# GIS in Fisheries Resources Research: Current Situation and Prospects

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## Abstract

As convenors of the recent "International Symposium on GIS in Fishery Science" held in Seattle, USA (March, 1999), we noticed that a large number of presentations and a great deal of interest were centered on a particular theme, "GIS in Fisheries Resources Research." Because GIS is an effective analytical method for studying space-oriented fisheries resources, it is appropriate to review the current state of research. With the permission from the speakers at the Symposium, an outline of selected papers on this theme is summarized under the following four categories: (a) presentation (mapping) of parameters relating to fisheries resources, (b) fisheries oceanography and ecosystems, (c) geo-referenced fish resources assessment and analyses, and (d) space-based fisheries management. Through the recent adoption of the UN/FAO's "Code of Conduct for Responsible Fisheries (1995)," the world's fishing nations are gradually adopting practices for promoting sustainable fisheries, protecting the resource base, and maintaining ecosystem health. To achieve these objectives, fisheries scientists and managers have expressed a great interest in developing fisheries GIS. Such specific GIS applications are directed towards the understanding of the spatial processes of fish populations and their ecosystems to promote sustainable fisheries and ecosystem management practices. In this paper, we present the current situation of GIS in fisheries resources research based upon the above-mentioned summary and also discuss prospects for future applications.

## Introduction

In recent years, the term "Geographic Information System (GIS)" has been frequently used in various fields and society interest in GIS has also been increasing. This paper will introduce GIS particularly in fisheries resources research. This paper initially outlines the background and history of GIS in fisheries resources research, then describes the complexities, recent situation, software and lastly prospects for the future. A summary of the current situation is described, based upon more than 130 papers presented during the recent "First International Symposium on GIS in Fishery Science" held in Seattle, USA (March 2-4, 1999), which we organized.

## Background and history

Application of GIS started in the 1960s in terrestrial management fields for which a sufficient amount of information is available to conduct GIS analyses effectively. Until now, GIS had been applied in a wide range of terrestrial fields from primary industries, manufacturing industries, to business and service industries. In primary industries, GIS is applied to manage agriculture, land, water, forest resources, etc. In manufacturing industries, GIS is utilized, for example, by electric power and gas companies for disaster crisis control. In the

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business and service industries, GIS is effectively used, for example, in traffic control, real estate management, site selection for new stores and city planning.

In fisheries resources research or fisheries management in general, application of GIS has been considerably slow and only started in the 1980s. Applications primarily focused on near- or on-shore management of inland and coastal water fisheries and site selection of aquaculture industries. This was because more information was available in these areas, compared to areas in off-shore and distant waters. Such near-shore applications are frequently conducted using satellite information. In the 1990s, although applications gradually expanded further to off-shore and distant waters and covered all of the oceans, the number of applications were still very limited compared to those in the terrestrial fields. Table 1 summarizes the stages in the growth of GIS applications in fisheries resources research. Two major reasons for the slow growth and limitation of the fishery applications are (a) types of information are different from those for land, in terms of quality and quantity and (b) no effective GIS software for handling of fisheries and oceanographic data is available. Different types of information in this case refer to "limited quantity of information", "4-dimensional information (3D + time) that makes mapping difficult", "difficulty in handling information due to combination of vectors with different properties and raster data" and "necessity to estimate contours such as density of fish resources and environmental factors such as temperature".

**Table 1 Stages in the growth of GIS applications to fisheries science**

| Stage | Characteristics | Dates | Motivation |
|---|---|---|---|
| 1 | Tentative emergence; very slow growth; mainly used in inland water fisheries management and aquaculture site selection (inland to in-shore). | 1984 - 1990 | Developments in remote sensing; GIS work at FAO; imitation of other terrestrial GIS activities. |
| 2 | Accelerating growth into a wider range of fisheries fields (in-shore to off-shore). | 1991 - 1997 | Increased opportunities through the development of more powerful PCs and certain publications. |
| 3 | Consolidation and expansion into more fields. Wider interest base (off-shore to distant waters). | 1997 → | Data availability and storage; increasing publicity and needs for recognition. |

Note: It is too early to determine whether Stage 3 is simply an extension of Stage 2, though there appears to be a leveling off in the publication rate.

# Inherent complexities

In the previous section, unique and different attributes of fisheries and oceanography information for GIS application compared to those of terrestrial information, were pointed out. In this section, inherent complexities of these fisheries and oceanography data for GIS application are further discussed (Note: This section is based on the report of Meaden, 2000, in press)

## 1 Complex factors

Basic and simple mapping of fisheries parameters such as catch, catch per unit of effort (CPUE), etc. has been frequently and commonly presented in papers, documents and reports in the past using simple mapping software or self-programing. However, why has integrated fisheries GIS together with bathymetry, oceanography and satellite information been slow to materialize ? To answer this question, it is appropriate to develop two conceptual models. The first deals with the "task components" which make up a GIS task. At its basic level, a mapping task must include three components, (a) an object, located (b) in space and (c) in time and a GIS task would normally require that additionally some space/time change be examined and/or that extra objects be considered. It is possible to consider that the main "task components" relating to the use of GIS in fisheries resources research are those shown in Fig. 1(a). Therefore, although any general GIS task must relate to at least components 1, 2 and 4 (of Fig. 1a), integrated GIS task in fisheries resources research will usually require a consideration of all seven components. For each "task component", there will be considerations relating to data

