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INSTIGATION OF THE WORLD'S FIRST MARINE FISHERIES GIS

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ABSTRACT

Although marine fishing is the world's most extensive economic activity, and marine resources are presently exploited in a near "free-for-all" manner, there have been no national attempts to utilise Geographical Information Systems (GIS) as an aid to monitoring or controlling the industry. The paper will show why this is so and it will briefly reveal the management success which GIS is having in a similar resource based industry.

The main body of the paper shows how Libya, a country having a long coastline but no tradition of marine fishing, is planning to instigate a marine GIS to manage the complete "fisheries industry" which it is purchasing. It is suggested that the GIS could best operate using the following database areas:

a) Marine water conditions and habitats.
b) Natural marine resources.
c) Fisheries management and regulation.
d) Fishing effort and catch.
e) Marine resource marketing.
f) Mariculture.
g) The coastal environment.

Presently, no useful Libyan digital data exists and indeed there are no practical data gathering systems in place. These are the two main operational problems, though the paper will outline many other methodological barriers which need to be faced before a GIS can output valuable data. Experience gained from implementing this Libyan GIS should prove invaluable when it comes to instigating other marine fisheries GIS's on a larger scale.

Why a Marine Fisheries GIS?

An interested outsider, looking at the management of the marine fisheries industry for the first time, may be really quite shocked. He will be confronted with an activity which appears, in comparison with other economic activities, to be in a state of near anarchy, with resources being exploited in an apparent "free-for-all". Manifestations of this include world-wide fisheries disputes, blockades of ports, dwindling fish stocks, "walls of death" or "vacuuming" catching methods, idle boats and men whilst new boats are still being commissioned, the near extinction of many sea mammals and the random dumping of a range of often toxic materials.

How can it be that the world's most spatially extensive economic activity, one that employs directly and indirectly millions of people and whose output is measured in billions of dollars, is in this state? Most of you know that the reasons are diverse and they include such factors as the fragmentary nature of the exploiting agencies; that, until recently, resource depletion has not been a severe problem; that data recording systems are difficult to implement and that much existing data is of uncertain validity; that there have, again until recently, been few legal rights of prohibition to fishing grounds and that the sea is undoubtedly perceived as a milieu which should enjoy unfettered access (e.g. Caddy and Griffiths, 1990; English et al, 1988; Juda, 1991; Lodge, 1992; Pontecorvo, 1990; Sherman, 1990; Symes, 1992). But, additionally and perhaps because of the problems and complexities involved, there also seems to be a reluctance amongst fisheries managers to tackle the management problems through the instigation of information technology (IT) based controlling systems. Yet, over the past two decades, there has evolved a management aid, generally known as Geographical Information Systems (GIS), which can completely revolutionise the ways in which fisheries management could be obtained (Hogan and Clark, 1989; Simpson, 1992).

Geographical Information Systems

GIS's are one of the fastest growing branches of IT (Tomlinson, 1989). They have been called...."the telescope, the microscope, the computer and the xerox machine of regional analysis and synthesis." (Abler, 1988; p137). Basically, they comprise of a collection of integrated computer hardware and software which together are used for inputting, storing, manipulating and presenting geographical data (Figure 1). The data being input must be in digital form, though it can be in textual, numeric or mapped format. It is first "captured" by any of a number of methods:

i) By creating database files manually using the keyboard and a database or spreadsheet type software package.

