Spatial fish resources analyses using GIS (Geographical Information Systems): Current situation and prospects

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SUMMARY: This paper reviews the current situation vis-à-vis GIS in spatial marine fish resources analyses. It is based upon some 200 selected papers presented in four symposia in 1999, i.e., “First International Symposium on GIS in Fishery Science”, “Ecosystem Effects of Fishing”, “GIS Applications for Agro-Environmental Issues in Developing Regions” and “Spatial Process and Management of Fish Population. The selected papers are summarized under following four categories: (a) basic presentation (mapping) of parameters, (b) fisheries oceanography and marine ecosystems research, (c) geo-referenced fish resource assessments and analyses, and (d) space-based management and predictions. Based on the current situation, we further discuss prospects and future applications for spatial fish resources analyses using GIS.

KEY WORDS: 4D, contour estimation, ecosystem, geo-referenced, GIS, raster, responsible fisheries, spatial data

INTRODUCTION

This paper reviews the current situation on Geographical Information Systems (GIS) in spatial analyses of marine fish resources, and also discusses software and future prospects. The primary sources of information used in this review paper are some 200 published papers available in the Proceedings of the following four symposia held in 1999: (a) “First International Symposium on GIS in Fishery Science” (Seattle, USA)¹, ² (which we organized), (b) “Ecosystem Effects of Fishing” (Montpellier, France)³, (c) “GIS Applications for Agro-Environmental Issues in Developing Regions” (Tsukuba, Japan)⁴ and (d) “Spatial Process and Management of Fish Population” (Anchorage, USA)⁵, ⁶

BACKGROUND ⁷)

Applications of GIS started in the 1960’s in terrestrial management fields, for which a sufficient amount of information was available to conduct GIS analyses effectively. In spatial analyses of fish resources, applications of GIS have been much slower, only starting in the 1980’s. Applications have primarily focused on near- or on-shore management of inland and coastal water fisheries, plus site selection for aquaculture industries. This was because more information was available in these areas, compared to off-shore areas or distant waters. Such near-shore applications are frequently conducted using satellite information. In the 1990’s, although applications gradually expanded further off-shore, and indeed now cover all Oceanic waters, the number of applications is still very limited compared to those in terrestrial fields.

Two major reasons for the slow growth and limitation of fishery applications are (a) the types of information are different from those needed for land, in terms of quality and quantity and (b) no effective GIS software for handling fisheries and oceanographic data are available. The different types of information needed for marine work, refers to the “limited quantity of information”, “4 dimensional information (3D + time) that makes mapping difficult”, “difficulty in handling information due to the fuzzy nature of data sets that may need combining” and “the necessity to interpolate contours such as for density of fish resources and environmental factors such as temperature”.

CURRENT SITUATION

To assess the current situation and progress in the use of GIS for spatial analyses of marine fish resources, recent applications were carefully reviewed based on some 200
papers mentioned previously. As a result, they were classified into the following four subject areas, determined by different GIS functionality, and indicated in italics 6), i.e., (a) habitats and distributions (basic mapping), (b) fisheries oceanography and marine ecosystems (overlaying multiple parameters), (c) geo-referenced fish resource analyses (spatial numerical analyses) and (d) space-based fisheries management (integrated GIS analyses). Fig. 1 illustrates the relationships among these subjects. Each subject is now discussed.

![Diagram](image)

**Fig. 1** Relationships among four types of spatial analyses of marine fish resources using GIS. 6) (These four subjects frequently overlap)

(a) **Habitats and Distributions (Basic mappings)**

Simple mapping, in order to study parameters of fish resources such as habitat, distribution of catch and biodiversity, is the most basic and common research area. Such GIS work has been applied over a long period because it requires relatively basic and fundamental techniques, allowing even beginners in GIS to conduct the necessary spatial analyses. Hence, a large number of papers dealt with studies in this area. It is sometimes suggested that basic mapping should not be considered as GIS. 6) However, in a broad sense, simple mapping is a basic GIS component because advanced overlay or numerical analyses are conducted by integrating or manipulating such basic maps.

(b) **Fisheries oceanography and marine ecosystems**  
**Overlaying multiple parameters**

"Fisheries oceanography" and "Marine ecosystems" refers to research areas relating to spatial relationships among fish resources, oceanography and marine ecology. GIS has been recognized as the most effective tool for these researches. There are three major analytical areas under this subject, i.e., "Spatial dynamics between fisheries and marine ecosystems" 9), "Migration dynamics" 10) and "Remote sensing" 11) GIS applications in these research areas involve multivariate parameters that utilize overlay functions to search for spatially correlated regions.

(c) **Geo-referenced fish resource analyses**  
**Spatial numerical analyses**

The need to manage fisheries from a spatial perspective is clear. 12) This is because commercial catches are geo-referenced, with fish being harvested at specific geographic locations as a function of the fishing effort and stock abundance at that location. By neglecting this spatial component, existing assessment models evaluate the status and productivity of the stock based on pooled catch-at-age data, fisheries independent survey indices and key population parameters. Few attempts, however, have been made to incorporate the spatial variability of a fish stocks’ age-structure, maturity and growth patterns, together with catch and effort data, into an assessment framework. 13, 14, 15)

Under such circumstances, there is currently a growing interest in the development of marine GIS, both to visualize these spatial data sets and to provide a platform on which to link to stock assessments and forecasting. As a result, a GIS incorporating spatially referenced fisheries data and assessment models would contribute significantly towards integrating these with other data sources thus providing quantitative and qualitative management advice, and consequently to improve integrated resource management.

