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Geographical information system (GIS) environmental models for aquaculture development in Sinaloa State, Mexico

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This paper describes the use of a geographical information system (GIS) to construct environmental models for land-based aquaculture development in the State of Sinaloa, Mexico. Based on the source data, submodels were created focusing on three different themes: general environmental issues, water resources and water quality. Models enabled multicriteria and multiobjective decision making concerning site selection and location. In assessing site considerations these general models identified wider resource management options and solved conflicts of land allocation and land use between aquaculture and agriculture. Smaller-scale, more specific models enabled more detailed studies on environmental issues.

KEYWORDS: Aquaculture development, Environmental models, Geographical information system (GIS), Sinaloa Mexico, Site selection

INTRODUCTION

Geographical information systems (GIS) have an increasingly important role in management and use of natural resources (Burrough, 1986). GIS has a capacity for dynamic modelling of environmental parameters (Meaden and Kapetsky, 1991; Eastman, 1993) and this feature, in addition to the cartographic capabilities of GIS, means that these systems are of enormous potential in aquaculture and related studies.

The correct choice of a site in any aquatic farming operation is crucially important because it can greatly influence economic viability by determining capital outlay, and by affecting running costs, rate of production and mortality factors (Beveridge, 1987). Resource allocation decisions are prime candidates for analyses with GIS. With the advent of GIS, we now have the opportunity for a more explicitly reasoned land evaluation process.

The basic principles of GIS for land resource assessment have been explained by Burrough (1986), and many natural resource and environmental applications have been found for this technology. Burrough noted that GIS can serve as a test bed for studying environmental processes and can enable managers to test the consequences of various actions 'before the mistakes have been irrevocably made in the landscape itself'. Environmental decisions are complex and require the exploration of numerous options,

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often under conditions involving considerable risk and uncertainty. GIS technology provides some, but by no means all, of the capabilities required for decision support.

GIS technology has only started to be used in aquaculture in the last 8 years and there are only a few examples of GIS applications in aquaculture in the literature. To date, GIS has principally been applied to regional studies for aquaculture, in which not only data on resources and sites, but also data on economics, markets and socio-cultural resources were used. Kapetsky *et al.* (1987) looked at opportunities for farming shrimp in ponds on the Gulf of Nicoya, Costa Rica, for farming shellfish in intertidal and subtidal areas and for suspended culture of shellfish and farming of fish in cages in open waters. Kapetsky (1987) assessed shrimp farming in ponds and culture of fish in cages in Johor, Malaysia, and Kapetsky *et al.* (1991) assessed opportunities for farming in freshwater ponds at a country level in Ghana. A species-related GIS for Channel catfish (*Ictalurus punctatus*) culture was developed by Kapetsky *et al.* (1988) and a simplified use of this technique was outlined by Ali *et al.* (1991) for a regional study of carp culture in Pakistan. In addition, Ross *et al.* (1993) assessed the usefulness of GIS for detailed site selection based on an example for salmonid cage culture on the West of Scotland. A GIS study of aquaculture in Tabasco State, Mexico, by Aguilar-Manjarrez and Ross (1993) showed how system-related models could be developed. The current interest and state of development of GIS for aquaculture is summarized by Meaden and Kapetsky (1991).

This paper describes the development and exploration of environmentally based land-use models, implemented in a GIS for land-based aquaculture development in Sinaloa State, Mexico.

Aquaculture in Sinaloa

Sinaloa is primarily an agricultural area which raises cotton, tobacco, sugarcane, fruits and vegetables. The most important coastal industry is fishing, chiefly for sharks and shrimps, processed locally. Sinaloa is ranked in first place for shrimp capture in Mexico. Nonetheless, overexploitation and pollution have decreased capture fisheries and hence, shrimp farming has helped increase production on a local basis.