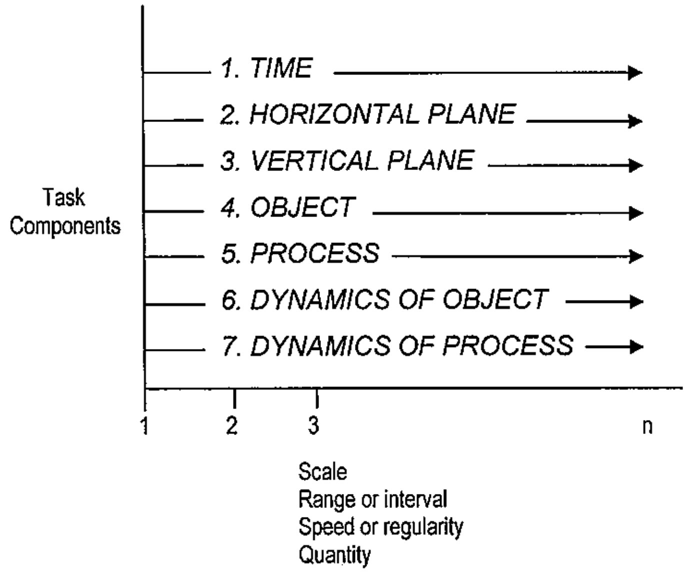


**Fig. 1 (a) 'Task components' in a Fisheries-Based GIS**

Note: The quantitative values relate to the degree of complexity and the output precision required. Although the components will be inter-related, for conceptual purposes they are displayed as separate components.

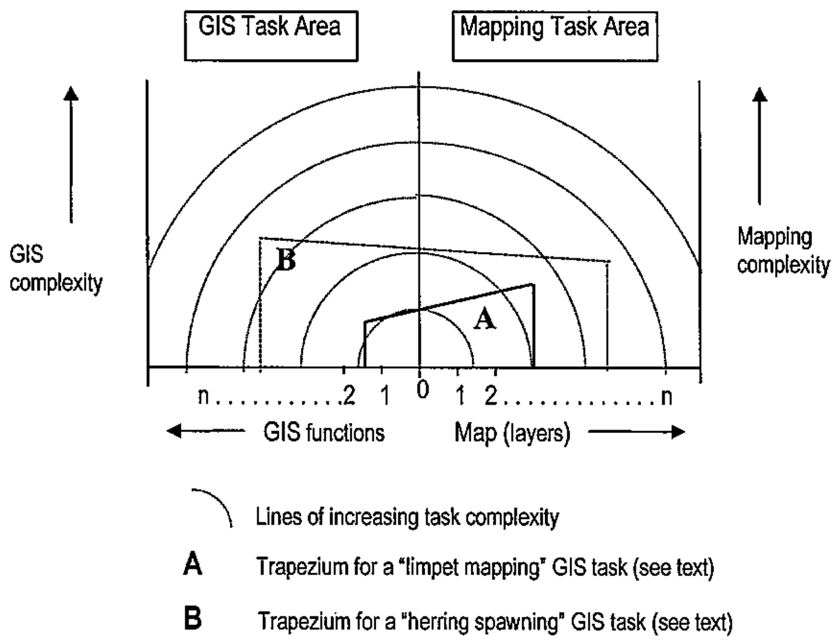


**Fig. 1 (b) Conceptual model showing the complexities of total GIS projects**

collection, data entry, cartographic representation, object and process classification, etc. Given this complex range of "task components", it can be seen why integrated fisheries adoption of GIS might be slow to materialize.

However, it should be noted that in reality, an integrated fisheries GIS project will require more than just the array of "task components". A general GIS project can involve two main areas of consideration, *i.e.* GIS functionality and spatial data. Thus, within the GIS a range of functions will be performed on a variety of spatial data. It is useful to again consider this aspect in the form of a second conceptual model shown in Fig. 1(b). Here, it can be seen that a spatial (mapping) task area on the right side has been "matched" to a GIS functionality task area on the left side. The x axis records both the number of maps (layers) and the number of GIS functions, with quantity increasing from the center. The y axis for both task areas records increasing complexity. Complexity in the integrated GIS functionality task area might be considered in terms of a hierarchy of difficulties in programing or understanding, in hardware requirements, in the acquisition or source range of data and in data formatting requirements, etc. In the mapping task area, complexity might relate to increasing intricacies associated with more complex mapped surfaces or accuracy levels required, the periodicy of mapping required, the ease of data acquisition, or it might more simply relate to a wider geographic area. Radiating around the center (zero point) of the x axis are lines which show increasing total task (or project) complexity. In the case of an integrated fisheries GIS, total project complexity can also be considered to consist of a composite of the seven task components outlined in Fig. 1(a), *i.e.* each task component increases in quantity and/or complexity as it moves outwards from the central (zero) point.