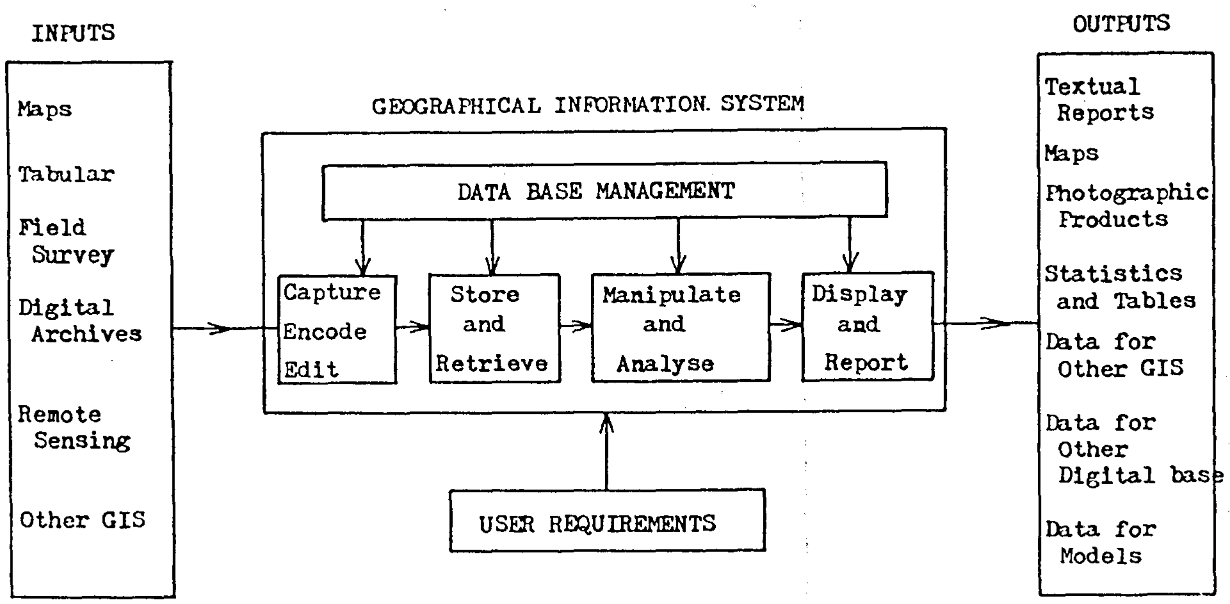
ii) By importing digital data from another suitable package.

iii) By recording information, perhaps whilst on a field survey, directly into a specialised data logging device.

iv) By using a manual digitiser to capture map outlines.

v) By using an electronic scanner to automatically record images

Figure 1. <u>Systems Diagram to Illustrate GIS</u>



of maps (or other data) in digital form.

vi) By using video-digitising methods.

The storage of captured data is usually on hard or floppy disks, CD-ROM's, or computer compatible tapes. Table 1 lists the main functions which the GIS and the database management software packages perform to carry out manipulations and analyses or to control the storage and presentation of data to the GIS software. There are a large number of GIS software packages, many of which are individually made to suit specific customer requirements. Output from the computer may be in various forms (see Figure 1) and capture of this may be on lineprinters, laser or inkjet printers, drum or flatbed mechanical plotters, electrostatic or thermal plotters, the VDU screen, film or to other digital storage media.

The recent emergence and proliferation of GIS has resulted from developments in the fields of micro-chip technology, computer graphics, computer aided design, image processing plus associated factors such as an explosion of data, a reduction in computing costs, growth in GIS educational provision and the recognition of the value of GIS. The range and pace of these advances is now so great that it is extremely difficult to keep abreast of applications potential in anything other than a narrow GIS field.

Though some GIS applications are now being made in areas which are peripheral to marine fisheries, e.g. in mariculture location, in coastal zone management, in oil spill modelling or in associated

Table 1. A Classification of GIS and Database Management Software Functions

A) DATA CAPTURE, ENCODING, EDITING.

i) Data capture, e.g. digitising and integration of external data.
ii) Data validation and editing, e.g. checking and correction.

B) DATA STORE AND RETRIEVE.

i) Data structuring and storage, e.g. quadtrees or run length encoding.
ii) Retrieval of information based on user-defined themes or on Boolean logic.

C) MANIPULATION AND ANALYSES.

i) Structure conversion, e.g. conversion from vector to raster.
ii) Geometric conversion, e.g. map registration, scale changes, various transformations, map projection change.
iii) Generalisation and classification, e.g. reclassifying data, aggregating or disaggregating data.
iv) Integration, e.g. combining layers of different surfaces.
v) Enhancement, e.g. image edge enhancement.
vi) Abstraction, e.g. calculations of area centroids and Thiessen polygons.
vii) Buffer generation.
viii) Spatial analysis, e.g. route allocation, slope and aspect calculations, visibility.
ix) Statistical analysis, e.g. histograms, frequency analysis, measures of dispersion.
x) Measurement, e.g. line length, area and volume calculations, distance and directions.

