Peer Reviewed Paper

GIS in Fisheries Management

Geoff Meaden

Marine Fisheries GIS Unit, Department of Geography, Canterbury Christ Church University College, North Holmes Road, Canterbury, CT1 1QU, Kent, UK, Tel: 01227 767700; Fax: 01227 767531; EMail: g.j.meaden@cant.ac.uk

ABSTRACT

Fisheries managers are increasingly confronted by an array of problems, and it is clear that most of these concern matters where there are variable disparities in the spatial domain. Given this spatio-temporal perspective, then the use of GIS would appear to offer a viable management solution. This paper reviews the basic challenges to the use of GIS in a mobile marine milieu, and notes that many of these challenges are based as much on confronting the human, fisheries-based organisational structures as with problem solving in the difficult physical environment. A brief examination is made of areas within fisheries in which GIS is currently being employed. Most attention is given to describing the practical challenges to GIS adoption for fisheries management, and to discussing and illustrating how these challenges might be overcome. The conclusion outlines some of the ways in which GIS is likely to be adopted in the near future for the improvement of fisheries per se.

Key Words: Geographical Information Systems, GIS, Fisheries Management, Management Solution, Spatio-Temporal.

INTRODUCTION

The aim of this paper is to briefly review the prevailing status of GIS applications in the fisheries management domain as at the start of this century. Since the domain is relatively extensive, then the review will not attempt an in-depth study, though a fairly extensive bibliography has been included. The main focus will be upon the problems and challenges that are inherent in using GIS in the marine fisheries domain, though some consideration will also be given to the present fields of activity, and the likely future avenues of GIS use. As a prelude to the review, it is important to examine the reasons why GIS is likely to be important to fisheries management. The reasons are varied, but obvious ones may be identified as:

- The growth of GIS as an analytical tool. GIS, as a separate and clearly identifiable part of the IT industry, has sustained a compound annual growth rate of about 14% during the whole of the 1990's. In 1998 the world market for geo-spatial systems and services was approximately £3 billion sterling (Wilson, 1999). This growth has largely been spawned by technological advances in the whole IT sector, and by the fact that GIS has proven itself in a range of terrestrial applications.
- The scale of the World's fisheries. At the World scale, fisheries are the second largest employer after agriculture, with some 300 million world-wide being

© (2000) theUKcoastalzone.com

employed directly or indirectly. In many individual countries, especially in the developing world, it is a hugely important sector, and world-wide fish represents the major source of protein for over 1 billion people.

- The spatial extent of the activity. With oceans occupying 71% of the World's surface, and additional to which there are lakes and inland rivers, then fisheries are the most spatially extensive economic activity. Nearly 20% of world marine areas have a natural productivity that encourages abundant fish populations, e.g. continental shelf areas, inland seas, estuaries, coral reefs and upwellings. Even the other 80% has scattered though large populations of pelagic species – sharks, tuna, etc.
- The plight of the World's fisheries. Probably 60% of fish stocks are exploited to their maximum sustainable extent, and many other stocks are exploited at a level that, given the present state of knowledge, then catches should not be increased. There is a catalogue of what might be described as "fishery disaster areas", i.e. areas where excessive fishing has resulted in either or both of major cut-backs in fishing fleet size and substantial changes to fish assemblages. These areas include the Yellow Sea, Black Sea, North Sea, the Gulf of Maine, and the Gulf of Thailand. In some areas whole fishing communities are now either out of work (e.g. Nova Scotia, Newfoundland, New England), or they are rapidly leaving the industry. The North Sea cod (*Gadus morhua*) is now on the CITES list of endangered species!
- Problems are in the spatial domain. Nearly all problems in fisheries are caused by the fact that different facets that effect fish populations are in dis-equilibrium (Laevastu and Favorite, 1988; Cushing, 1995; Symes, 1996). Nearly all of this dis-equilibrium can be manifest as disparities in the spatial domain. Many examples could illustrate this, but some notable factors include:
    - Ecosystems have been destroyed, e.g. areas are too heavily trawled, coral reefs are damaged, and mangroves have been removed.
    - Wide areas of the marine milieu are suffering from pollution.
    - There is too much fishing effort in specific areas.
    - Many fisheries management system's are poor or ineffective.
    - Global warming is variably effecting marine community distributions.

The important point here is that these are all spatially related problems, and it is just such problems that GIS is designed to address. It is also worth considering here that geographers, under whose domain many of the GISs work, are likely to be able to give an educated and neutral view on problems that have a spatial perspective in the fishery sphere.

THE CURRENT STATUS OF GIS USE IN FISHERIES MANAGEMENT

GIS has been very slow to grow in the fisheries sector, i.e. relative to its growth in the terrestrial sector. This is basically to do with the complexities of working in the marine domain. This can be illustrated by Figure 1 that shows "task components" that need to be considered when undertaking any fisheries related GIS work (Meaden, 2000a). So, terrestrial GIS has only to be concerned with components 1, 2 and 4, whereas any fisheries GIS must also be concerned with 3, 5, 6, and 7. This is because fisheries take place in a 2.5D or 3D spatial environment, but it is an environment that

© (2000) theUKcoastalzone.com

is largely in a state of continual movement. Thus movement of the water body itself is occurring differentially, and most of the objects within it are moving independently. The variable movement then has an effect on spatial distributions, which in turn means that the periodicy of any mapping becomes an essential issue. The marine milieu itself therefore provides a fundamental problem to any GIS-based work.

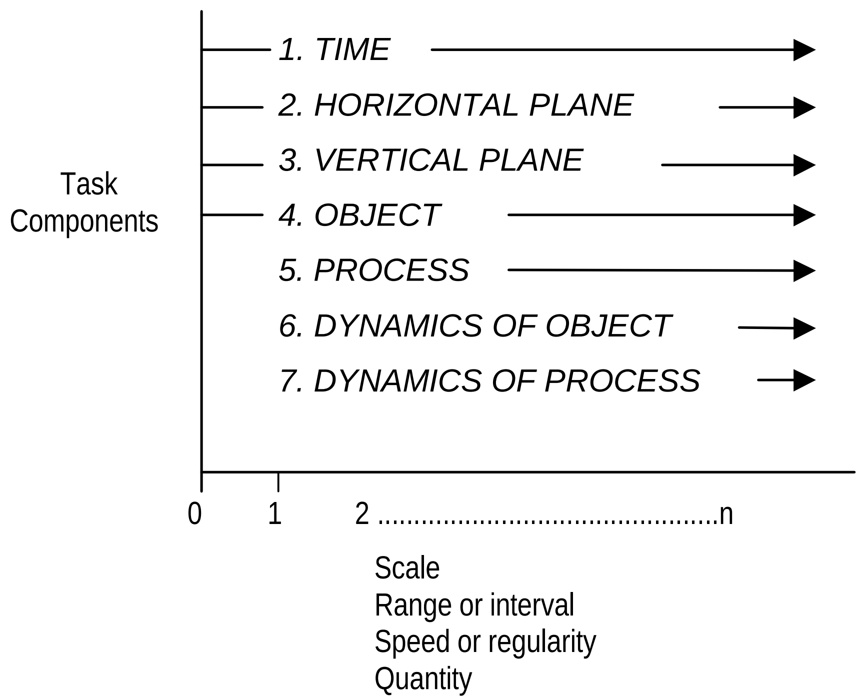

Figure 1. Task Components in a Fisheries-Based GIS (from Meaden, 2000a)

A further fundamental factor causing slow growth in GIS use is concerned with the human organisational structure of fisheries *per se*, and especially in the fragmented nature of the activities. Thus fisheries research and management tends to take place in an array of types of institutions – universities, fishery management authorities, consultants, research institutions, etc. These are scattered world-wide, often in peripheral, seashore locations, and many institutions are either not conversant with GIS as a management or decision making facility, or they are too small to support such activities. GIS publications relating to fisheries tend not to appear in the more established literature – they are more frequently in the form of governmental reports or in other “grey literature” resources (Figure 2). Additionally, as an economic activity, the fisheries industry is exceedingly diverse. So, it is possible to conceive that there are forces operating that tend to retard the development of fisheries GIS, whilst

© (2000) theUKcoastalzone.com

counter-balancing this there are accelerating forces that are now beginning to exert a significant influence in promoting the use of GIS (Figure 3).

