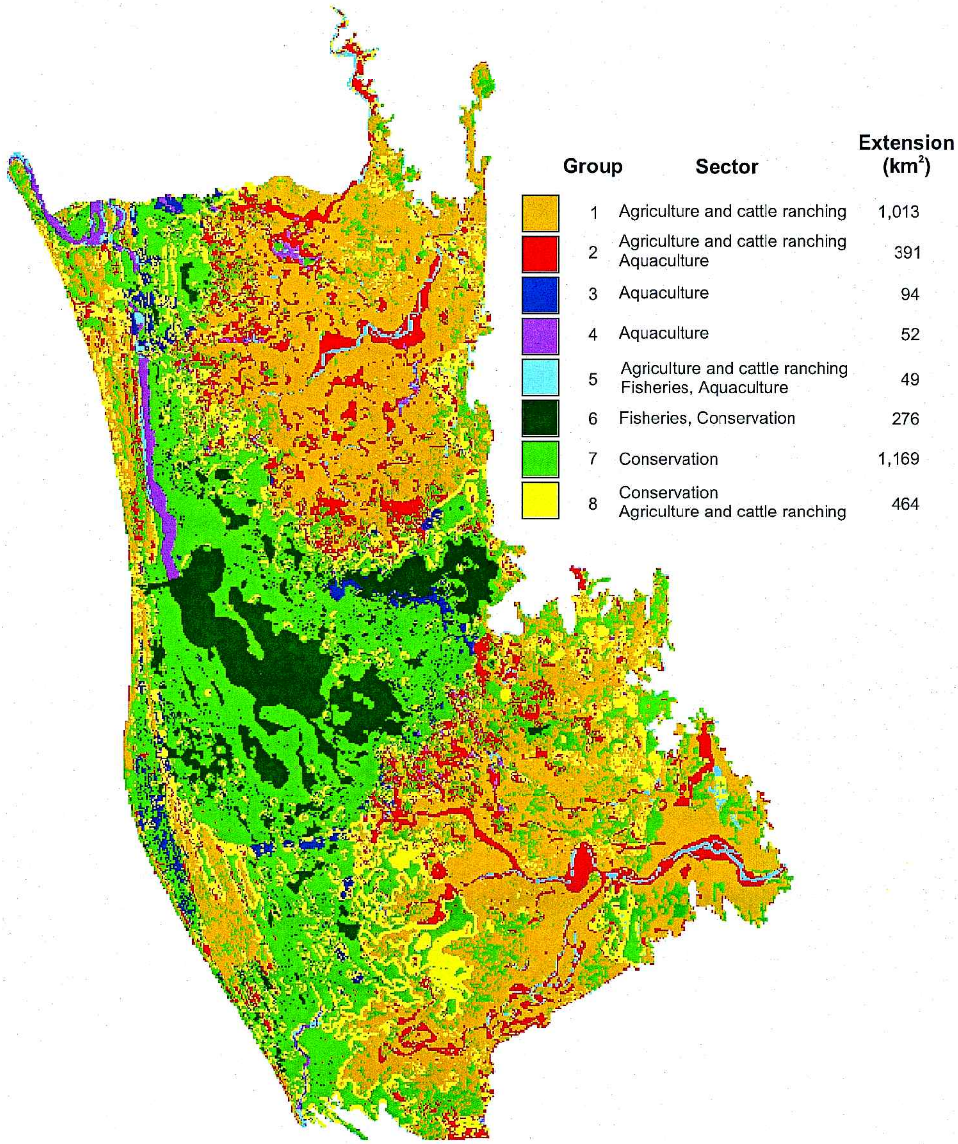

Figure 6. Land suitability groups for the Costa Norte de Nayarit, Mexico.

The error matrix of the land suitability map layer consisted of the eight groups and five land cover classes (table 3). The overall error was acceptable ($p = 0.18$). High errors of commission were detected for Groups IV (suitable for aquaculture), which was mistaken with terrestrial natural cover (suitable for conservation), and Group VII (suitable for conservation), which was mistaken with agricultural and cattle ranching areas. Likewise, a high error of omission was generated by confusion of tropical deciduous forest and scrub cover, that was assigned to agriculture instead of conservation. In the computation of commission error for Group IV, the cover type of agricultural and cattle ranching was considered as correct because the