Superimposed on the model in Fig. 1(b) are two trapeziums, A and B. They each illustrate facets relating to the relative complexity of a single GIS project. Thus, for any one trapezium, two points can be imagined which are placed on the model respectively indicating (a) the number of GIS functions to be performed and the relative complexity of GIS operations and (b) the number of map layers and the complexity of the mapping. The points are joined and perpendiculars are extended from each point to the base line. The relative shape and size of the trapezium formed gives a relative perception of the total complexity of the integrated GIS project. In Fig. 1(b) trapezium, A represents a comparatively simple mapping-biased task, such as "mapping mussel distribution in a rock pool", while trapezium B illustrates a more complex project such as "analyzing the relationship between herring spawning grounds and the marine ecology of estuary x". Generally, for the integrated fisheries GIS projects, the trapezium size is considerably larger than for a terrestrial-based project.

In the real world, integrated GIS projects or tasks must take place within a complex socio-economic milieu. Therefore, as well as considering task complexity variations, there will be differences in task budgets, in data costs, in access to training, in management expectations, in back-up support, etc. In addition to these operational considerations, there may be a combination of social, political, cultural and institutional constraints to the particular country or area in which the GIS work is being undertaken.

The models illustrate that there is an array of factors which result in the complexity of (integrated) fisheries-related GIS projects or tasks, *i.e.* relative to terrestrial-based activities. For researchers dealing with GIS, the challenge of operating in this complex milieu might not be worth attempting, *i.e.* given that there are plenty of easier opportunities in GIS.

Because of this range of domain tasks and their components, fisheries-based GIS projects and publications have been slow to come to the fore, and it is not surprising that the array of fisheries GIS output is so diverse, especially given the fact that most of this GIS-based research takes place in a large number of scattered and mainly smaller institutions. The combined factors of diversity, fragmentation and complexity may be conceived as retardation forces which have resulted in the relative immaturity of GIS applications to fisheries resources research.

## 2 Dimensional complexity

For terrestrial-based GIS projects, most of the captured data are represented by point, line or polygon entities that are located individually in 2D space. For many marine projects this is not the case. Here most of the input data are in the form of continuous data in 3D space. In order to structure and conceptualize this type of data array, it is important that a nested, hierarchical data array structure be developed. An imaginary conception of this is shown in Fig. 2. This construct consists of a hierarchy of nested, tessellating tiles each of which forming a 3D 'voxel'. Tiles, representing the marine area, could be subdivided recursively, with data being stored in hierarchical octtrees. The final resolution of tiles would vary according to the nature of the variability of the parameter being mapped. Given that most marine areas have a dimensionality such that the horizontal plane corresponds to approximately 100 times the distance of the vertical plane, then the cuboid tiles (voxels) could have dimensions which reflected this, e.g. a water temperature tile might be 1,000 x 1,000 x 10 meter, whereas an ocean current tile might be 5,000 x 5,000 x 50 meter, and a tile showing species distribution of a single plankton type might be as small as 10 x 10 x 0.1 meter. Just as there are standard geo-referencing units in 2D space, i.e. latitude and longitude, or grid referencing systems, then an international 3D referencing system could be constructed having a world datum point. For data storage and transfer purposes, there would need to be agreements on the initial volumetric dimension of the tiles for each marine parameter, though obviously for particular projects the dimensions of tiles might vary. Clearly Fig. 2 shows the conceptual idea - the actual way in which the data held in a database could be varied at will.

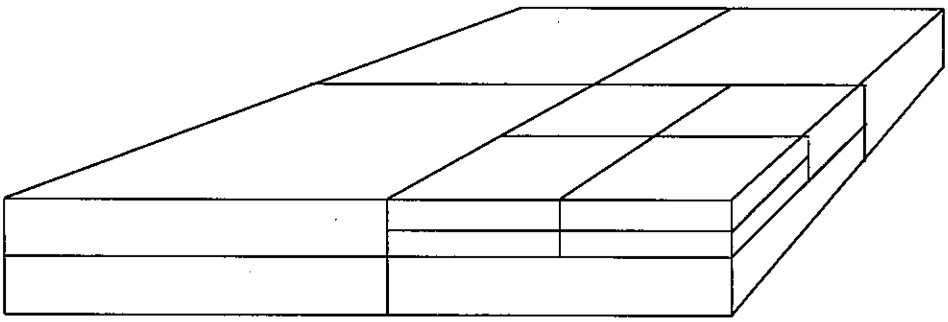

**Fig. 2 Hierarchical data structure formed from the recursive tessellation of nested 3D tiles**

Note: Separated, though jointly geo-referenced, constructs would exist for individual marine areas. For data allocation, different tile sizes would accord to different marine parameters according to an agreed variability index for that parameter

## Current situation

To analyze the current situation of GIS applications in fisheries resources research, 130 papers presented during the recent "First International Symposium on GIS in Fishery Science" held in Seattle, USA (March 2-4, 1999), were carefully reviewed to classify them into several categories. As a result, they were classified into four specific categories, i.e., (a) presentation (mapping) of parameters related to fisheries resources, (b) fisheries oceanography and ecosystems, (c) geo-referenced fish resources assessment and analyses and (d) space-based fisheries management. The area in these four categories covers the global oceans. Outline of these four categories is as follows: "Presentation of parameters related to fisheries resources" refers to the construction of distribution maps of parameters from fisheries and oceanography such as catch, fishing effort, temperature, etc. "Fisheries oceanography and ecosystem" refers to research relating to spatial relationships among fish, fisheries, oceanography and ecology. "Geo-referenced fish resources assessment and analyses" refers to the numerical spatial analysis and assessment of fisheries resources and fish population abundance. "Management" refers to