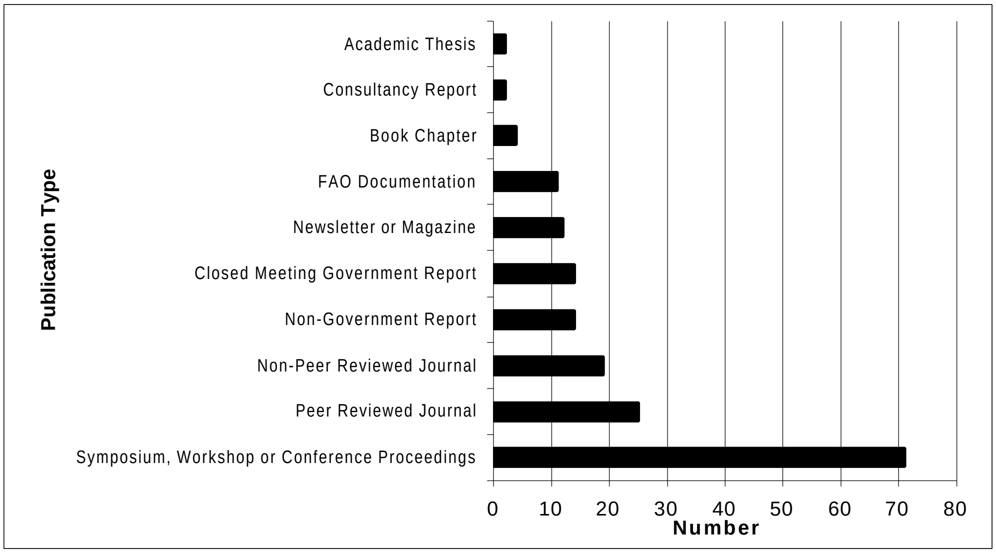

Figure 2. Publication Mode of 174 Fisheries GIS Related Works produced between 1984 and 1998 (from Meaden, in press)

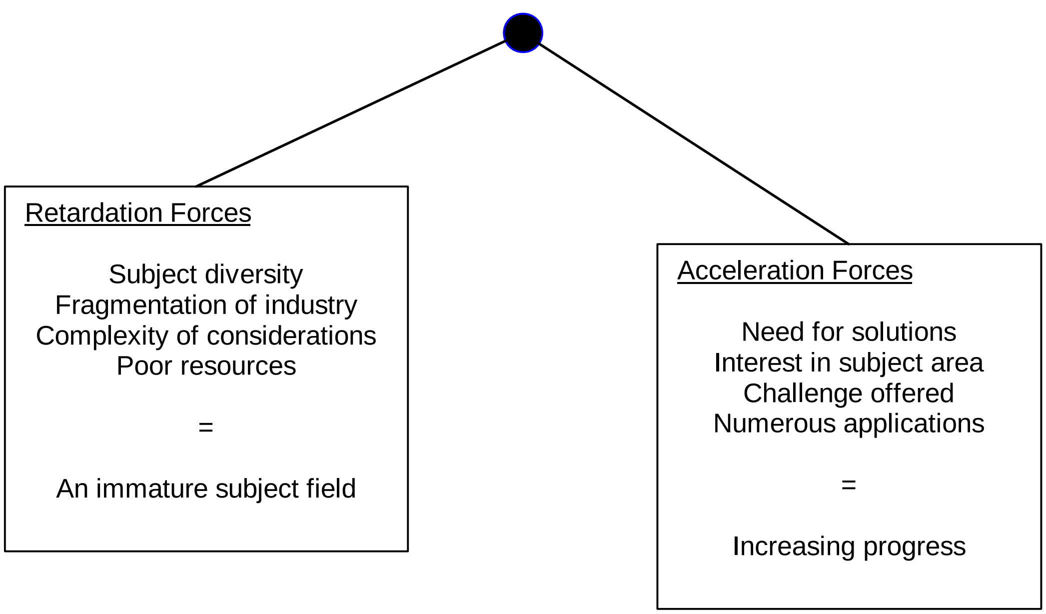

Figure 3. Forces both Retarding and Accelerating the Use of GIS in Fisheries Management

Ó **(2000) theUKcoastalzone.com**

The first GIS applications in fisheries came in mid-1980's, but little growth occurred until the 1990's. The early applications tended to be for aquaculture site location, e.g. Meaden, 1987; Kapetsky et al., 1987; Kapetsky et al., 1988; Kapetsky, 1989; Ali et al., 1991; Ross et al., 1993, because this is largely a terrestrial, static application where data is easily acquired. During the 1990's there was significant growth in applications of fisheries GIS (see Meaden and Do Chi, 1996 for a summary), and Table 1 gives an indication of applications in the early and mid-1990's. Fisheries GIS is now growing extraordinarily rapidly, and in 1999 there was the First International Symposium on GIS in Fisheries Science (Seattle, Washington, USA) and the "Spatial Processes and Management of Fish Populations" conference at Anchorage, Alaska. Most of the activity is taking place in the USA, although actual fisheries GIS applications occur in a wide range of countries.

Table 1. Examples of Fisheries Related GIS Work Produced During the 1991 to 1997 Period

Fisheries Theme or Topic Covered	Examples of Studies
Marine Mapping and Atlases	Selvik et al. (1993), Ostrowski (1994), Ramster (1994), Carocci and Majkowski (1996), Ramos et al. (1996)
Habitat Mapping (Riverine and Marine)	Gordon (1994), Liebig (1994), Somers and Long (1994), O'Brien-White and Thomason (1995), Rubec (1996), Castillo et al. (1996), Keleher and Rahel (1996), Long and Skewes (1996), Rogers and Bergersen (1996), Sotheran et al. (1997)
Marine Productivity Mapping	Caddy et al. (1995)
Fisheries Management	Legault (1992), Meaden (1994), Long et al. (1994), Jordan et al. (1995), Meaden (1996), Al-A'ali and Bakiri (1996), Kemp and Meaden (1996), Smith and Lalwani (1996)
Human Impacts on Fishing Environments	Wood and Ferguson (1995), Irwin and Noble (1996), Porter et al., (1997)
Land Use or Classification	Klemas et al. (1993)
General	Swartzman et al. (1992), Kapetsky (1994), Do Chi and Taconet (1994), Taconet (1995), Le Corre (1995)
Aquaculture Location and Activities	Ali et al. (1991), Paw et al. (1992), Ross et al. (1993), Beveridge et al. (1994), Aguilar-Manjarrez and Ross (1995), McGowan et al. (1995), Habbane et al. (1997)

© **(2000) theUKcoastalzone.com**

FIELDS IN WHICH GIS IS CURRENTLY USED FOR FISHERIES MANAGEMENT

Before delimiting the actual fields in which GIS is being used, it is important to note that the activities are being carried out in the range of institutions mentioned in Section 2. The uses to which GIS is being put vary considerably in their scale. This means that some GIS studies are continental wide, whilst others are at a micro-scale, e.g. looking at individual aquaculture sites or at particular stretches along a stream or river, or to very specific marine locations.