To date, most aquatic farms in Sinaloa are dedicated to shrimp farming, growing *Penaeus vannamei* and *P. stylirostris*. However, some other aquatic species are also cultured such as cichlids, oysters, crayfish, and sea bream. Moreover, catfish and frog culture also have the highest production in Mexico (Secretaría de Pesca, 1991). Common culture systems for shrimps are semi-intensive using ponds; other types of systems are few. Cage culture, for example, has only been done at an experimental level in the northern region of the state in Topolobampo bay (Zuñiga-Rodriguez, 1992) for fish such as Lutjanidae, Serranidae and Sclanidae. However, Zuñiga's study revealed positive production results and showed that there was potential to develop cage culture further. Some aquatic farms have not been successful and in some cases they have been abandoned, the principal constraints being lack of capital investment, lack of trained personnel and overall a general lack of management. Furthermore, Mexico's shrimp production has not grown as expected and has not reached optimum levels in the past decade, due principally to constraints of legislation which reserved ownership and use of land for cooperatives. However, Mexico has recently permitted private aquatic farming which could boost this country's production.

Although there is great aquaculture potential in Sinaloa, planning studies are rare. Environmental impact studies have only recently become compulsory in Mexico. There is an increasing concern for the future and it is becoming clear that major development of the industry may only be possible if healthy (low-stress and antibiotic-free) culture techniques are adopted (Hopkins and Sandifer, 1993). To date, because most common planning studies still use simple manual map-making technology, banks and insurance companies have had a difficult task allocating time, personnel and finances for aquaculture development.

Vast land areas are used for shrimp farming in Sinaloa, Mexico (an average semi-intensive shrimp farm is 5 km^2) and hence the region needs careful resource management. The government has been attempting to have a foreknowledge of where the prospects for aquaculture are most promising before continuing to commit its scarce resources to aquaculture development. To this end, GIS can serve as an analytical and predicting tool for aquaculture development, enabling managers to assess the present aquaculture development and most importantly to test the consequences of various development decisions before they are carried out in the landscape. Hence, GIS could very well assess and direct future aquaculture development.

MATERIALS AND METHODS

The Mexican state of Sinaloa is situated at the north-west end of the Mexican Republic. Sinaloa's long, narrow coastline extends some 560 km along the Gulf of California. The area of the state comprises about 58 480 km^2. The spatial analysis comprised the zone between 22°12′–27°13′N and 105°19′–109°33′W, ensuring coverage of the entire state as well as areas of neighbouring states (Sonora, Chihuahua, Durango, Nayarit) and the Gulf of California.

The GIS software used in this study was IDRISI version 4.1, a low-cost, raster-based (spatial information is in the form of regular grid cells or pixels) GIS, developed at Clark University, USA. The software was operated on a 486DX, 66 MHz, PC with 8 Mb RAM, 504 Mb hard disk and a 2 Gb DAT parallel-stream backup running with ARCSOLO software version 2.2 for DOS. Display was via an EIZO Flexscan T660i 52 cm colour monitor with an AA51 ultra high resolution colour graphics controller and an 8514/A adapter interface emulator; running under MS DOS version 6.22.

To produce the Sinaloa database, thematic maps of the area, literature, statistical information and data available on computer discs (i.e. population census) from Mexican information sources such as INEGI (National Institute of Geography, Statistics and Information), SPP (Planning and Budget Secretariat) as well as maps from studies carried out by Mexican consultancy companies were digitized at a spatial resolution of 250 m using an ALTEK DATATAB digitizing table (107 × 152 cm).

Analytical framework

To plan for an aquaculture venture and to reduce environmental damage and economic risks, the areas which are suitable for aquaculture and agriculture development were spatially defined. Thirty source layers (i.e. thematic maps) were compiled into fourteen environmental criteria. These criteria were of two kinds: factors and constraints. A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. For example, a forestry company may determine that the steeper the slope, the more costly it is to transport wood. As a result, better areas for logging would be those on shallow slopes, the shallower the better. A constraint serves to limit the alternatives under consideration. A good example of a constraint would be the exclusion from development of areas designated as wildlife reserves. In many cases constraints may be expressed in the form of a Boolean (logical) map: areas excluded from consideration being coded with a 0 and those open for consideration with a 1. However, in some instances the constraint will be expressed as some characteristic that the final solution must possess. For example, we might require that the total areas of lands selected for development be not less than 1000 km^2. Nonetheless, both forms of constraints have the same ultimate meaning, which is to limit the alternatives under consideration.

The selected factors fell broadly into two categories. The first category was primarily concerned with the natural resources and environmental states involved (water resources, climate, mangroves, temperature, soils, topography and sources of post-larvae) whilst the second category reviewed land uses (agriculture, irrigation, livestock rearing, pasture, existing shrimp farms, industries, urban development and roads). Constraints were identified which were the same for both aquaculture and agriculture, for example, either activity would be constrained to areas outside mangroves and polluted areas (i.e. urban development, factories).