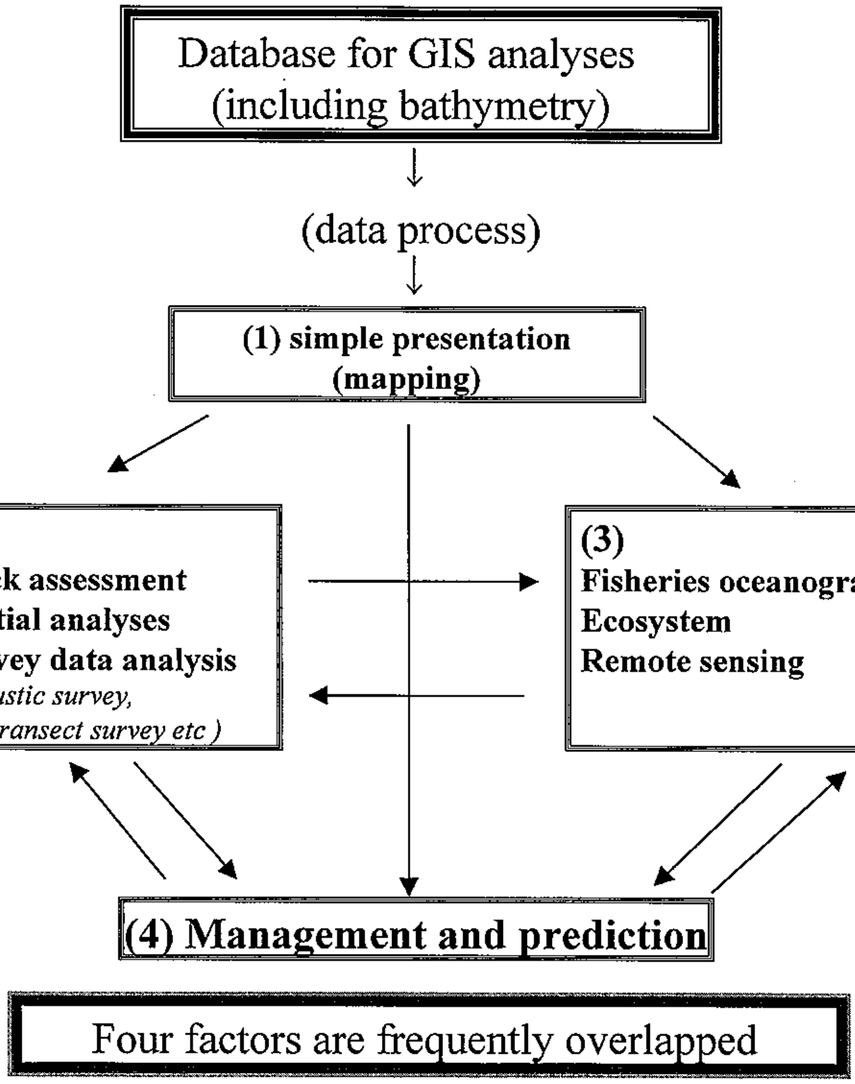


**Fig. 3 Relationship among four types of spatial analyses using GIS in fisheries resources research**

monitoring of fishing vessels by fisheries managers, decisions about time-area closure of fisheries, by-catch and ecosystem management. Fig. 3 depicts the relationship among these four categories, which overlap and are interrelated. Further concrete descriptions and case studies of these four categories are presented and introduced.

## 1 Presentation (mapping)

Simple mapping to study habitat and biodiversity of aquatic animals is the most basic and common research area to which marine GIS work has been applied over a long period of time because it requires relatively basic and fundamental techniques, which allow even beginners in GIS to conduct the necessary spatial analyses. Hence, a large number of papers dealt with studies relating to research on essential habitats and biodiversity. Some studies here dealt with just simple mapping. In the Fishery GIS Symposium (and elsewhere), it was sometimes suggested that basic mapping should not be considered as GIS. However, in a broad sense, univariate mapping is a basic GIS component because advanced GIS analyses are conducted by integrating, or manipulating, such univariate parameters. For example, the paper by Ali *et al.* (1999), showed that GIS can effectively map acoustic survey data to indicate waters with abundant fish resources. Even if a simple map is produced, the estimated contours were derived by a complex kriging process. By overlaying the resultant map with, for instance, bathymetry, further insights may be gained into aggregated factors concerning waters with abundant fish resources. This illustrates the value of many basic GIS mapping techniques, and therefore the simple map can be rightly defined as a valid GIS product.

There were also a number of papers dealing with Essential Fish Habitats (EFH), *e.g.* Brown *et al.* (1999), Nishida and Miyashita (2000, in press) (Map 1, as an example), Parke (1999) and many others.