The main fields in which GIS are currently being used for fisheries related purposes are:

1. Site selection for mariculture or aquaculture. This was an original use for GIS in fisheries related work. It is mostly pursued at a small spatial scale, though its actual use is not as wide spread as it might be. Thus there have been many problems caused by the poor siting of aquaculture facilities, e.g. extensive disease problems has occurred on shrimp farms in Thailand and Sri Lanka, and many of the disease outbreaks on salmon farms could undoubtedly have been minimised had more careful site selection procedures (using GIS) been employed. Figure 4 illustrates sites selected for shrimp farming potential in central, western Sri Lanka, a GIS exercise that was unfortunately carried out after a major white spot disease outbreak, which itself had been caused by poor farm-site location.

2. Matching fish distributions to environmental parameters. Clearly it will be of the utmost interest for those working in fisheries management or science to know the relationships between fish distributions and various environmental parameters. The types of parameters being commonly used include water temperatures (especially thermal fronts), upwelling indices, water depth, marine chlorophyll abundance, bottom sediment type, and salinity. Recent examples of this GIS-based work here include; Booth (1998); Sakurai et al. (1998); and Brown and Norcross (1999).

3. Modelling fish activity and movement. These applications area is really just getting underway. Here the aim is to attach numerical models to a GIS in order to simulate, describe or predict a range of processes. Examples include – movement models (Ault and Luo, 1998), economic cost surfaces, and the diffusion of fishing effort over time (Caddy and Carocci, 1999; Corsi et al. (in press). Clearly, a range of statistical

Ó (2000) theUKcoastalzone.com

analyses and modelling could utilise GIS raster or vector surfaces as platforms upon which algorithms may be tested.

4. Analysis of fisheries catch and effort. Fishery managers are interested in where fishing effort is concentrated; how much fish is caught where; what is the relationship between catch and effort, etc., and much interesting work is now being produced, e.g. Meaden and Kemp (1996); Denis and Robin (1998); Fogarty and Murawski (1998); and Pierce et al. (1998). Statistical output can be obtained from many GIS programs. Obviously catches can be explained in terms of various environmental parameters, or in terms of fish life cycles. Figure 5 shows January catches in small unit areas off the coast of South Africa.

5. Establishing regional and national fisheries databases. Although not directly a GIS application to fisheries management, it is clear that without huge data inputs then fisheries GISs could not function. So in some major fishery regions a massive effort has gone into establishing databases, metadata sets, e.g. Durand (1996), Valavanis et al. (1998), and in setting up regional data centres, e.g. in eastern Canada or at the various World Data Centres. Fisheries related data sets are slowly becoming accessible over the Internet.

PRESENT CHALLENGES TO THE USE OF GIS IN FISHERIES MANAGEMENT

The challenges to the use of GIS for any fisheries related purpose are very significant. Here only an indication of what the main challenges are is given.Obviously it should be noted that other challenges are relevant but are beyond the capability of most workers in this field to influence – for instance, matters relating to IT developments, to GIS training, to institutional constraints, etc. Again the challenges can best be covered by the use of a descriptive list:

1. Mapping and analysis of movement. As mentioned in Section 2, not only does the water itself move, but so does everything within it - and it moves either regularly, randomly, chaotically or unpredictably, as do most of the things within it. It is easy to imagine the difficulties that this gives to those who are trying to “draw maps” (Schneider et al., 1999; Hooge et al., 1999). One of the ways of coping with the

Ó **(2000) theUKcoastalzone.com**

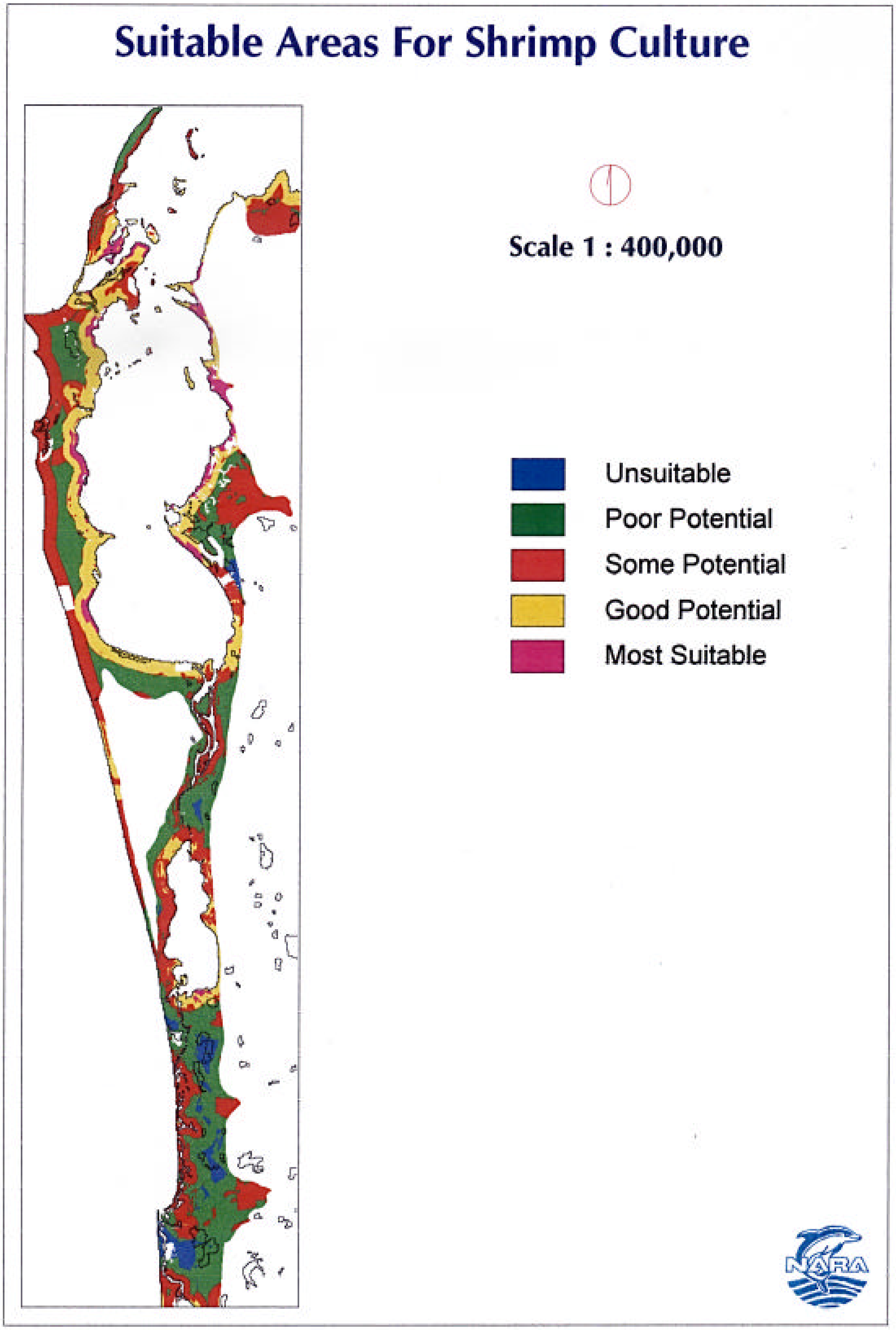

Figure 4. Shrimp Farming Potential in Central, Western Sri Lanka.