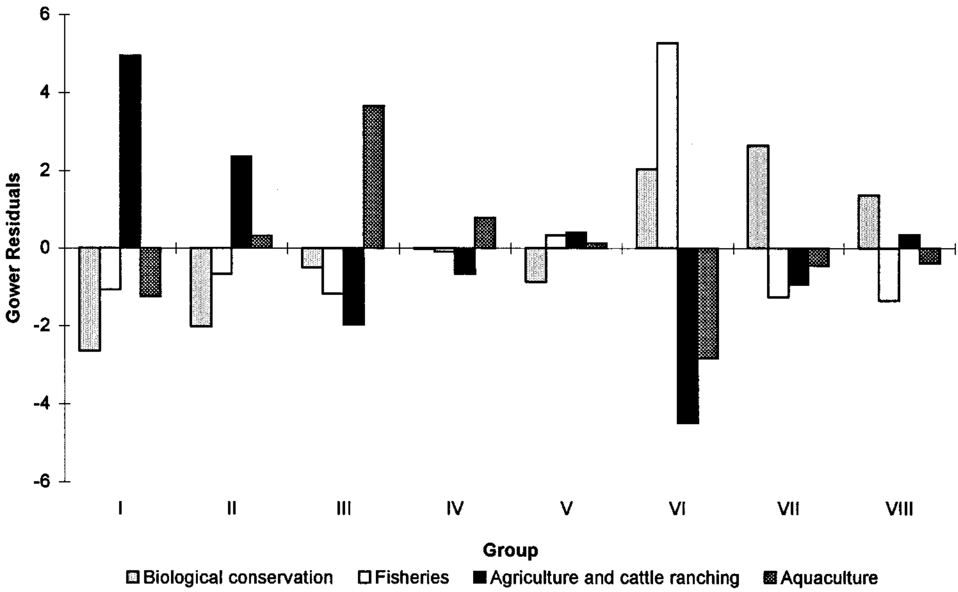

Figure 7. Gower residuals for land suitability groups of Costa Norte de Nayarit, Mexico.

Table 2. Mean suitability scores for the Costa Norte de Nayarit suitability assessment.

	Sector			
	Conservation	Fisheries	Agriculture and cattle ranching	Aquaculture
I	2.54	1.00	7.84	1.13
II	2.76	1.00	4.83	2.30
III	4.78	1.00	1.01	6.15
IV	4.17	1.00	1.23	2.18
V	2.77	0.86	1.76	0.97
VI	9.88	10.00	1.04	2.20
VII	9.06	2.05	3.18	3.17
VIII	7.07	1.25	3.76	2.52

proximity of the corroboration sites to flood prone areas was within the range of the inherent inaccuracy of videography positional recordings.

5. Discussion and conclusions

The land suitability assessment for the Costa Norte exemplifies how effective public participation in land suitability assessments can be attained. Although four sectors were identified as relevant in the study region, emphasis was given to locating appropriate sites for shrimp farming projects. The rationale was that most of the environmental conflicts in the region would be generated by a governmental program for aquaculture development. Such an emphasis was congruent with previous experiences on the negative effects of shrimp farming on wetland ecosystems and their prevention (Snedaker *et al.* 1988, Larsson *et al.* 1994, Flaherty and Karnjanakesom 1995).

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Table 3. Error matrix of the Costa Norte de Nayarit land suitability map (see figure 6 for group description). Numbers in bold type are the correct land cover categories with respect to the land suitability groups.

	Land cover						
Land suitability group	Crop lands and cattle ranching	Coastal lagoons and estuaries	Riparian zones	Mangroves and salt marches	Deciduous forests and scrubland	Total points	Commission error
1	889	1	2	55	120	1067	0.16
2	395	2	17	71	58	543	0.11
3	7	2	0	149	16	174	0.14
4	16	5	0	16	11	48	0.23
5	36	2	9	5	10	62	0.16
6	0	98	0	90	2	190	0.00
7	333	50	7	473	237	1100	0.31
8	215	7	5	182	114	523	0.01
Total points	1891	167	40	1041	568	3707	
Omission error	0.19	0.06	0.18	0.05	0.38		

was a laborious process. During the participatory planning workshop, a combination of lectures and group dynamics techniques were used to solicit the opinions of diverse stakeholders. But, it was precisely during the group dynamics sessions that the difficulties in participatory planning difficult became evident. Understanding of the assessment's objectives varied among stakeholder representatives; for some of them, it was especially difficult to grasp the analysis because of their lack of formal education. Furthermore, the ability for conceiving decision rules was uneven among participants and sectors (for example, representatives of aquaculture investment groups had more technical training than representatives of organizations that grouped poor farmers and ranchers). For some of the representatives, problems in devising decision rules were related to geographical scale (for example, the need for a regional suitability assessment when their immediate problems were local), and to the type of issues that could be examined spatially (for example, corruption or financial problems of producers issues had to be excluded from the GIS analysis).