To establish a consistent classification, a 1–4 scale range was chosen as the most suitable because it was found that most thematic maps were classified to a range of four values. Based on the original thematic paper maps, each factor was classified to the consistent numeric range from 1 to 4 (i.e. in a soils map a value of 4 would indicate highest suitability). Depending on the origin of the particular thematic map, some factors were classified according to previous classifications (i.e. polygon data such as agriculture) whilst for some others it was necessary to manipulate them. For example, to evaluate water availability from a lagoon, a proximity range was created using the DISTANCE module in IDRISI. Therefore, a range of values was created (1–4); those closest to the water body were given a score of 4, and those furthest away a score of 1. Each constraint was developed as a Boolean map (0 and 1) either to prevent or minimize possible pollution problems or when there were restrictions such as conservation areas.

The next stage was to establish a weighting for each of the factors. Although a variety of techniques exist for the development of weights, one of the most promising is that of pairwise comparisons developed by Saaty (1977) in the context of a decision-making process known as the analytical hierarchy process (AHP). The first introduction of this technique to a GIS application was that of Rao *et al.* (1991), although the procedure was developed outside the GIS software using a variety of analytical resources. Weightings were developed according to Saaty (1977) and Eastman (1993) using pairwise comparisons, in which the relative importance between the criteria was evaluated on a 9-point continuous rating scale from 1/9 (least important) to 9 (most important) in respect of the activity being evaluated.

To illustrate the approach, five factors were chosen to infer the relative quality of the water for aquaculture: suitable temperature (a very important limiting factor because it regulates factors such as species behaviour, feeding and growth), suitable soils (to avoid acidic soils harmful to aquatic life), distance from forests (indicators of good water quality but far enough to minimize construction costs), low-input agriculture (small risk of pesticide and herbicide pollution), and distance from irrigation (to minimize risk of pollution). The procedure then required that the matrix be computed to produce a best-fit set of weightings. Because the weightings sum to one, the resulting suitability map had

TABLE 1. Weightings derived by the pairwise comparison matrix for assessing five water quality factors for land-based aquaculture development in Sinaloa State, Mexico (numbers show the rating of the row factor relative to the column)

Factor maps	Temperature*	Soils	Forests	Agriculture	Irrigation	Weightings
Temperature	1					0.49
Soils	1/4	1				0.12
Forests	1/8	1/3	1			0.06
Agriculture	1/3	3	2	1		0.16
Irrigation	1/4	1	3	2	1	0.17
Sum						1.00

*Temperature was assigned the highest weight, signifying that it was the most important factor between the other four factors for determining the relative quality of the water for aquaculture.

a range of values that matched those of the standardized factor maps (1–15). As the matrix is symmetrical, only the lower half actually needed to be completed; the remaining cells simply mirrored the lower half as shown in Table 1.

The procedure then required that the pairwise comparison matrix be computed to a best fit of weights. A good approximation to this result can be achieved by calculating the weights with each column and then averaging over all columns. For example, if we take the first column of figures from Table 1, they sum to 1.96. Dividing each of the entries in the first column by 1.96 yields weights of 0.51, 0.13, 0.06, 0.17 and 0.18 (compare to the values in Table 1). Repeating this for each column and averaging the weights over the columns gives a good approximation. However, IDRISI has a module named WEIGHT which can do this directly.

Because the pairwise comparison matrix contains multiple paths by which the relative importance of criteria can be assessed, it was necessary to determine the degree of consistency that had been used in developing the ratings (1/9 to 9). Saaty (1977) provides a procedure by which an index of consistency known as consistency ratio (CR) can be produced. The CR indicates the probability that the matrix ratings were randomly generated. Table I has a consistency ratio of 0.07, well within the ratio recommended by Saaty (1977) of equal to or less than 0.10, signifying a small probability that the weightings were developed by chance. In addition to the overall CR, it was also possible to analyse the matrix where the inconsistencies arose. Both the consistency ratio and the matrix for inconsistency analyses were calculated as part of the WEIGHT module in IDRISI.