Ó (2000) theUKcoastalzone.com

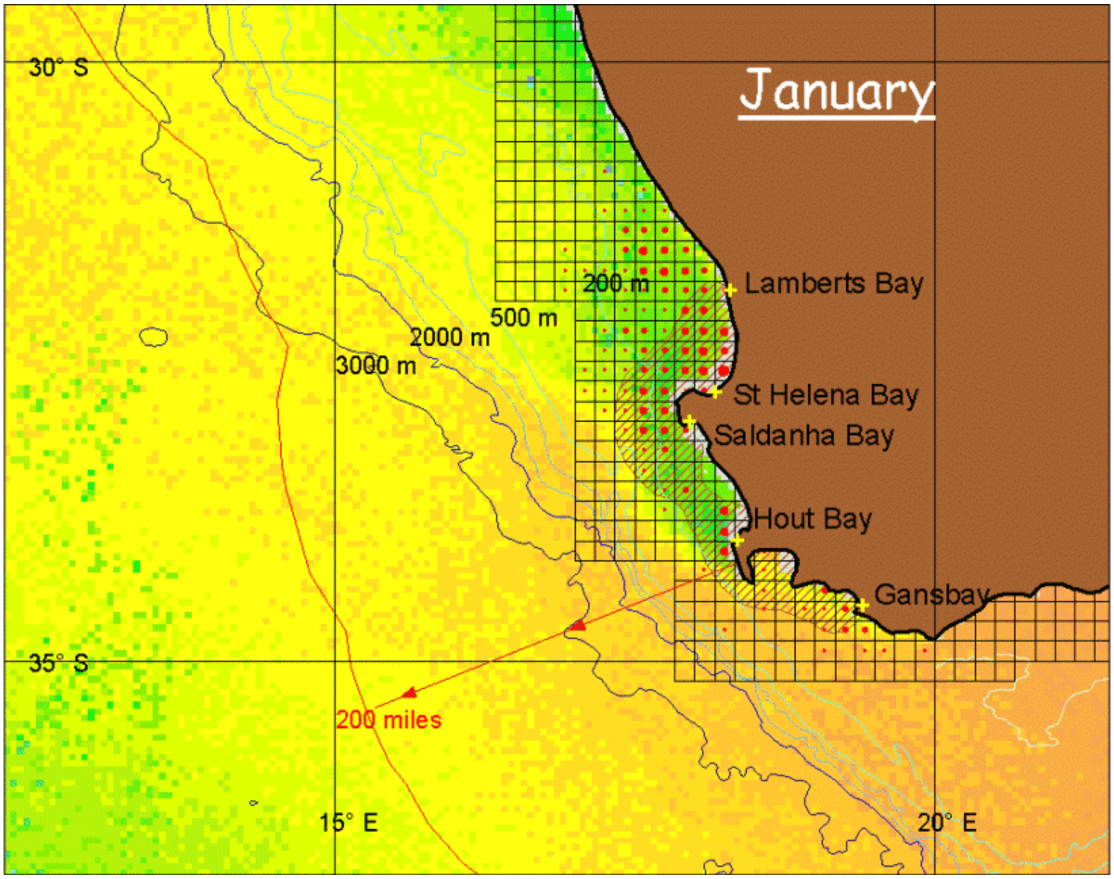

Figure 5. Aggregated Pelagic Catches off the Coast of South Africa

problems caused by this mobile environment, is to consider carefully the scale of the movement. At a small scale (large area), then movement will be less of a problem since relative, quantifiable movements will be low and they will usually be on a predictable, cyclic basis. But unfortunately, most fisheries research projects are initially examined at a detailed scale (small area), and here movement may be relatively pronounced (and thus important). Given this fact, Schneider (1998) has hinted that a primary concern when studying movement is to try to optimise the scale of study, and to at least identify the nature of the movements involved. It will clearly be some considerable time before many movement models can be adequately developed and incorporated into GIS analyses (see 6 below).

2. Working in a 3/4D marine environment. Another major challenge is the 3 (and 4D) nature of the marine environment. Analyses might need to be accomplished, and maps produced, that examine variable "slices" through specific water bodies. At the present time there are no proprietary marine GISs that have the capability of working

© (2000) theUKcoastalzone.com

in a 3D marine context. Several authors are working on this, and Figure 6 shows a universal 3/4D hierarchical data structure that this author is working on, a structure that will enable data to be stored and used at up to 6 different resolutions (Meaden, 1999). Other work is in progress, some of which has produced 3D marine visual capability, but only in demonstration projects (e.g. Harding et al., 2000; Kiefer et al., 1999).

3. Applications of spatio-temporal models and statistics. As indicated earlier, models are increasingly being applied within GIS to fishery management problems. Work is now underway on applications of complex movement models, stock prediction models, habitat suitability models (e.g. Rubec et al., 1998; Eastwood and Meaden, 2000), plus various economic models. Figure 7 illustrates this modelling by showing the relative habitat suitability for juvenile sole (Solea solea) in the Straits of Dover.