D) DISPLAY AND REPORT.

i) Graphical display, e.g. maps, graphs.
ii) Textual display, e.g. report writing, production of tables.

E) DATABASE MANAGEMENT.

i) Support and monitoring of multi-user access to database.
ii) Coping with systems failures.
iii) Communications linkages with other systems.
iv) Up-dating of databases.
v) Organisation of the database for efficient storage and retrieval.
vi) Maintenance of database security and integrity.
vii) Providing a "data-independent" view of the database.

fields such as the production of digital marine atlases or hydrographic charts, and despite much data being available, as yet there is no record of a marine fisheries GIS (Simpson, 1992). This undoubtedly reflects (i) the difficulties of functioning and modelling in a 4D environment (Gurney and Mason, 1992; O'Conaill et al, 1992), (ii) the fact that GIS require the integration of both regular, dynamic events and random, chaotic events, and (iii) because of the fragmentary nature of the industry and its databases (Jeffries-Harris, 1992). Yet in other fields of natural resource exploitation, GIS's are proving invaluable. It is pertinent to briefly examine some of the successes which are now being achieved, especially in the forestry industry.

Over the past ten years Forestry Departments have collected data which has allowed for the generation of digital maps on such variables as soil quality, slope angle, aspect, species distribution, wildlife habitats, climatic variables, etc. By the use of various mapping overlays, manipulations, measurements, abstractions, reclassifications, etc, foresters have had a valuable visual tool to aid in progressive management. Apart from an overall increase in the output of factual information, the GIS facility has allowed for, amongst many things, yield calculations under different species combinations, the 3D visualization of proposed management decisions (through the draping of tree images over digital elevation models of the forested area) and for the modelling of "what if" situations with regard to the impact of public access or various conservation measures (e.g. Davidson, 1991; Priestnall et al, 1993). Some forests are no longer being clear felled in a haphazard way and their full visual, environmental and ecosystems potential are increasingly being recognized (Collins, 1991). Other fields in which the application of GIS has had a major positive impact include local authorities (for highway planning, for various routing schedules, for park management), the utilities (for pipe management, new routing, emergency repairs), private companies (for the optimizing of business locations) and in the emergency services.

Why a Marine Fisheries GIS for Libya?

The information in this section has mostly been obtained directly from UNDP (1990). This is a project document which outlines in detail how Libya, with the help of the Food and Agricultural Organization (FAO) of the United Nations, are planning to implement a fisheries development programme.

Libya (population 3.8 million), located on the central north African coast, has one of the longest Mediterranean coastlines. Despite this, and its long period of settlement, it has almost no fisheries tradition. Presently its fleet consists of some 400 small wooden vessels (<10 metres) plus some 20 stern or side trawlers. In 1989 total fisheries catch was approximately 10 000 tonnes, though some additional fish catches were made by foreign licensed vessels fishing in Libyan waters. Fish makes up a very low proportion of Libyan national protein intake, with consumption being less than 1kg/cap/year in 1986.

In order to diversify the country's industrial base into the exploitation of resources other than oil, the Libyan Secretariat of Marine Wealth was established in 1988 with a basic remit of implementing a marine fisheries industry. In the period to 1994 it is proposed that 30 new purse seiners or stern trawlers be purchased, that the provision of suitable harbours, ice plants and cold stores be made, that a state marketing scheme be set up, that fishing gear supplies be guaranteed, that a national small boat construction yard be established and that a major training programme for Libyan fishermen be set up within the country. To assess and control the effects on fish stocks of this dramatic rise in fisheries effort, the Secretariat will be undertaking marine resource surveys and will be establishing a valid data collection system. The main resource advising and guidance functions will be provided to the Secretariat from the Marine Biology Research Centre at Tajura near Tripoli. Whilst funding for the fisheries developments are from Libyan sources, overall guidance is provided and administered by the FAO.

During the project planning stages it was recognized that there was an ideal opportunity to utilize GIS as a management tool, i.e. because a large amount of data would need to be compiled, most of which had a spatial significance. Since the fishery resource base is completely unknown a research vessel has been purchased whose main purpose is data gathering on both resources and water quality parameters. Also, it is the intention of the project to promote mariculture, and to this end it is important that site allocations are carefully made. Other data gathering functions having a spatial aspect include markets, transport provision, socio-economic variations in population, plus the likely environmental impacts of any of the developments. From a GIS viewpoint, this setting up of a new fisheries industry virtually from scratch, which will be both on a small scale and have few financial constraints, will be an excellent opportunity to test GIS implementation potential.