Once the factors had been developed, each factor map with a score from 1 to 4 was then multiplied by the weights derived from Table 1. However, because the original score range was too small (although it was most suitable at the initial stages of classification) and the number of factors involved was too large (14 criteria), it was necessary that the original 1–4 score range be standardized to a larger range of values of 1–15. This is explained by the fact that, for example, if we multiply 0.48 (weight from temperature in Table 1) by a score of 4 it would only yield a value of 1.92 and hence the image would consist of a very small range of values. To solve this problem the STRETCH module in IDRISI allowed the factor scores (1–4) to be expressed according to a consistent numeric range of 1–15 (15 being the most suitable). Using this stretched score range, a value of 15 when multiplied by 0.48 gives 7.2 and so the final image has a larger range of values and does not lose valuable information.

After all the factor maps had been incorporated, the resulting suitability map was then multiplied by each of the constraints in turn to remove unsuitable areas. In IDRISI a special module named MCE (multi-criteria evaluation) has been developed to undertake all of these steps. The procedure has been optimized for speed and has the effect of multiplying each factor by its weighting, adding the results and then multiplying the result by each of the constraints.

Once the MCE suitability map had been created for both aquacultural and agricultural activities, it was necessary to determine which cells belonged to the set that met a particular land allocation area target as well as to determine the suitability classes. The IDRISI module named RANK allows a rapid ranking of cells within an image. The ranked suitability maps for aquaculture and agriculture could then be reclassified to extract the suitability classes.

In assessing aquaculture site considerations it was considered vitally important to evaluate the allocation of land for aquaculture between other production activities competing for resources. The first consideration was to determine whether activities were in conflict or not. As a preliminary assessment, to determine the kind of relationship (complementary or conflicting) a cross-tabulation was carried out (using the module CROSSTAB) which enabled us to find the correlation coefficient level between the different activities (i.e. aquaculture, agriculture, livestock rearing, urban development and forestry). Using CROSSTAB it was found that agriculture had a very high correlation value with most of the activities, especially aquaculture, which meant that a large amount of land was suitable for both activities.

Because aquaculture could be well integrated with agriculture it was initially thought that a complementary approach between activities would be most suitable. However, this procedure would combine both activities and hence it was very likely that there could be problems such as pollution from pesticides and herbicides. Therefore, both activities were considered as areas of conflict because they were competing for the same area of land, and hence a multi-objective land allocation (MOLA) technique available in IDRISI was used. MOLA uses the set of ranked suitability maps, one for each activity, the relative weights assigned to each [(the weight determines the relative weight that the objective in resolving conflicting claims for land),] the amount of area to be assigned to each (the amount of area desired) and an areal tolerance (refers to the point at which MOLA decides that it has come close enough to satisfying the area needs of the objectives for it to stop with the iterations). From this, a compromise solution was determined which maximized the availability of suitable land for each objective.

To find an exact solution, weights for each activity were set to be the same (0.50 for each). With MOLA a trade-off was achieved between both production alternatives on the basis of the weights and area goals established. It was decided to establish area goals similar to those found by the manual survey carried out by two Mexican consultancy companies (Cosmocolor, 1991; Ecoingeniería, 1991). This enabled us to establish comparisons between the GIS in this study and the manual techniques which they used. An area tolerance of zero was set for both activities. Then, the ranked maps for aquaculture and agriculture (derived from the MCE suitability maps which were ranked by the module RANK) were evaluated using the IDRISI MOLA module to resolve conflicts based on the weighted logic.

Taking this, and the source data into account, criteria in the GIS were developed into submodels which logically grouped certain factors. Submodels were focused into three different themes: general environmental issues, water resources and water quality. Due to the nature of the factors involved, and so as to make comprehensive analyses, it was reasoned that submodels should be created differently. Some models were created by multicriteria evaluations (MCE) whilst others such as the water resources submodel were created by a mathematical approach. Moreover, because an MCE is based on positive factors and the lowest value in IDRISI is zero (which meant that negative numbers could not be used in the evaluation), it was found that to evaluate the negative influence of some of the factors (i.e. pollution), positive (i.e. suitable temperature) and negative factors (i.e. distance from a city) had to be grouped separately so as to subtract them. MS-DOS batch files for these models were used to create and to combine submodels using both manipulation techniques. The water resource submodel (Equation 1), was created mathematically by the integration of the water balance, lagoons, lakes, rivers, streams, groundwater and dams. To estimate a water balance it was necessary to subtract the evaporation from the rainfall. Moreover, proximity maps were created for lagoons, lakes, rivers, streams, groundwater and dams to evaluate their suitability for water abstraction. In these maps, proximity to a water resource indicated more suitability. The water resource submodel is given by:

$$\mathrm{WR} = (P - E) + L_1 + L_2 + R + S + G + D \qquad (1)$$

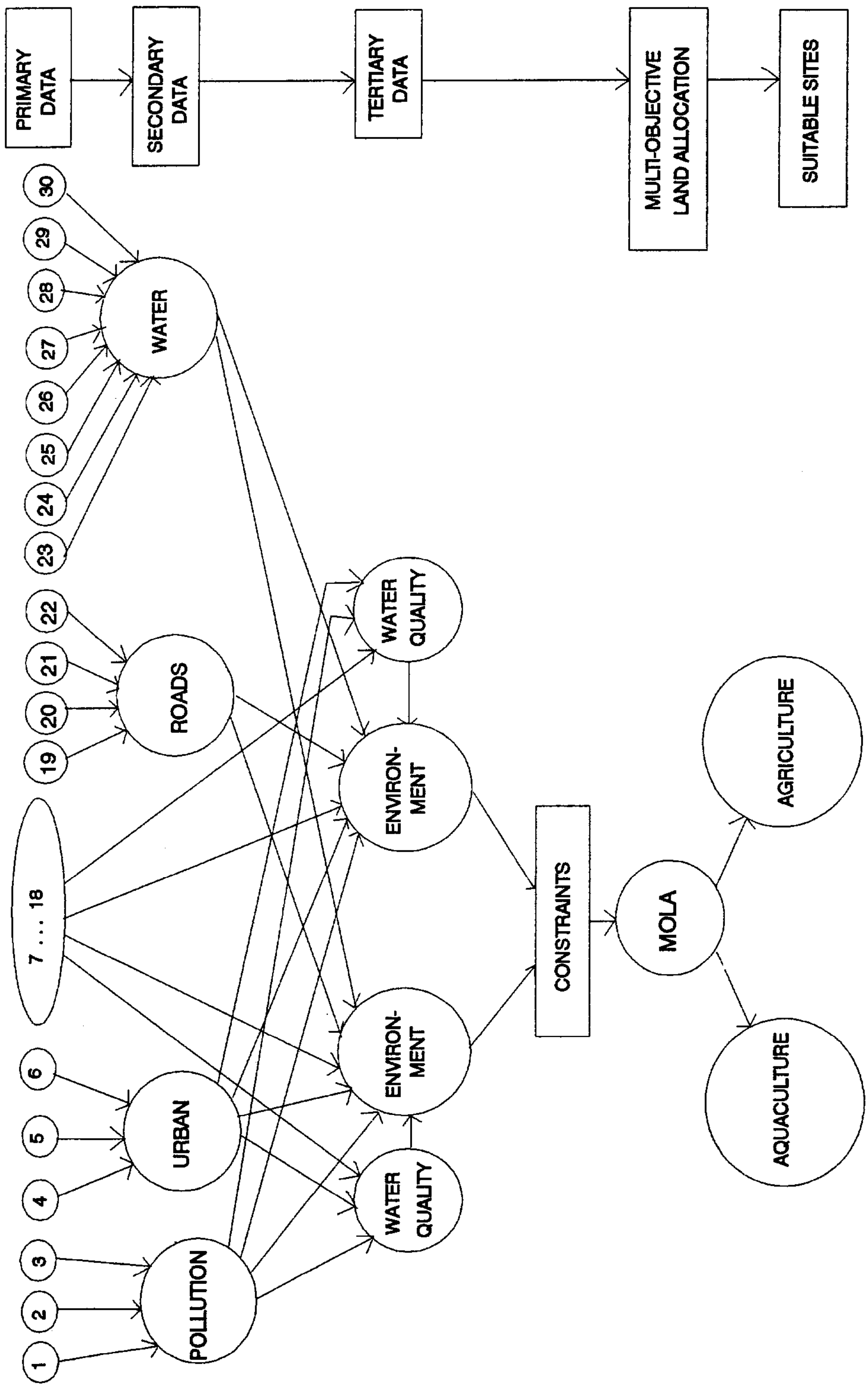
where WR denotes water resources (area), P is rainfall (mm), E is evaporation (mm), L_1 is lagoons (area), L_2 is lakes (area), R is rivers (area), S is streams (area), G is groundwater (area), and D is dams (area).