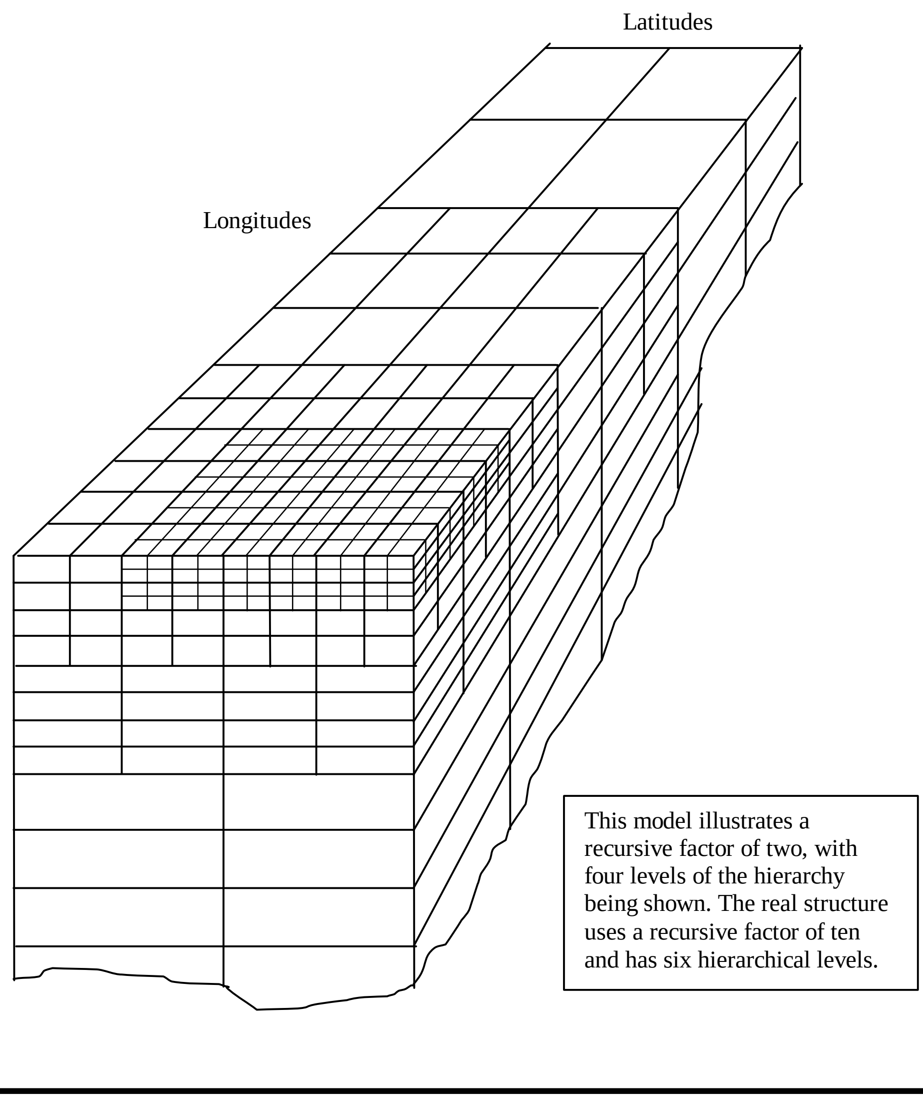

Figure 6. A Recursively Tessellated, Hierarchical 3D Structure for Storing Marine Data at a Range of Resolutions

Given the vagaries of the marine environment, then it is no easy task to fit these statistical models, and amongst other problems this means that to get an indication of statistical significance when working with marine data is extremely problematic.

4. Data gathering and data standardisation. Another challenge of immense importance is data gathering. Until recently there has existed what is really only a scattered number of data-sets covering a very small part of the total marine environment. But new data gathering systems are coming in rapidly, and these will exponentially increase potential data inputs to many fisheries GIS. Thus remotely

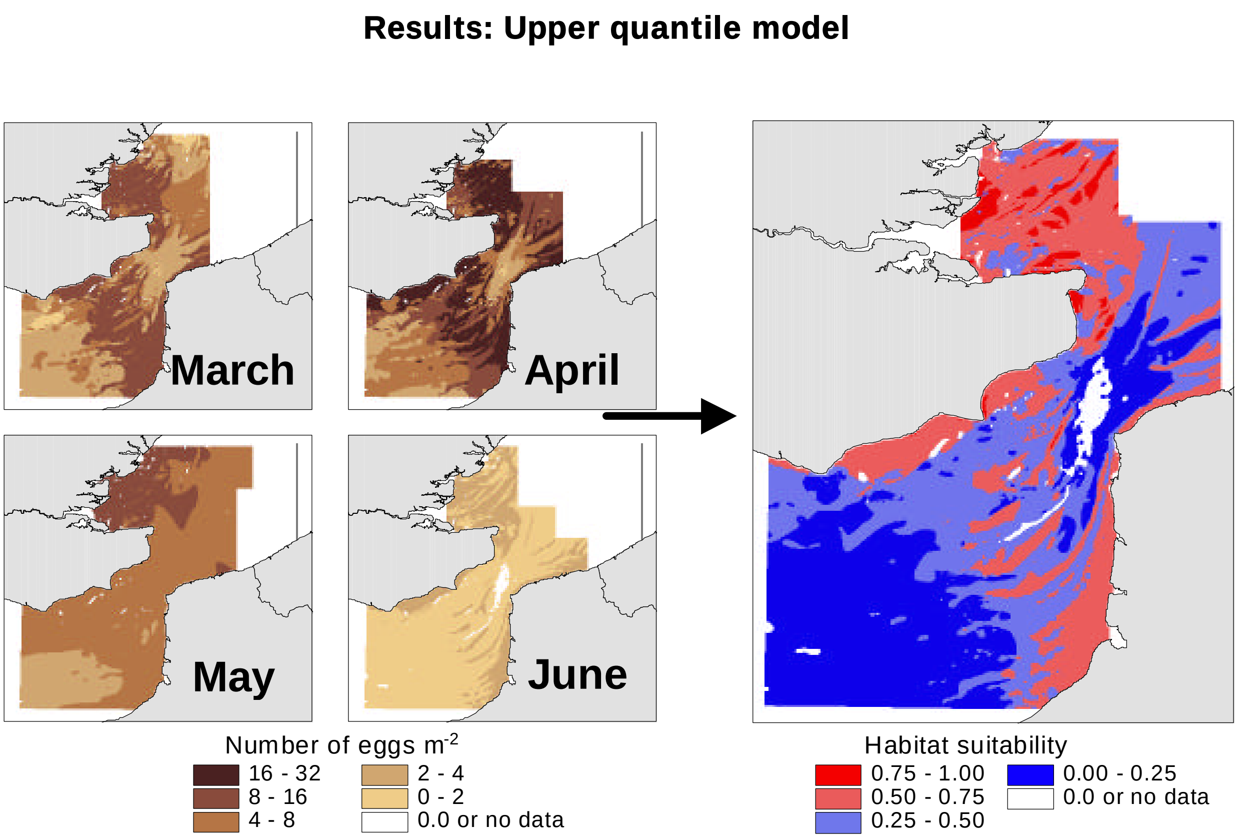

Figure 7. GIS Generated Model Showing Habitat Suitability for Juvenile Sole (Solea solea) in the Straits of Dover.

operated vehicles, (ROV’s), tethered and floating buoys, acoustic sonar, plus better quality satellite data will soon initiate vast data streams, and the problem will then be more concerned with establishing ways to store, handle and best utilise the data. An additional problem is that marine data is badly in need of standardisation in terms of

Ó **(2000) theUKcoastalzone.com**

its formats, uniformity of meaning, data gathering quality, etc., and no single organisation appears to be taking responsibility for this (Bartlett and Wright, 2000; Meaden, 2000b).

5. Fuzzy boundaries and other entities. A problem with data is that concerning "fuzzy" boundaries. How is data best classified? What is meant by, for instance, the "Southern Ocean"? Do we map by species or genera? How are sub-species best categorised for mapping? The questions here are endless, and in the marine environment fuzziness is exacerbated by having the 3rd or 4th dimension, and by the fact that there do not exist all the useful anthropogenic boundaries that have been created across the terrestrial landscape.

6. Visualisation. This topic covers the area of how we best view and understand mapped data. What colour combinations should be used? What legend symbols can best be interpreted? What temporal frequency is needed in order to show change? What frequency classes should be used? It is important that some considerable effort is given to establishing the best visualisation formats for fisheries decision makers to use (Kemp and Meaden, in press). Huge improvements are being made, especially in 3D visualisation, and fly through sequencing of maps (or dynamic mapping) is now being used in fisheries GIS (Ault and Luo, 1998). The use of dynamic sequencing techniques will allow for visualisation of scenarios such as the daily increments of fish migration movements, the passage of thermal fronts, or the spread of perhaps toxic algal blooms, and indeed any movement that can be readily modelled.

7. Organisational problems. Under this heading the concern is with doing something about the fragmented nature of GIS use in fisheries management. In Section 2 above, some indication was given concerning the extremely fragmented nature of work being carried out here. There are many possibilities to confront this problem. Should there be more conferences? Is a fisheries GIS journal needed? Should there be a major Internet site, and if so, how should it be updated? Undoubtedly the future will see some organisational improvements through the proliferation of dedicated conferences and/or workshops, but the major challenge will be in getting regional fishery management institutions to adopt GIS as a major aid to improving decision making.