(d) **Space-based fisheries management and Prediction**  
**Integrated GIS analyses**

After the adoption of the UN/FAO’s “Code of Conduct for Responsible Fisheries” 16) in 1995, spaced-based fisheries management concerned with marine ecosystems has been growing rapidly in the following four areas, i.e., Fishing
effort management, By-catch management, Ecosystem management and predication. The current situation using GIS in these four areas is described briefly.

Fishing effort management have been developed by linking GIS with the information from satellite, air planes, Vessel Monitoring Systems (VMS) and Global Positioning Systems (GPS) to monitor and control fishing vessel activities.1,2,17 Regarding 'By-catch management', using the GIS overlay function, waters excluding the by-catch habitat areas might be the recommended as fishing grounds.18 'Ecosystem management' is the spatially integrating approach to optimize marine ecosystem, catch, by-catch, benefits of fishing vessels and other related parameters.9,19 This research area and 'Prediction' are still in a developmental stage.6)

SOFTWARE

Whereas most GIS platforms contain 2D database functionality and high quality graphical outputs, few progressed past 2+D databases, simple geostatistical analyses and Boolean logic-based overlaying and buffering procedures. These platforms have terrestrial origins and do not have the capacity of handling or analyzing highly spatio-temporally variant datasets. As a result there is no generic commercial software that can efficiently handle fisheries information and its analytical demands. This limits the use of GIS for fisheries. Terrestrial GIS's have tackled the problems with specialized analyses through customized modules. Fisheries GIS equivalents have been noted in this review.

More than 95% of the papers used terrestrial 2D or 2+D GIS software. These software platforms could only handle fisheries and oceanography data to a limited extent, specializing in only a few specific functions such as simple presentation, navigation systems (electrical charts), satellite data processing, contour estimation (interpolation), database, vertical profiling for oceanographic information and bathymetry mapping. Although these systems were functional they could not incorporate all of the specific functions into one system.

The development of integrated GIS software is required. In addition, such software needs to be used for conducting spatial numerical analyses and for modeling that is linked to stock assessments, simulations and ecosystems management. Furthermore, such software must be user-friendly, and ideally it would run without requiring any programming since fishery scientists in many countries have limited funds to hire GIS specialists, and they cannot spend time on programming themselves. Several systems are in the developmental stages.30,21)

PROSPECTS AND SUMMARY

Our assessment of the current status on the application of the GIS in the spatial analysis of fish resources, is summarized in Fig 2. As noted, there are few applications in Spatial numerical analyses and Predictions, both of which will be challenging areas for the future.7)

![Fig. 2 Summary of the current situation of GIS application in spatial analyses of marine fish resources. Areas of subjects in the isosceles triangle represent rates of their application. (There are only limited numbers of application in quantitative analyses, while majority of applications are for qualitative analyses)](image)

There is an urgent need to develop spatially-oriented fish management methodologies due to the limitations of the traditional management concept of the pooled single-stock maximum sustainable yield (MSY) or total allowable catch (TAC). Management measures need to be applied in space and time along with considering ecosystem implications, by-catch, multi-species interactions and the socio-economic importance of fisheries. In this manner, responsible fishing practices can be pursued, along with securing protein sources that may be able to mitigate food crises expected in the beginning of the 21st century. It is certain that such ecosystems management schemes for responsible fisheries will be complex, prompting the use of GIS as a most suitable management and assessment tool.

Finally, Table 1 summarizes major challenging areas for future GIS applications in the spatial analyses of marine fish resources.
Table 1. Major challenging areas, listed by subject, that can be considered important for future GIS applications in the spatial analyses of marine fish resources.

<table>
<thead>
<tr>
<th>Data</th>
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<tbody>
<tr>
<td>Standardization of data collection structures with adjustment</td>
<td>for discrepancies in space or time.</td>
</tr>
<tr>
<td>Conversion of analog data to digital data.</td>
<td></td>
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<tr>
<td>Consolidation of data gathering and databases.</td>
<td></td>
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<tr>
<td>Automation of data collection.</td>
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<tr>
<td>Establishment of simple database linked to GIS platform</td>
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<tr>
<td>Consideration of 3D or 4D database for the GIS.</td>
<td></td>
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<tr>
<td>Development of easy methods to access oceanography and</td>
<td>satellite information.</td>
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<tr>
<td>Development of easy methods to process matrix (raster) information</td>
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Presentation

- Application of enhanced visualization to fisheries GIS
- Effective and easy ways to present 3D and 4D parameters of fisheries and Oceanography information such as catch, CPUE, temperature and salinity

Stock assessment, prediction and spatial numeral analyses

- Development of linkages between GIS and stock assessment
- Applying GIS methods, models, simulations and geo-statistics in a fluid, dynamic 3D environment
- Development of space oriented prediction methods for fishing and oceanographic conditions

Fisheries management using GIS

- Space oriented fisheries management
- Ecosystem-based fisheries management
- Essential fish habitats and marine reserves
- Fishing effort monitoring systems using GPS and VMS
- Fisheries impact assessment (development of space-based stock assessment)
- Spatial allocation of the results of stock assessments such as MSY and TAC
- Monitoring and modeling of quota arrangements

Software

- Development of user-friendly and high performance fisheries GIS software that can handle simple parameters and also satellite information, and that can perform simple mapping as well as complex integrated spatial numerical analyses.

Human interaction

- Establishment of the international fisheries GIS association for networking to exchange ideas and information.
- Collaborative and interactive GIS activities in fisheries resources research by fisheries scientists, oceanographers, fishers and fisheries managers for effective, meaningful and realistic achievements.
- Fostering a trustful relationship between researchers, fishers and politicians

ACKNOWLEDGEMENTS

We wish to thank Dr Neil Klare (GIS expert, former CSIRO/Marine Research, Australia) and anonymous referees for their comments to improve this manuscript.

REFERENCES