The Organization of, and Output from, a Libyan Marine Fisheries GIS

Given that "uncharted territory" is being entered in establishing this GIS, what is described here is still very much theoretical. The databases outlined are only those which relate directly to the marine fisheries industry, though clearly, with such an inter-disciplinary field as this, it could be envisaged that much other data will eventually be usefully adopted. Within each database area described, space will only allow for a brief examination of the types of data to be collected and their methods of collection. This seems relevant since most of the subject fields will be familiar to this audience. Factors relating to data formats and structure, possible linkages between databases, geo-referencing, possible data manipulations and problems in data collection would also need consideration before the system could be made fully operational some of these points are reviewed in the final section.

a) Marine Water Conditions and Habitats. Parameters relating to water quality such as temperature, salinity, DO levels, water colour/algae content, turbidity, sea currents, etc., will be captured using various digital data logging techniques aboard the research vessel. The readings thus obtained will form the bases for interpolating isoline maps. The use of remotely sensed (RS) and other data, will allow for sea bed type mapping, e.g. sands, muds, reefs, seagrass beds and for sea surface roughness (e.g. Simpson, 1992; UNESCO, 1992). Sufficiently detailed bathymetric data already exists in Libya for the construction of useful digital water depth maps, and eventually these maps are likely to be digitally constructed and maintained (Carter and Hambrey, 1993).

b) Natural Marine Resources. The Marine Biology Research Centre will be advising on the relevant parameters for this mapping of what is essentially biomass estimation. Suggested criteria might be by individual fish species, sea mammals, planktons, cephalopods, sea-weeds, shell fish, etc. Clearly species distribution will vary both spatially and temporally. Data quantification methods would need to be resolved and the data itself would be obtained from both the research vessel and from commercial catch data, using both netting procedures and acoustic survey equipment.

c) Fisheries Management and Regulation. This might also be viewed as resource allocation. It should be a simple matter to draw up maps showing the various economic or legal zones, though presently Libya is disputing the 200 mile Exclusive Economic Zone. Maps showing the apportionment of quotas or fishing rights (if relevant in specific areas), by local or foreign fleets, will be essential. Local maps at a larger scale can be used where community based management is in operation. Maps showing optimum or maximum sustainable yields by species will eventually be constructed, as will those recording any fish stocking which might be undertaken.

d) Fishing Effort and Catch. Maps here will firstly show fishery infrastructure plus perhaps local fishing zones (based on any chosen criteria). There are a variety of ways of measuring effort for mapping purposes, e.g. by boat size or type, by fishing methods, by man-hours, etc. Catches can be mapped for any area, by species caught, by size, by net type/size or by season. Both catch and effort data should be recorded whilst fishing vessels are at sea. Finally, landings by ports for different species, quantities and product types (chilled, frozen, fresh, etc) will be recorded, probably in geo-referenced tabular form for later mapping.

e) Marine Resource Marketing. Retail market location may be represented by a general population distribution or density map, but wholesale markets are likely to be more concentrated into specific point locations according to the siting of freezing, canning or other general wholesale outlets or processing plants. Marketing surveys are currently being conducted which might reveal spatial and/or seasonal variations in product preferences, as well as data on income or other socio-economic factors affecting fish consumption or demand levels. Included in the marketing category would be digitized maps showing both storage and transport systems.

f) Mariculture. GIS analyses have already been used elsewhere as a method of site optimization for aquaculture facilities (e.g. Cordell and Nolte, 1988; Ibrekk, 1993; Kapetsky et al, 1988; Kapetsky, 1989; Meaden, 1987; Meaden and Kapetsky, 1991). This basically involves the integration of maps showing the distribution of the requisite aquaculture production functions - these have already been identified in the Libyan context. Also relevant is monitoring the performance of different sites, testing the viability of land based v. marine based facilities and for assessing and optimising marine cage siting at the micro-scale.

g) The Coastal Environment. Since the interface between the land and the sea is crucial in many ways to both marine resources and mariculture, it is important to record (for mapping purposes) the inshore zone, the littoral and the immediate coastal hinterland, i.e. for recreational uses, land uses, potential point pollution sources, estuarine conditions, and the physical landscape. Again, examples of this type of monitoring are already available (e.g. Clark, 1992; FAO, 1991; Riddell, 1992; Schauser et al, 1992), and in the case of Libya, much of the data would be comparatively easy to assemble.