8. Economic challenges. Although the economic challenges of adopting GIS for fisheries management are reducing, data inputs are still very costly – primarily

© **(2000) theUKcoastalzone.com**

because collection costs are expensive at sea. But the main challenge lies in proving the cost:benefit of using GIS to potential customers.

9. Socio-cultural challenges. Although the world of GIS might be quite straight-forward in the US, Europe and in other developed areas, this does not apply everywhere. There are still taboos of various kinds. Do fishing vessel owners wish to confront this new technology? Should western nations be imposing complex IT solutions upon communities to which GIS may seem to have little relevance? It is also clear that the structural organisation of fisheries in some geographical areas is so complex and fragmented, that no single group exists who are able to act as a focal point around which GIS-based analytical systems might function. This author has been involved in a number of major fisheries related GIS implementations, and in each one there has arisen an array of socio-cultural issues, some of which have proved to be insurmountable to the extent that GIS has not proven to be a viable option.

10. Gaining a geographical perspective. Allied to the above, a final but important challenge is that of gaining a full understanding of the spatial perspective. Many people working in the fisheries field cannot be expected to comprehend spatial relationships as shown by GIS maps and analyses. They often do not detect subtle trends in terms of adjacency, ubiquity, contiguity, heterogeneity, etc. Flows, interactions, spatial patterns, surface trends all have to be recognised, otherwise the use of GIS is simply wasted. But it is far from easy to teach, or to learn, spatial awareness.

LIKELY FUTURE FISHERIES MANAGEMENT AREAS FOR GIS

Although the ideas expressed here must be somewhat speculative, it is reasonable to postulate on some major directions in which the use of GIS for fisheries management are likely to move. Table 2 briefly sets out some additional ways, i.e. beyond those already being worked on and those that have been detailed in section 3 above.

CONCLUSIONS

GIS is slowly entering into the realm of fisheries management, and it will increasingly influence decision making at all levels. Given the state of the world's fisheries, and the fact that there is now a universal recognition of the relationship that exists

© **(2000) theUKcoastalzone.com**

between fish and their environment, then the role that GIS can play is advancing rapidly. However, those who are involved in this process of advocating GIS adoption must be aware that changes are taking place so rapidly within the fisheries milieu, that it will prove a major challenge both to keep abreast with these changes, and to adapt databases and GIS systems at the necessary rate so that genuine progress can be achieved. It might not be too much of an exaggeration to say that decisions on the adoption and implementation of GIS must be quickly acted upon if commercial fishing is to remain a mainstream human activity.

Table 2. Some Major Ways in which GIS Might be Used to Further Fisheries Management

1. For the management of catch and effort in commercial fisheries using electronic log books that are integrated to GIS for a range of spatio-temporal analyses.
2. As an aid to establishing essential fish habitats and marine reserves.
3. For stock enhancement purposes. It is essential that various careful spatial analyses are carried out before fish can be successfully (and economically) placed into marine waters.
4. For the assessment of trawl impact damage.
5. For assessing the effect of fish removals on local marine ecosystems. This means finding out what are the effects, both forward and backward, of removing potentially large numbers of fish from overall aquatic food chains.
6. For establishing optimum locations for the siting of deep-sea mariculture cages. Cage siting in sheltered embayments and fjords is causing concern, so it is likely that more exposed deep water sites will in the future be preferred.
7. For the monitoring and modelling of quota arrangements, including the sub-division of marine space into smaller, more flexible zonal management units.
8. GIS implementational procedures, i.e. how best to implement GIS into fisheries management.

ACKNOWLEDGEMENTS

Much of the substance of this paper has evolved from papers presented at recent fisheries conferences or workshops in Falmouth (UK), Hamburg (Germany), Rhode Island (USA), Washington (USA) and Seattle (USA).

REFERENCES

Aguilar-Manjarrez, J., and Ross, L.G., 1995 Managing Aquaculture Development: The role of GIS in environmental studies for aquaculture. *GIS World.* Vol.8, No.3. pp.52-56.

Al-A'ali, M. and Bakiri, G., 1996. A GIS for Bahrain fisheries management. *Proceedings of the 1996 ESRI User Conference.* Palm Springs, California, USA.

© **(2000) theUKcoastalzone.com**

Ali, C., Ross, L.G. and Beveridge, M.C.M., 1991. Microcomputer spreadsheets for the implementation of geographic information systems in aquaculture: A case study on carp in Pakistan. *Aquaculture.* Vol.92. pp.199-205.

Ault, J. S. and Luo, J., 1998. Coastal bays to coral reefs: Visualizations of a spatial multi-stock production model. *Paper presented at ICES Annual Science Conference, ICES CM 1998/S:1.* Lisbon, Portugal.
Bartlett, D.J. and Wright, D.J., 2000. Epilogue. In, *Marine and Coastal Geographic Information Systems.* (Eds. D. Wright and D. Bartlett). Taylor & Francis, London, UK. pp.309-315.

Beveridge, M.C.M., Ross, L.G. and Mendoza, Q.M., E.A., 1994. Geographical Information Systems (GIS) for coastal aquaculture site selection and planning. In *Ecology of Marine Aquaculture.* (Ed. K. Koops). pp.26-47.

Booth, A.J., 1998. Spatial analysis of fish distribution and abundance patterns: A GIS approach. In *Fishery Stock Assessment Models; Alaska Sea Grant College Program. AK-SG-98-01.* 22 p.

Brown, E.D. and Norcross, B.L., 1999. Effect of herring egg distribution and ecology on year-class strength and adult distribution. *Paper presented at 17th Lowell Wakefield Fisheries Symposium*. October 27-30, 1999, Anchorage, Alaska, USA.

Caddy, J.F.; Refk, R. and Do-Chi, T., 1995. Productivity estimates for the Mediterranean: Evidence of accelerating ecological change. *Ocean and Coastal Management.* Vol.26, No.1. pp.1-18.

Caddy, J.F. and Carocci, F., 1999. The spatial allocation of fishing intensity by port-based inshore fleets: a GIS application. *ICES Journal of Marine Science,* Vol.56. pp.388-403.

Carocci, F. and Majkowski, J., 1996. *Pacific Tunas and Billfishes: Atlas of Commercial Catches.* FAO, Rome, Italy.

Castillo, J., Barbieri, M.A., and Gonzalez, A., 1996. Relationships between sea surface temperature, salinity, and pelagic fish distribution off northern Chile. *ICES Journal of Marine Science*. Vol.53**,** pp.139-146.

Corsi, F., Agnesi, S. and Ardizzone, G. (in press). Integrating GIS and surplus production models: a new approach for spatial assessment of demersal resources? *Proceedings of the First International Symposium on GIS in Fishery Science*. March 2-4, 1999, Seattle, Washington, USA.

Cushing, D., 1995. *Population Production and Regulation in the Sea: A Fisheries Perspective*. Cambridge Univ. Press, Cambridge, UK.

Denis, V. and Robin, J.P., 1998. Present status of French Atlantic fishery for cuttlefish (Sepia officinalis). *Paper presented at ICES Annual Science Conference. ICES CM 1998/M:43.* Lisbon, Portugal. 14 p.