These areas of research will become gradually more important topics in fisheries management, especially in the USA, due to the 1996 re-authorization of the Magnuson-Stevens Fishery Conservation and Management Act requiring amendments of all U.S. federal fisheries management plans to describe, identify, conserve, and enhance EFHs. The designation of an EFH will involve the characterization and mapping of habitat and habitat requirements for the critical life stages of each species. In addition, threats (including damage from fishing gear) to EFHs need to be identified, and conservation and enhancement measures must be promoted. GIS technologies will be essential for the successful implementation of this new fisheries management target, particularly in the initial characterization of habitat, the spatial correlation of potential threats with habitat, the evaluation of cumulative impacts and the monitoring of habitat quality and quantity.

## 2 Fisheries oceanography and marine ecosystems

Fisheries oceanography and marine ecosystems refer to the research area related to spatial relationships among fish, fisheries, oceanography and marine ecology. Thus, knowledge obtained through these studies will be useful to implement "Responsible Fisheries" and fisheries management effectively. "Responsible Fisheries" was adopted through the UN/FAO's "Code of Conduct for Responsible Fisheries (1995)." Since this adoption, the world's fishing nations are presently gradually adopting practices for promoting sustainable fisheries, protecting the resource base, and maintaining ecosystem health. In this section, three research areas are introduced, *i.e.* "Fisheries vs. marine ecosystems", "Migration dynamics and monitoring" and "Remote sensing."

### 1) Fisheries vs. marine ecosystems

In four papers, the relationships between fisheries and ecosystems were analyzed using GIS. The study areas and authors here were: Georges Bank (USA) by Edwards et al. (2000, in press), Gulf of Mexico by Vidal (1999) and others. In all the papers, it was indicated that GIS is still in the developing, pilot or planning stages. Thus, the results were presented in draft or preliminary formats. A prominent paper was entitled: "Ecosystem-based management of fishery resources of the Northeast shelf ecosystem: evidence from GIS analysis of fishery and environmental data on Georges Bank" by Edwards et al. (2000, in press). Here, GIS was used to display and analyze spatial data for investigating ecosystem-based management of fisheries resources. Distributions of species, fishing effort and landing revenues based on 10-minute squares over Georges Bank during a 3-year period were spatially analyzed. Similar maps of fishing effort by gear (*e.g.* fish trawl, scallop dredge) suggest the scope for likely by-catch. An indication of the economic importance of the groundfish closed areas to other fisheries, especially to the Atlantic sea scallop fishery, is suggested by revenue coverages. GIS could well handle the spatial analysis of ecological, technological and economic relationships, and could facilitate reviews of management plans for their consistency with ecosystem requisites (Map 2).

The objective of this research is to determine whether the management of marine fisheries resources in the Northeast region of the United States is consistent with ecosystem-based management for aggregate sustainable yield of commercially valuable species. An essential component of this study is a clear understanding of the spatial distribution of interactions among species, fishing effort and technologies and markets for fisheries products. It is concluded that GIS will be the only tool for such complex spatial analyses and the research is now progressing with this particular objective.

An interesting GIS area to be developed in the future is the linking of ecosystem-fisheries research with the use of Ecopath software (Pauly *et al.*, 1999). Ecopath can handle numerical evaluations of ecosystem impact of fisheries and can conduct simulations of dynamics among ecosystem elements (trophic interactions in the food web) to provide an overview of the mechanism of marine ecosystem changes depending on fishing effort. If the results of the simulations could be visualized by GIS, more comprehensive spatio-temporal changes of ecosystem members could be portrayed, *e.g.* changes of biomass, consumption and production rates, diet composition, habitat preferences, movement rates, etc.

**2) Migration dynamics and monitoring**

A few papers dealt with migration dynamics and monitoring using GIS, *i.e.* Saitoh *et al.* (1999) and others. Migration is an important factor in the marine ecosystems where the distribution of marine aquatic living resources is concerned, because of the application of the precautionary approach towards conserving fisheries and the environment, and also because of its relationship with EFH. Specific examples here included the definition of habitat profiles for pelagic, highly migratory species and a recent, ongoing attempt to characterize the riparian habitats of anadromous species on a watershed scale. Some monitoring data can be obtained by satellite remote sensing. Thus, Saitoh *et al.* (1999) studied the migration dynamics of the Japanese saury by investigating the relationships between oceanic conditions and saury migration patterns through the observation of the movement of pursuing fishing vessels obtained from satellite imagery. The results of overlaying of sea surface temperature (SST) data, with fishing boats movement along the Oyashio front clearly indicated the migration dynamics of the Japanese saury.

**3) Remote sensing**

Three papers on remote sensing dealing with ecosystem effects of fishing using GIS applications were presented. Kiyofuji *et al.* (1999) studied the spatial and temporal distribution of squid fishing boats using visible images from the Defense Meteorological Satellite Programs (DMSP) and from the Operational Linescan System (OLS). The relationship between SST obtained from NOAA/AVHRR and fishing boat distribution was also investigated. The preliminary conclusion was that by applying marine GIS, visible images using DMSP/OLS can provide both the position where fishing boats gather and the relationship between fishing boat location and SSTs.