With the above in mind it was reasoned that the overall model would have to be a hybrid. Figure 1 illustrates the integration of the submodels into an overall hybrid model. Integration involved five stages:

1. Selection, reclassification and manipulation of environmental factors (primary data) according to aquaculture and agriculture suitability;
2. Creation of secondary data through the MCE techniques and mathematical manipulations for water resources;
3. Subtraction of the negative factors for water quality and environmental factors from MCE evaluations for aquacultural and agricultural developments;
4. Incorporation of map of constraints; up to this point, data were handled separately for both production alternatives.
5. Integration of both data together using the MOLA technique so as to determine the areas of conflict, and allocation of appropriate areas for each activity.

RESULTS

The results provide an index of the amount of land available for aquaculture and agriculture. There is potential for aquaculture development in many parts of Sinaloa State. Major exceptions are those areas reserved for conservation, as well as the areas of high slopes in the mountains. Nonetheless in these marginal areas there could still be sites available. Most suitable sites are found near coastal lagoons, which are primarily concentrated in the northern region of the state. Here, soils and topography are suitable



PRIMARY DATA
SECONDARY DATA
TERTIARY DATA
MULTI-OBJECTIVE LAND ALLOCATION
SUITABLE SITES
POLLUTION
URBAN
7 . . . 18
ROADS
WATER
WATER QUALITY
ENVIRON-MENT
ENVIRON-MENT
WATER QUALITY
CONSTRAINTS
MOLA
AGRICULTURE
AQUACULTURE

and water is abundant, although seasonality may be a major constraint in some areas. Moreover, sites are located so that pollution sources are either avoided or minimized. Opportunities for agriculture, on the other hand, were found to be high in almost the entire state, although there are similar restrictions to development such as excluding conservation areas. Potential sites for agriculture are near the rivers and dams where water is most abundant.

When comparing suitability maps for both aquaculture and agriculture before and after the MOLA technique, we found that for aquaculture there were initially 1076 km^2 of land classified as being the most suitable whilst, following the subsequent MOLA evaluation, 2090 km^2 were selected. Similarly, the suitability map for agriculture identified 5057 km^2 as most suitable whilst MOLA found 17 916 km^2. MOLA therefore classified additional sites as adequate to meet with the area goals.

Figure 2 shows the allocation of land for aquaculture and agriculture activities by the GIS model using the MOLA technique. A compromise solution was defined in which the land areas suitable for the two activities were established adjacent to each other. A trade-off was made between the proximity of one to the other for the possible integration of agriculture with some types of aquaculture (i.e. fish culture), and the separation of aquaculture from agriculture so as to minimize possible pollution problems.

DISCUSSION

The results of this GIS evaluation are partly confirmed by the fact that many pond farms already exist in those areas predicted by the GIS as being maximally suitable. Although further verification work is required, partial verification has been achieved by comparing the outcome of this GIS with data obtained in a manual survey by the combined work of two Mexican consultancy companies. Figure 3 indicates comparative results from the two techniques. The GIS predicted 2090 km^2 of land suitable for aquaculture whilst the manual survey predicted 2093 km^2, although there was a variation among the locations of the areas due to the different logical manipulations used. The coincidence of the two techniques was only 22%. This demonstrates the need for complete objectivity in every decision-making step involved in GIS and for systematic verification work. Thus, spatial