Do Chi, T. and Taconet, M., 1994. Development of GIS approach for marine fisheries: Potentials, constraints and training needs*. Paper presented at International Symposium on Geographical Information, Remote Sensing and Training.* GDTA, Toulouse, France. 17-19 May, 1994.

Ó **(2000) theUKcoastalzone.com**

Durand, C., 1996. Présentation de Patelle: Programmation graphique de chaînes de traitement SIG sous ArcView. *IFREMER: Note Technique TC/04.* Sillage/IFREMER, Plouzané, France. 19 p.

Eastwood, P. and Meaden, G.J., 2000. "Spatial modelling of spawning habitat suitability for the sole (Solea solea L.) in the eastern English Channel and southern North Sea". *Paper presented at the ICES Annual Science Conference.* No.CM2000/N:05. September 25-29, 2000, Bruges, Belgium.

Fogarty, M.J. and Murawski, S.A., 1998. Large-scale disturbance and the structure of marine systems: Fishery impacts on Georges Bank. *Ecological Applications,* Vol. 8(1) Supplement. pp.S6–S22.

Gordon, W.R., 1994. A role for comprehensive planning, Geographical Information System (GIS) technologies and program evaluation in aquatic habitat development. *Bulletin of Marine Science,* Vol.2-3. pp.995-1013.

Habbane, M., ElSahb, M.I., Dubois, J.M., 1997. Determination of potential for aquaculture activities via passive teledetection and a grid-based geographical information system: Application to coastal waters to the Baie-des-Chaleurs (Eastern Canada). *International Journal of Remote Sensing,* Vol.18**,** No.16. pp.3439-3457.

Harding, J., MacNab, R., Varma, H. and Hart, J., 2000. The HH Code: The management, manipulation and visualisation of bathymetric data. In *Integrated Coastal Zone Management.* (Ed. A. Pink). ICG Publishing, London, UK. pp.71-76.

Hooge, P.N., Eichenlaub, W.M. and Soloman, E.K., 1999. Integrating GIS with the statistical analysis and modeling of animal movements in the marine environment. *Paper presented at the 17th Lowell Wakefield Fisheries Symposium.* October 27-30, 1999. Anchorage, Alaska.

Irwin, E.R. and Noble, R.L., 1996. Effects of reservoir drawdown on littoral habitat: Assessment with on-site measures and geographic information systems. *Multidimensional Approaches to Reservoir Fisheries* (Eds. Miranda, L.E. and DeVries, D.R.) American Fisheries Society, Bethesda, Maryland, USA. Vol.16. pp.324-331 .

Jordan, S.J.; Greenhawk, K. and Smith, G.F., 1995. Maryland oyster geographical information system: Management and scientific applications. *Triennial Meeting of the Fish Culture Section of the American Fisheries Society and World Aquaculture Society.* Vol.14, No.1 pp. 269.

Kapetsky, J.M., 1989. A geographical information system for aquaculture development in Johor state. *FAO Technical Cooperation Programme, FI:TCP/MAL/6754.* FAO, Rome, Italy.

Kapetsky, J.M., 1994. A strategic assessment of warm-water fish farming potential in Africa. *CIFA Technical Paper No.27.* FAO, Rome, Italy. 67p.

Kapetsky, J.M., McGregor, L. and Nanne, E.H., 1987. A geographical information system to plan for aquaculture: A FAO-UNEP/GRID study in Costa Rica. *FAO Fisheries Technical Paper No.287.* FAO, Rome, Italy. 51 p.

Ó **(2000) theUKcoastalzone.com**

Kapetsky, J.M., Hill, J.M.,Worthy, L.D., 1988. A Geographical Information System for catfish farming development. *Aquaculture.* Vol.68. pp.311-320.

Keleher, C.J., and Rahel F.J., 1996. Thermal limits to salmonid distributions in the Rocky Mountain region and potential habitat loss due to global warming: A geographic information system (GIS) approach. *Trans. American. Fisheries. Soc.* Vol.125. pp.1-13.

Kemp, Z., and Meaden, G.J., 1996. Monitoring fisheries using a GIS and GPS. *Paper presented at AGI: Geographic Information Towards the Millennium: Conference Proceedings '96.* Birmingham, UK.

Kemp, Z. and Meaden, G.J. (in press) "Visualization for fisheries management from a spatiotemporal perspective". *ICES Journal of Marine Science*.

Kiefer, D.A., Tsontos, V.M., Atkinson, C.A. and O'Brien, F., 1999. A 4 dimensional oceanographic information system. *Paper presented at the First International Symposium on GIS in Fishery Science*. March 2-4, 1999, Seattle, Washington, USA.

Klemas, V.V.; Dobson, J.E.; Ferguson, R.L. and Haddad, K.D., 1993. A coastal land cover classification system for the NOAA coastwatch change analysis project. *Journal of Coastal Research*. Vol. 9, No. 3, pp.862-872.

Laevastu, T. and Favorite, F., 1988. *Fishing and Stock Fluctuations*. Fishing News Books, Farnham, UK.

Le Corre, G., 1995. Propositions d'usages de SIG en halieutique. *Etude et Séminarie sur les Systèmes d'Information Géographique (SIG) en Méditerranée.* Vol.2 : Contributions au Séminaire. Projet TR/MED/92/013 IFREMER-CEE.

Legault, J.A., 1992. Using a Geographic Information System to evaluate the effects of shellfish closure zones on shellfish leases, aquaculture and habitat availability. *Canadian Technical Report of Fisheries and Aquatic Sciences.* No.1882E, 14 p.

Liebig, W., 1994. Protecting the environment: GIS and the Wadden Sea. *GIS Europe.* Vol.3, No.2. pp.34–36.

Long, B.G., Skewes, T., Poiner, I., and Bishop, M., 1994. Geographic information systems helps manage Torres Strait fisheries. *Australian Fisheries.* Vol.53, No.2. pp.14-15.

Long, B.G. and Skewes, T.D., 1996. A technique for mapping mangroves with Landsat TM satellite data and geographic information systems. *Estuarine, Coastal and Shelf Science.* Vol.43. pp. 373–381.

McGowan, E.M., Nealon, J., and Brown, C., 1995. Needs assessment: Aquaculture GIS in northeastern Massachusetts. In *GIS/LIS '95 – Annual Conference and Exposition, Proceedings*, Vols I and II, 1995, Ch. 124, pp. 723-729*.*

Meaden, G.J., 1987. Where should trout farms be in Britain? *Fish Farmer.* Vol.10. No.2*.* pp. 33-35.

Ó **(2000) theUKcoastalzone.com**

Meaden, G.J., 1994. Background notes and prospects for a Libyan marine fisheries geographical information system. *Libfish Technical Briefing Notes No.3.* FAO, Tripoli, Libya. 55p.

Meaden, G.J., 1996. Potential for geographical information systems (GIS) in fisheries management. In *Computers in Fisheries Research. (*Eds. B.A., Megrey, and E. Moksness,) Chapman & Hall, London, England. pp.41-79.

Meaden, G.J., 1999. Towards a universal 3D data structure for marine information. *Paper presented at a workshop on the Ocean Biogeographical Information System.* 3-4 November, 1999; Washington, USA.

Meaden, G.J., 2000a. Applications of GIS to fisheries management. *Marine and Coastal Geographic Information Systems*. (Eds. D. Wright and D. Bartlett), Taylor & Francis, London, UK. pp.205-226.