Another interesting study showed the power of GIS when combined with remote sensing techniques. The paper by Sampson *et al.* (1999) provided a numerical assessment of kelp biomass off the West Cape coast of South Africa. High concentrations of kelp occur along this coast in relatively pristine conditions. In recent years, the importance of this resource has been emphasized in relation to its use in alginate extraction and as a commercially highly valuable food source for abalone. There is therefore a distinct need to manage this resource, including obtaining estimates of absolute biomass. Past biomass estimation methods had been based on the manual tracing of infrared aerial photography. The Sampson paper presents a comparison between the past photographic (qualitative) method and a new quantitative method based on GIS. The biomass of kelp beds from six areas ranging between 5 and 8 kilometer in length was calculated using a GIS, *i.e.* after being digitally scanned from the photographic aerial images. Results showed that the biomass of surface kelp had been overestimated, on average, by 230 % using the old methodology. The GIS method based on remote sensing inputs, proved to be a more successful tool in mapping and estimating the biomass of the kelp and it is in the process of being modified to model the amount of alginate and abalone that can be produced per annum.

## 3 Geo-referenced fish resources assessment

It has long been recognized that all the fisheries data have a spatial component. Few attempts, however, have been made to incorporate the inherent spatial variability of a stocks' age-structure, maturity, selection or growth patterns and commercial catch data into a stock assessment framework, or to move further into the forecasting area. This aspect is important as commercial catches are all geo-referenced, with fish being harvested at a specific geographic location as a function of the fishing effort and stock density at that location. By neglecting this spatial component, existing stock assessment models evaluate the status and productivity of the stock based on lumped or pooled catch-at-age data, fisheries independent survey indices and key population parameters.

Currently, there is a growing interest in the development of marine GIS, both to visualize these spatial data sets and to provide a platform for further stock assessments and forecasting. As a result, a GIS incorporating spatially referenced fisheries data and assessment models would contribute significantly towards integrating this with other data sources and providing quantitative and qualitative management advice, and therefore to consequently improving integrated resources management.

During the GIS symposium, a number of papers relating to geo-referenced monitoring, assessment and forecasting of marine ecosystems were presented - these can be briefly introduced and discussed. Corsi *et al.* (1999) described production model analyses using GIS for the determination of demersal fish resources in the Mediterranean Sea. They included spatial distributions of Catch Pen Unit of Effort (CPUE) and fishing efforts in the analyses. In the fishing effort data, distances between fishing grounds and ports, and also depth of the trawl nets, were taken into account in the analyses. For the age-structured model, Booth (1999) has been developing a simple per-recruit model to assess the panga, Pterogymnus laniarius stock in South Africa using GIS. Both papers are still in a developmental stage and further progress is anticipated.

There were several papers on population estimations from fisheries independent surveys using GIS. Nishida and Miyashita (1998) estimated southern bluefin tuna recruitment (age 1), using information obtained by omni scan sonar. In their approach, the precise size of the areas (waters) was evaluated by GIS. In the southern bluefin tuna study, they further detected a close linear relationship between the strength of the Leeuwin current into the survey area and the average school size as recorded by the sonar (Map 3 and Fig. 4). In the GIS, the strength of the Leeuwin current into the survey area was represented by areas having high SST gradients. This finding implied that young southern bluefin tuna schools were transported to the survey area depending on the expansion (strength) of the Leeuwin current into the survey area. Therefore, it was suggested that the estimated recruitment abundance needed to be standardized by adjusting for the strength of the Leeuwin current, so that an unbiased (accurate) recruitment abundance could be evaluated. This study also demonstrated the importance of GIS to assist in accurate population estimations.

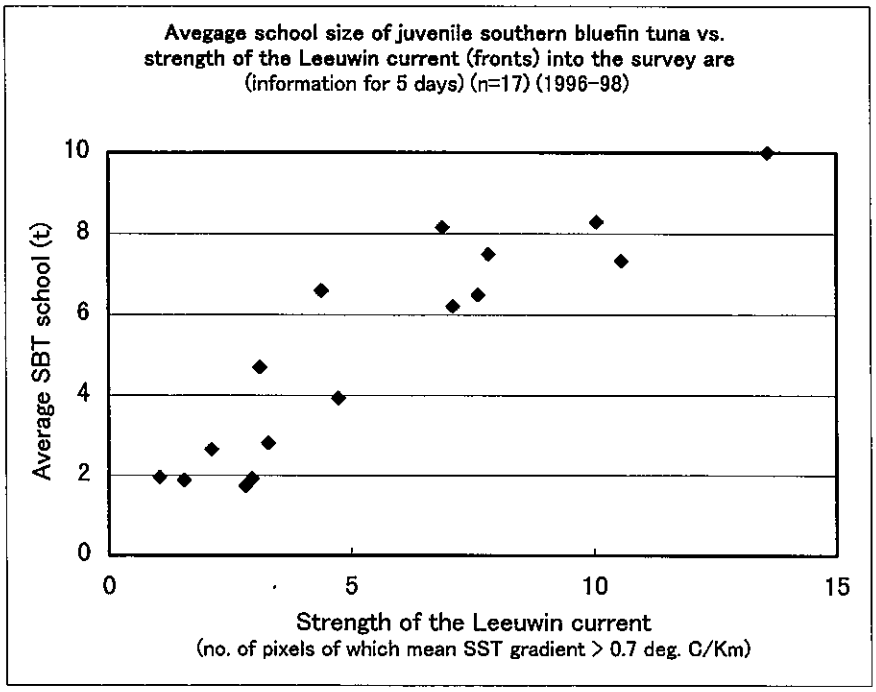


**Fig. 4 Relationship between the strength of the Leeuwin current into the survey area vs average weight of southern bluefin tuna school detected by the sonar survey**