Nonetheless, results show that, despite its difficulties, the participatory planning workshop was a practical mechanism for incorporating the sectoral issues and concerns into the assessment. The role of experts was important in the whole procedure because they acted as technical advisors to the sectors. As the participatory planning workshop progressed, such technical advise enabled the representatives to be aware of the importance of the issues, and assured the sharing of basic information among the sectors. Moreover, the specialists were able to interpret the requirements for each activity into a format useful for the spatial analysis. Later, the interaction of the specialist group and the core group ensured an appropriate representation of the sectors in the suitability analysis.

Another important factor in the process was the simplicity of the GIS-application developed for this case study. The multi-criteria/multi-objective procedure allowed the stakeholder representatives and decision makers to understand land suitability assessment, and enabled them to reach a general agreement on the results. It was uncomplicated for the public to grasp the weighted linear combination because of its plain arithmetic, while understanding the numerical classification was intuitive, although mathematically complex. Furthermore, the risk of misinterpreting the stakeholders′ criteria or introducing biases into the analysis was diminished by the whole procedure because it fostered strict definitions of issues and variables.

Therefore, the overall results of the Costa Norte case study corroborate some of the assertions about how to achieve credibility in land suitability assessments. First, they confirm that the team of experts needs to perform a double role in a land suitability assessment: (1) providing technical advises to the stakeholder representatives (Vasseur *et al.* 1997), and (2) complementing the data needed for the assessment (Xiang *et al.* 1992, Teng and Tzeng 1994). Second, they demonstrate that public participation is enhanced whenever the decision rules are derived from consensus among experts and non-experts (Banai-Kashani 1989). Finally, they show that the spatial analysis have to be simple to be understandable by the stakeholders, while being rigorous at the same time to serve as a conflict resolution tool (Eastman *et al.* 1993).

The relatively high accuracy of the land suitability groups map layer (table 3) indicated that the resulting land suitability groups were not sensitive to the critical assumption of the multicriteria model (namely, that the ranked criteria could be used as an interval scale). The errors of commission could be explained by the classification errors in the vegetation and land use map, which was derived from the interpretation of a satellite image. Indeed, it was difficult to differentiate the patches of natural cover from agricultural fields.

Then, we can conclude that, at the scale and purpose of the Costa Norte study, our approach was superior than alternative methods, such as the Analytical Hierarchy Process (AHP; Banai-Kashani 1989, Biodini and Giavelli 1992, Pereira and Duckstein 1993, Malczewski *et al.* 1997), or fuzzy logic (Eastman 1993). Although these methods generate an interval scale, we found that the time needed to apply these techniques exceeded the duration of the workshop. Also, the cognitive processing demanded by the AHP surpassed the qualification of the majority of the stakeholders. Similarly, fuzzy logic would have been more complicated to grasp by the participants of the workshops.

The method used in the Costa Norte assessment for identifying homogeneous land units resembles other numerical classification approaches (Martín de Agar *et al.* 1995, Betters and Rubingh 1978, Omi *et al.* 1979, Ferguson and Bowen 1991, Calvo *et al.* 1992, Klijn *et al.* 1995). However, most GIS applications base the clustering procedures on sampling subsets of pixels when applied to large raster layers, a rather inefficient technique. In contrast, the divisive polythetic partitioning method used in Costa Norte is capable of classifying entire raster layers without size limitations (Noy-Meir 1973, Pielou 1984, Bojórquez-Tapia *et al.* 1994).

Under conditions similar to those of Costa Norte, numerical classifications should be preferred over other approaches for delineating land suitability groups, such as the capability analysis (Cendrero and Diaz de Terán 1987, Cendrero *et al.* 1993), neural networks, and fuzzy logic (Banai-Kashani 1990, Yin and Xu 1991, Xiang *et al.* 1992). The first adjusts a Normal statistical distribution to the resulting land suitability scores and, then, a set of five land suitability classes are derived using the standardized deviations from the mean. Thus, the division among classes is subjective, and detrimental for attaining credibility in a participatory planning framework. With respect to the latter approaches, they are just as efficient as the more commonly used multivariate statistical procedures in depicting land suitability groups, with the disadvantage that they require specialized software.