There are other database areas which could be of use, e.g. climatic variables and models, oceanographic simulations and ecosystems models plus those associated with both land and marine based environmental management and with the location of fisheries infrastructure. Howvere, in the Libyan situation, where data is very scarce, it would be some time before any of these could be assembled and integrated.

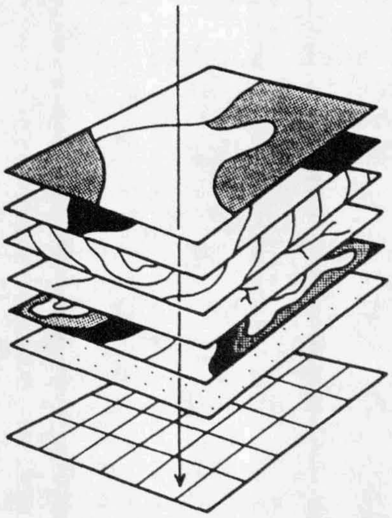
Having obtained data on each of these seven areas, it would be stored in separate database areas, on floppy disk, hard disk or magnetic tape, etc, usually in a relational database management software system such as dBASE or Oracle. It is easiest to envisage each database area as consisting of x number of digital "layers", each of which represents a mappable outline (see Figure 2). Of course, each "layer" could be merged with any other to produce a new layer as required, and tabular data could be imported in order to update layers.

Once the databases have been assembled, it is pertinent to exemplify the type of GIS output which might then be expected. Obviously space prohibits anything but a brief resume of some examples, and only limited details on how this GIS output would be generated.

a) Initially it would be desirable to ask simple "show me" type questions, e.g. "Show me the areas where species x are most prolific during y period" or "show me the relationship between fish catches and water depth."

b) How much biomass, of any given species, should be available

Figure 2. Example Showing Layer Integration in a GIS.



in x sector given known reproduction rates, food availability, levels of fish catches, water conditions, etc.?

c) Given the known biomass of any resource in an area, the amount of fishing effort in terms of boat numbers, man hours, net size, etc, can be easily calculated and allocated.

d) Given a known water quality regime in any area, and the ecological needs a specific marine species, then it should be possible to calculate the amount of fish ranching which might be desirable by unit area.

e) Having worked out the sizes of areas (or water volumes) containing any species, then total marine resource estimations will be quantifiable, i.e. by species, by water type, over what type of sea bed or at what season, etc.

f) GIS will enable the best matching of fish catches to the distribution of specific market outlets.

g) A knowledge of marine resource disposition throughout the year will greatly aid the development of coastal based enterprises, e.g. industrial, commercial or leisure, i.e. with a view to causing minimum ecosystems disruption.

Using GIS methods, and given suitable databases and a skilled GIS operator, then any of these queries could be answered quickly and the results could be output in any of the formats previously described. Whilst building up the capacity to obtain a range of reliable marine GIS output, it would be desirable to incorporate modelling procedures or to test the validity of any output. Indeed it is obvious that extensive modifications to data capture, input, manipulation or analytical methods is likely to be necessary before reliable and valid output is ensured. It is also clear that the theoretical outcome of the implementation of a marine GIS, is that the sea area being monitored and controlled would eventually become synonymous with a livestock ranch, i.e. with complete management for maximum yields being the ultimate goal.

Considerations and Problems to Setting Up the Libyan Marine GIS

Having set out the theoretical potential for a GIS, it cannot of escaped attention that there are a vast array of considerations to be made, or barriers to be overcome, before a marine GIS could even start to generate useable, accurate information. In this section some of the operational issues raised in providing the GIS framework will be examined. It is beyond the scope of this paper to examine how the GIS might be actually operated and supported.