For another example of GIS analyses for fisheries independent survey data, Ali *et al.* (1999) used scientific echo-sounders to investigate the fish resources. They used the line-transect method to estimate population and other ecological parameters. They further applied the kriging techniques available in GIS software in order to estimate densities based on the values of back-scattering Strength of Volume (SV). Then, the population in the whole water body was estimated by raising average densities in the survey area to the whole area.

Walden *et al.* (1999) combined GIS and a mathematical programing model to the multi-species demersal fisheries management in New England. In this method, spatial optimization is used in order to minimize the fishing mortality (F) for species at low stock level, and also to minimize the loss of fishing income. In this approach, the authors used 15' mesh (pixel) based on historical fisheries, and economic information by season in order to determine fine-scale time-area closures.

Warning *et al.* (1999) investigated the basic ecological characteristics of beaked whale (Ziphiidae) and sperm whale (Physeter macrocephalus) habitats in shelf-edge and deeper waters off the Northeast USA during summer using GIS. They used sighting data and corresponding information on bathymetry, slope, oceanic fronts and SST. Such digital data were extracted from the GIS maps, then standard statistical analyses (logistic regression analyses) were conducted. As a result, it was found that the distribution of sperm whales was more dependent on depth and slope, while that of beaked whales more on SST.

## 4 Space based fisheries management

### 1) By-catch management

Research using GIS into by-catch mitigation is an advanced and successful topic, although the number of case studies are limited because either GIS is not widely known in this field and/or user-friendly software is not available. Therefore, if more efficient software were to be developed, a large number of applications could be expected in the future because by-catch mitigation is arguably the most urgent and serious issue in world fisheries. From three papers on by-catch, we can now specify (even pinpoint) the habitat areas of by-catch species on a fine spatio-temporal resolution. The paper by Mikol (1999) displays by-catch information from 7 fishing vessels for catching Pacific hake off the Pacific Northwest US coast off Washington and Oregon. Fishermen now have GIS on some vessels and they can identify good fishing areas to best avoid by-catch.

The paper by Ackley (1999) used GIS to manage Alaska's groundfish fisheries by-catch. This was a superb graphics presentation of time-area closures necessary to minimize by-catch of four species (red king crab, blue king crab, chinook salmon, and chum salmon) in the Bering Sea groundfish fisheries. Map 4 shows one of the resultant maps. This GIS-based technique was applied as part of fisheries management procedures by the North Pacific Fisheries Management Council.

However, some problems have been pointed out. Because the time-area closure to mitigate by-catch is based on the average distribution patterns of these species, effective closure areas sometimes differ depending on the year, *i.e.* due to annual variations of the environmental conditions, and in areas that lacked sufficient information, it was reported that closure would sometimes be ineffective. The use of GIS in management issues here needs to be further evaluated by incorporating annual physical oceanographic information (such as temperature, and currents) plus depth, although it is already obvious that some of the closed areas are best associated with specific gyres. In conclusion, careful consideration is necessary to establish geographically fixed closure zones in a dynamic environment.

### 2) Monitoring and management of fishing effort

Because enforcement of fishing effort is a direct way to mitigate fishing impacts on the marine ecosystem as well as fish resources, fisheries managers have been giving some priority to monitoring the locations of fishing vessels. With this in mind, GIS software which allows for GPS integration to an on-board computer has been developed and was demonstrated during the GIS Symposium. Some GPS capability is used by fishermen for relocation to good fishing grounds by analyzing historical data using GIS (Simpson *et al.*, 1999). This is an interesting field in which GIS will be developed for use by both fishermen and managers, though obviously with each having different objectives.

## Software

GIS, as defined in many textbooks, is an information system that works specifically with spatial data and consists of a chain of operations from planning of the observations, to collection of the data and to the management of these data for decision-making. A GIS, therefore, consists of various separate yet interactive components, each dealing with spatially referenced data sets. These components include a database facility, a visualization platform and a series of analytical tools. Unfortunately, few GIS software packages comprehensively satisfy this definition. While GIS software contains extensive databases and high quality graphical output, few systems have progressed beyond simple geostatistical analysis and Boolean logic-based overlaying and buffering procedures.

GIS software, in particular for fisheries resources research is far behind that for terrestrial systems as there is no specific software that can efficiently handle fisheries information and its analytical demands. This limits the GIS potential and restricts the applications in fisheries resources research. If we could successfully develop user-friendly GIS software that can be operated without requiring any programing, and that can also handle unique information of fisheries and oceanography and necessary analytic aspects, more advanced research and case studies could be conducted in the future. Fortunately, movement towards this objective was observed in the Fishery GIS symposium. If such high-performance software for fishery science were well developed, scientists or managers could quickly complete analyses, then spend more time on feedback between the interpretation of results and re-analysis, which is the more important task. Decision- making would then be greatly enhanced.