Land suitability assessments have to be based on an appropriate spatial framework such as administrative units (i.e. municipalities, land tenure, or natural protected areas), cartographic divisions (i.e. grids, sections, or quarter sections), and ecological components (Cendrero and Diaz de Terán 1987, Steiner 1991, Yin and Xu 1991).

Nonetheless, for our case study, any of those spatial frameworks would have been inadequate for the integration of the biophysical and socioeconomic factors related to the infrastructure, structure, and superstructure elements of land-use decisions (*sensu* Smith *et al.* 1995). Administrative units and cartographic divisions did not correspond to ecological components, and socioeconomic data were limited to administrative units. Moreover, biophysical data about ecological components were available at a small scale. For these reasons, we decided to use each pixel as the spatial framework in the Costa Norte assessment. This facilitated the tasks of integrating data from different sources (i.e. biophysical and socioeconomic), and locating areas of distinct land suitability for a sector within administrative or ecological units (figures 6 and 7). In the end, when conflicting objectives were predicted simultaneously in a land suitability group, the activity with the highest suitability score was recommended, or a set of environmental guidelines were prescribed for a negotiated solution.

We acknowledge that the political climate may influence the final adoption of a land suitability assessment. Certainly, the implementation of any assessment rests on predominating institutional and political circumstances. In the case of the Costa Norte de Nayarit, the results of the land suitability assessment have not been implemented by state and federal authorities. Therefore, it has not been possible to evaluate formally the acceptance of the results by the official sectoral representatives.

Nevertheless, the worth of a land suitability assessment as a strategic planning tool at the regional level must be evaluated in light of the following premises (Hollick 1981, Bojórquez-Tapia and Ongay-Delhumeau 1992): (1) resulting land use patterns must be in the best interest of the group at large, (2) environmental planning is a continuous process of narrowing steps and monitoring studies, and related to this, (3) regional planning is a prerequisite for better environmental planning at a larger scale, primarily environmental impact assessments (EIA) of individual projects.

Regarding the first premise, a contribution of the Costa Norte case study to the whole group betterment resides in the identification of a set of land suitability groups generated from sectoral preferences. Thus, it can be asserted that the ensuing land use pattern maximizes consensus among the stakeholders, and minimizes conflict between competitive land uses. This assertion is supported by a follow-up telephone survey, which was conducted to ascertain indirectly the usefulness of the Costa Norte assessment. The following potential users of the case study were questioned: Wetlands International, a non-governmental organization for conservation, one private investor in aquaculture developments, three consultants in environmental impact assessments, local delegates of Secretaría de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP, the federal environmental ministry responsible for implementing land suitability assessments), academics of the Universidad Autónoma de Nayarit (the state university), and state and municipal officials.

The survey showed that Wetlands International was using the land suitability groups for designing conservation strategies for the region; the private investor and the consultants were incorporating the results in their projects; academics were recommending the implementation of assessment; and state and federal environmental authorities were using the study for initiating compromises with other administrative agencies. Therefore, it is evident that the land suitability assessment has been used by some relevant sectors to base decisions over allocation of land uses.

In relation to the two last premises, it is evident that information generated at a regional scale is of limited use for decision making at the local level. More complex models are needed to sanction projects at that level and they should be included in Environmental Impact Assessments (EIA) (Bojórquez-Tapia and Ongay-Delhumeau 1992, Hollick 1981). Given the circumstances of the study region, combination of data at the regional and local scales is especially important for preventing the problems generated by localized shrimp farming endeavors. Thus, Costa Norte de Nayarit land suitability assessment furnishes a set of environmental guidelines that must be incorporated into the respective EIA. To that end, a prototypical GIS-multimedia application is available to assist the authorities in the integration of the land suitability assessment and EIA (Moreno-Sánchez *et al.* 1997), so that the appraisal of projects at the local scale can be based on information and considerations at the regional scale as well.

Consequently, it can be concluded that the Costa Norte de Nayarit land suitability assessment provides a technical basis for sensible land-use planning at the regional level. Because of the prevailing political factors in the region, it is the foundation of a legal framework towards environmental conflict resolution, and for improving the decision making process in the region. When linked to the mandatory EIAs, the land suitability analysis will enable the local and federal authorities to have access to both regional information and local data for appraising individual projects and inhibiting environmental conflicts.

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