FIG. 1. Overall hybrid model integrating submodels for assessing site considerations for aquaculture and agriculture developments in Sinaloa State, Mexico. Primary data: 1, industries; 2, sugar factories; 3, domestic pollution; 4, cities; 5, towns; 6, villages; 7, temperature; 8, soils; 9, topography; 10, agriculture; 11, natural postlarvae; 12, population density; 13, forestry; 14, livestock rearing; 15, irrigation; 16, shrimp farms; 17, mangroves; 18, conservation areas; 19, paved roads; 20, railways; 21, gravel roads; 22, dirt roads; 23, lagoons; 24, rivers; 25, streams; 26, rainfall; 27, evaporation; 28, groundwater; 29, lakes; 30, dams. Data are integrated for both activities in this hybrid model and therefore lines derived from the secondary data submodels in Figure 1 were duplicated (although classification of primary data for aquaculture and agriculture was different). Moreover, some of the data was used by one activity and not by the other (i.e. natural postlarvae); the difference in data is not presented but is symbolically presented in the primary data stage (values 7 to 18). Additionally, only two lines are duplicated from values 7 to 18 so as to avoid confusion between lines. Similarly, the constraints (i.e. distance from mangroves, conservation areas) were incorporated into a submodel named 'constraints' as a final manipulation to find the suitability maps but these lines are also not shown.

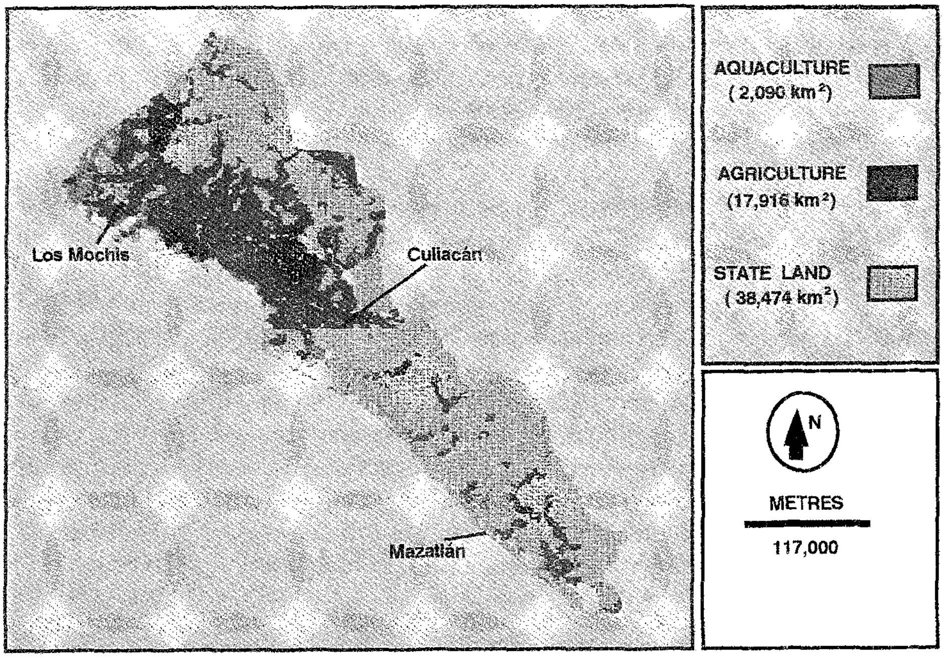


FIG. 2. GIS-based derived allocation of land for aquaculture and agriculture, Sinaloa State, Mexico. Constraints are shown as white. State land (lightest grey) represents areas classified as fair to moderate.

modelling in GIS provides a more comprehensive and integrated treatment for aquaculture development criteria than is usually possible by manual analytical and map-mapping technology concerning site selection and location. In assessing final aquaculture site considerations these general models also identified wider resource management options, and helped to show areas of potential conflict.

As shown in Fig. 3, some shrimp farms are located within the areas predicted by each technique, as well as in areas which were found as maximally suitable for both (three small shrimp farms located adjacent to the coastal lagoon in the central part of the figure). More importantly, the largest shrimp farm, located on the left of the figure and some other smaller ones are almost entirely located on a white area signifying that the sites selected for those farms are unsuitable. Furthermore, it was found that the large shrimp farm was constructed right in the middle of a mangrove and hence lies on an area considered to be a constraint.

Overall, it was noted that the procedures used have a strong effect on the outcome of the final results. It was found that the choice of weights is crucial in the analyses and that the wrong weights could be chosen even if the CR was very low. Because the assignments are extremely flexible, a great variety of scenarios can be generated by the GIS models. To determine these weights, guidance was obtained from literature relevant to the study area, and from the opinion of experienced personnel and staff. Ultimately, however, subjective decisions had to be made.