Meaden, G.J., 2000b. Data standards everywhere and not a one to share! *Paper presented at EurOcean2000*, Hamburg, Germany. August 31st, 2000.

Meaden, G.J., and Do Chi, T., 1996. Geographical Information Systems: Applications to marine fisheries. *FAO Fisheries Technical Paper No.356.* FAO, Rome, Italy. 335 p.

Meaden, G.J. and Kemp, Z., 1996. Monitoring fisheries effort and catch using a Geographical Information System and a Global Positioning System. *Developing and Sustaining World Fisheries Resources: The State of Science and Management.* (Eds. Hancock, D.A., Smith, D.C., Grant, A. and Beumer, J.P.) Second World Fisheries Congress, Brisbane, Australia. pp.238-244.

O'Brien-White, S. and Thomason, C.S., 1995. Evaluating fish habitat in a South Carolina watershed using GIS. *Proceedings of the 49th Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* , Nashville, TN (USA), 23-27 Sep 1995. pp.153-166.

Ostrowski, M., 1994. *The Skagex Atlas: User's Guide.* ICES and the Nordic Council of Ministers, Bergen, Norway.

Paw, J.N., Diamante D.A.D., Robles, N.A., Chua, T.-E., Quitos, L.N. and Cargamento, A.G.A., 1992. Site selection for brackishwater aquaculture development and mangrove reforestation in Lingayen Gulf, Philippines using geographic information systems. *Canadian Conference on GIS,* 24-26 March 1992. Ottawa, Canada.

Pierce, G.J., Wang, J., Bellido, J.M., Waluda, C.M., Robin, J.P., Denis, V., Koutsoubas, D., Valavanis, V. and Boyle, P.R., 1998. Relationships between cephalopod abundance and environmental conditions in the northeast Atlantic and Mediterranean as revealed by GIS. *Paper Presented at the ICES Annual Science Conference. ICES CM 1998/M:20.* Lisbon, Portugal. 22 p.

Porter, D.E., Edwards, D., Scott, G., Jones, B. and Street, W.S.,1997. Assessing the impacts of anthropogenic and physiographic influences on grass shrimp in localized salt-marsh estuaries. *Aquatic Botany.* Vol.58. No.3-4. pp.289-306.

Ó **(2000) theUKcoastalzone.com**

Ramos, F., Sobrino, I. and Jiménez, M.P. ,1996. *Cartografía de Especies y Caladeros – "Golfo de Cádiz".* Informaciones Técnicas 45/96. Consejeria de Agricultura y Pesca, Junta de Andalucia, Espana.

Ramster, J., 1994. Marine resources atlas: The implications for policymakers and planners. *Underwater Technology.* Vol.19, No.4. pp.12-19.

Rogers, K.B. and Bergersen, E.P., 1996. Application of geographic information systems in fisheries:Habitat use by northern pike and largemouth bass. *Multidimensional Approaches to Reservoir Fisheries* (Eds. Miranda, L.E. and DeVries, D.R.) American Fisheries Society, Bethesda, Maryland, USA. Vol.16. pp.315-323.

Ross, L.G., Mendoza, QM,E.A., and Beveridge, M.C.M., 1993. The application of geographical information systems to site selection for coastal aquaculture: An example based on salmonid cage culture. *Aquaculture.* Vol.112. No's.2–3. pp.165–178.

Rubec, P.J., 1996. GIS applications for fisheries: For database management, data sharing, sampling, analysis, and visualization in support of ecosystem management. *Proceedings of GIS Applications for Fisheries and Coastal Resources Management.* (Eds. Rubec, P.J. and O'Hop, J) March 18, 1993. Palm Beach, FL, Ocean Springs, MS. Gulf States Marine Fisheries Commission. pp.157-191.

Rubec, P.J., Coyne, M.S., McMichael, R.H. and Monaco, M.E., 1998. Spatial methods being developed in Florida to determine essential fish habitat. *Fisheries*, Vol.23, No.7. pp.21–25.

Sakurai, Y., Bower, J.R., Kiyofuji, H., Saitoh, S., Goto, T., Hiyama, Y., Mori, K. and Nakamura, Y., 1998. Changes in inferred spawning sites of Todarodes pacificus (Caphalopoda ommastrephidae) due to changing environmental conditions. *Paper Presented at the ICES Annual Science Conference. ICES CM 1998/M:18.* Lisbon, Portugal. 7 p.

Schneider, D.C., 1998. Applied scaling theory. In *Ecological Scale: Theory and Applications*. (Eds. D.L. Peterson and V.T. Parker). Columbia University Press, New York, USA. pp.253-269.

Schneider, D.C., Bult, T., Gregory, R.S., Methven, D.A., Ings, D.W. and Gotceitas, V., 1999. Mortality, movement and body size: Critical scales for Atlantic Cod (*Gadus morhua*) in the northwest Atlantic. *Canadian Journal of Fisheries and Aquatic Sciences.* Vol. 56 (Supp). pp.180-187.

Selvik, J.R., Behren, H.L., Gjetrang, L.M., Langfeldt, J.N., Lystad, E., Marthinsen, I., Moe, K.A., Nedrebo, M. and Skeie, G.M., 1993. Marine Resources Data Base (MRDB):A database on vulnerable marine resources in Norway. *Paper presented at the ICES Statutory Conference.* No.C.M.1993/D:44. Dublin, Ireland.

Smith, H.D. and Lalwani, C.S., 1996. : The North Sea: Co-ordinated sea use management. *Geojournal.* Vol.39. No.2. pp.109-115.

Somers, I.F. and Long, B.G., 1994. Note on the sediments and hydrology of the Gulf of Carpentaria, Australia. *Australian Journal of Marine and Freshwater Research.* Vol.45, pp.283–291.

Ó **(2000) theUKcoastalzone.com**

Sotheran, I.S., Foster-Smith, R.L. and Davies, J., 1997. Mapping of marine benthic habitats using image processing techniques within a raster-based GIS. *Estuary and Coastal Shelf Science,* Vol.44 (suppl A).

Swartzman, G., Huang, C., and Kaluzny, S., 1992. Spatial analysis of Bering Sea groundfish survey data using Generalized Additive Models. In *Canadian. J. Fisheries and Aquatic Science.* Vol.49. pp.1366-1378.

Symes, D., 1996. Fishing in troubled waters, *Fisheries Management in Crisis*, (Eds. Crean, K. and Symes, D). Fishing News Books, Farnham, UK. pp.3-16.

Taconet, M., 1995. Development of a Geographic Information System for artisanal fisheries: The experience of FAO in West Africa. *Report of the Ninth IDAF Liasion Officers Meeting.* Conakry, Guinea. 9-10 November 1995. pp.41-62.

Valavanis, V., Georgakarakos, S. and Haralambous, J., 1998. A methodology for GIS interfacing of marine data. *Paper Presented at the GISPlaNET'98 International Conference.* Lisbon, Portugal.

Wilson, J.D., 1999. Stellar performances: Top companies vie for position in the GIS universe. *GEOurope.* Issue 3. pp.36-41.

Wood, L.L. and Ferguson, R.L., 1995. Monitoring the effects of sidecast dredging on seagrass habitat using aerial photography and GIS. *Proceedings of the 61st Annual Convention of the American Society for Photogrammetry and Remote Sensing.* ASPRS, Charlotte, North Carolina, USA. pp.403.

© **(2000) theUKcoastalzone.com**