In the case of Libya, there is no immediately available useful digital data. The authorities there claimed that satellite RS data was available from their Bironi Remote Sensing facility, but this was not able to be verified. There is little doubt though that a range of RS material would be procurable via an intermediary source such as the FAO. When obtained, this digital data would be useful for some of the water qualitative and coastal zone parameters. Other data which could soon be digitized for map generation purposes includes government mapping of the coastline, roads, settlements, bathymetry, ports, etc., or pre-digitised outline data could be purchased if desired (Soluri and Woodson, 1990).

Other data capture systems are in the process of being put in place. As previously mentioned, a 30 metre marine research vessel has been purchased and equipped specifically for data gathering purposes (plus some training). It will have both trawling gear and a comprehensive range of digital recording devices, plus a global positioning system (GPS), and it is intended that all data collected is geo-referenced for compatibility with any GIS. Indeed, all trawlers operating in Libyan waters will be required to log their activities complete with GPS based referencing. Market and socio-economic surveys are about to commence and again all samples and records should log some geo-referenced information, the nature of which will depend on the type and scale of the survey.

There are other important decisions which still need to be faced, some of which should be mentioned here. Firstly, the exact type of GIS, or the scale on which it will operate, i.e. should it be networked over a wide area, comprise of a mainframe or local workstations, etc, has yet to be considered, as has any time frame for its implementation or venue for its location. Secondly, it is clear that all marine based resources and processes operate in 4D (Mason et al, 1992). Though marine based data may be recorded in these dimensions, we are still some way from having a truly 4D functional GIS. However, recent advances in "dynamic GIS" are providing the capability to regularly sequence (in map form) any combination of geographic variables for the purposes of obtaining any range of GIS output at each sequential stage (Albaredes, 1993).

Thirdly, the decision on what will constitute data gathering units may be quite complex in 3D space, i.e. should it be cuboid blocks or should it be based on isoline interpolations in 3D. Also at what scale should the units be on, and what time-scale units will constitute the 4th dimension? Fourthly, another considerable problem is that data is being gathered for the mapping of a resource which is mobile and therefore impossible to record at the micro-scale for anything other than at one random instant in time. This, of course, means that whatever is plotted as a mapped distribution can, at the best, only be based on "averaged" data - data whose reliability would decrease with both the enlarging of the map scale and the shortening of the time scale (Warner, 1987).

Other important considerations include:

a) Should access be freely available to a wide range of parties, e.g. fishermen, managers, fisheries biologists, government departments?

b) How should any data gathered be stored and structured?

c) At what stage will it be necessary to introduce other data to the GIS, e.g. the climatic, ecological or environmental data?

d) What actual data gathering systems still need to be put into place? How permanent need these be and can the costs and effort best be shared with other data users?

e) How is back-up and guidance for the GIS best organized?

f) Should a marine resources GIS be integrated with other GIS's?

g) Is it worth selecting a pilot marine survey area first, in which to intensively gather data and to do experimental work in?

h) To what extent should Libya's waters be considered as a closed system?

As well as these considerations, in the Libyan context there are a range of further potential problems. The political situation is such that contacts with many potential GIS overseas collaborators are both tenuous and physically difficult. This means that the interplay and flow of advice and guidance is constantly hindered. Internal mechanisms for obtaining information quickly and easily within the country do not exist. Libya appears to have a policy of constantly changing or swapping its senior government personnel - this is clearly not conducive to the smooth running of a GIS programme whose implementation may take many years. The country is suffering from a severe labour shortage and skilled computer literate personnel are almost non-existent. Also, so far as GIS is concerned, there is almost no internal back up provision for the requisite software or hardware. And, perhaps most worrying of all, once the FAO project overseeing GIS implementation comes to an end, will the Libyans be in a position to continue it?

In conclusion, this author would like to suggest that the only way a marine fisheries GIS is ever likely to become operational is for its implementation to occur "piecemeal". In other words, the complexities are so varied and the array of problems and considerations so great, that if we were to await their solutions before starting the implementation process, then we would not only be waiting for a long time but, more importantly, how many fish would be left in the sea? So, a start has been made. Information is already being assembled and the marine fisheries GIS should begin to gain functionality over the next two years. It will be a long time before it could be fully operational, probably about 10 years. However, the experience gained from this comparatively simple and small scale implementation should prove to be invaluable when it comes to setting up more complex marine GIS's elsewhere.

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