The outcome of the results was strongly dependent on the quality of the raw data (thematic maps or primary data). Although most of the data were found to be very

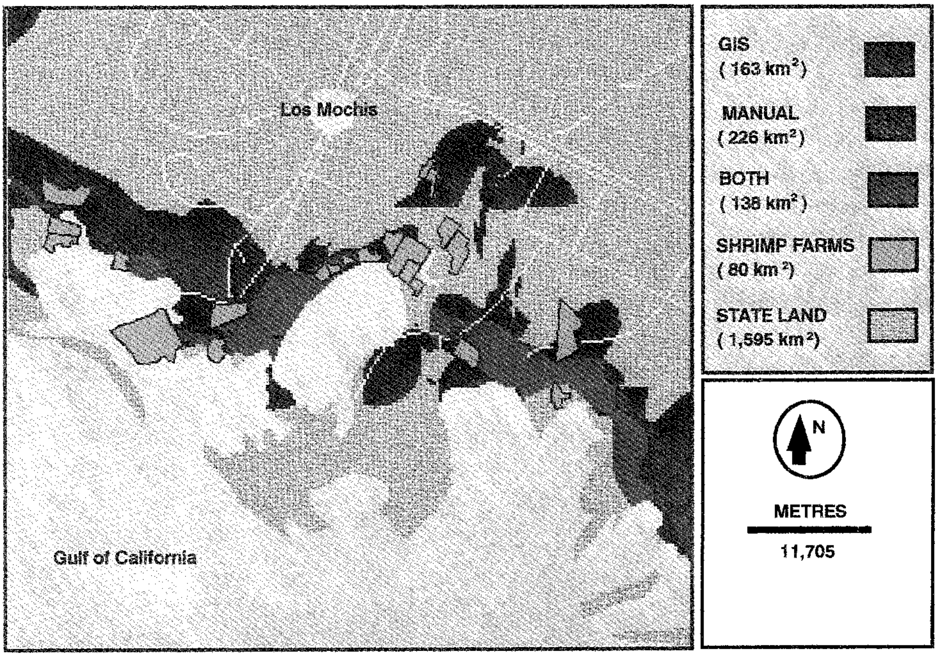


FIG. 3. A zoomed section in Los Mochis reveals the accuracy of the manual and GIS techniques. Mangroves, water bodies (this study deals only with land-based aquaculture), and areas occupied by roads and urban developments are constraints and therefore they are presented in white (they have a value of zero). Areas that were classified as moderate and fair are presented as the state land.

suitable, some other data (such as rainfall and evaporation) were only available in the form of yearly averages and therefore it was difficult to establish a more accurate water balance, because rainfall could be insufficient during many months of the year. Nonetheless, recent developments in digital cartography (Tarleton, 1994) enabled the Mexican National Institute of Geography, Statistics and Information (INEGI) to provide a considerable amount of information. Through a rapid development, digital information is already available to the public in the form of floppy and compact discs readily compatible with GIS software (e.g. population census computer discs created by INEGI were used to evaluate population density in Sinaloa). This development is typical of the massive increase in availability of digital data worldwide, and improved data quality and accessibility in the future will lead to wider and more accurate use of GIS as an aquaculture planning tool.

CONCLUSIONS

1. GIS can be used to assess and direct aquaculture development very comprehensively when used to the full. Natural resources data benefit from the use of GIS, which can play an important role in aquaculture development because data can be naturally partitioned by layers or areas, thus enhancing their management and retrieval.

2. This study revealed the usefulness of GIS as an aquaculture planning tool and shows on a reasonably objective basis, the extent of opportunities for land-based aquaculture in Sinaloa, Mexico.
3. Final aquaculture site considerations must be established after evaluating the relationship between other production activities. Although agriculture was found to be the most important activity, there are other activities which must be integrated into the model such as urban development and livestock rearing. To this end, the multi-objective decision-making technique proved to be very useful for solving these types of land-allocation problems.
4. Model programming was found to be a very useful tool. In general it was reasoned that creating submodels in natural groupings such as water quality allows the user to evaluate and manipulate these criteria independently before integrating them into a model.
5. At a more detailed level, GIS can be very effective in modelling the wider effects of an activity on its surroundings and clearly has potential for dynamic modelling of environmental impacts.

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