An important point to note is that since the GIS software predominantly used in fisheries resources research is designed for terrestrial-based applications, it is often inappropriate for handling information relating to fisheries, oceanography and bathymetric data. This is because these types of data have unique features and different qualities compared to the terrestrial data, *i.e.* "limited quantity of information", "4-dimensional information (3D + time) that makes mapping difficult", "difficulty in handling information due to mixture of quality of vector and raster data" and "necessity to estimate contour such as density of fish resources and environmental factors such as temperature." Therefore, it is necessary to develop user-friendly software that can handle such information.

In fact, more than 95% of the papers presented during the Fishery GIS Symposium used terrestrial GIS software, which was primarily operated by GIS specialists. In general, in many countries, budgets are usually limited for hiring such GIS technicians except in a few countries such as USA, Canada and others. Thus, researchers and scientists have to learn the use of complex terrestrial GIS software, which requires time. Where budgets allow, in many cases GIS consultant companies are hired to build specific applications. However, such an approach has problems because of the huge cost and such applications can not be widely and commonly used by others. Such a situation seriously delays the use of GIS in fisheries resources research in general.

At present, there are few (terrestrial) specific software packages that can handle fisheries and oceanography data. These software packages focus on and specialize only in specific functions such as simple presentation, navigation systems (electrical charts), satellite data processing, contour estimation, database, vertical profiling for oceanographic information, bathymetry mapping, etc. Although they are well developed, there is no practical GIS software that incorporates all these specific functions into one system. Such integrated GIS software would be ideal and is required for fisheries application. It is not practical to change the GIS software, whenever we conduct different types of specific spatial analyses. In addition, such software needs to be used for conducting spatial numerical analyses and modeling which are linked to stock assessments, plus simulations and ecosystem management. Furthermore, such software must be user-friendly and ideally would run without requiring any programing because fisheries scientists in many countries have no funds to hire GIS specialists and they cannot spend time on programing themselves. In the software demonstrations at the Fishery GIS symposium, some moves satisfied such requirements, although they were still in the developmental stage, *e.g.* Kiefer *et al.* (1999) and Itoh (1999). Fig. 5 shows the outline of the marine GIS (Marine Explorer) developed by Itoh (1999) and National Research Institute of Far Seas Fisheries, as one example of GIS software for fisheries and oceanography.

## Prospects and summary

We are responsible for developing spatially oriented management methodologies because the simple traditional concept of the pooled single-stock Maximum Sustainable Yield (MSY) or Total Allowable Catch (TAC) is very limited. Management measures need to be applied in space and time along with considering ecosystem implications, by-catch, multi-species interactions, socio-economic factors of fisheries, etc. In that way, responsible fisheries can be pursued, along with securing protein sources that may be able to mitigate food crises expected in

**Table 2 Major prospects (challenging areas) for future GIS application in fisheries resource research by subject (Summary of this paper)**

**Data**
* Standardization of data collection structures (adjustment of discrepancies in space or time)
* Conversion of analog data to digital data
* Consolidation of data gathering and databases
* Automation of data collection
* Establishment of simple database linked to GIS platform
* Consideration of 3D or 4D database for the GIS
* Development of easy method to access oceanography and satellite information
* Development of easy method to process matrix (raster) information

**Presentation**
* Application of enhanced visualization to fisheries GIS
* Effective and easy way to present 3D and 4D parameters of fisheries and oceanography
* information such as catch, CPUE, temperature, salinity, etc.

**Stock assessment, prediction and spatial numeral analyses**
* Development of linkage 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 system using GPS and VMS
* Fisheries impact assessment (development of space-based stock assessment)
* Spatial allocation of 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 mappings as well as complex integrated spatial (numerical) analyses

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

the beginning of 21st century. It is certain that such ecosystem management schemes for responsible fisheries will be very complex, as we observed in the papers presented during the Fishery GIS symposium. However, GIS, especially if all the necessary functions are integrated for fisheries and ecosystem research will be the only tool capable to handle such complex tasks.

Therefore, integrated ecosystem fisheries management is likely the most important and challenging area for future GIS in fisheries resources research. However, there are many other important aspects to consider for future GIS application in fisheries resources research. Table 2 outlines the prospects (future fisheries GIS) by subject, which are primarily based on the discussion made in this paper. Now, we know the prospects or the orientation for future GIS in fisheries resources research. Table 2 is also presented as a summary of this paper.

Some prospects are achievable in the immediate future, while some, in the long run. Clearly some of the challenges are intrinsically interrelated and therefore difficult to separate and it is of little relevance to attempt to compartmentalize challenges between inland, coastal and marine fisheries. Obviously there is a hierarchy of challenges such that some of them will only affect a minority of activists in this field, and some are likely to be more or less easily overcome.

It is the authors' hope that this paper can contribute to promoting more fisheries scientists, biologists, managers, fisherfolk and educators to apply fisheries GIS for sustainable utilization and management of our fisheries resources effectively, while we preserve the ecosystems.

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*Note*: 'GIS Symposium' is the abbreviation for 'Abstract booklet (proceedings), First International Symposium on GIS in Fishery Science, Seattle, Washington, USA, 2-4 March, 1999'

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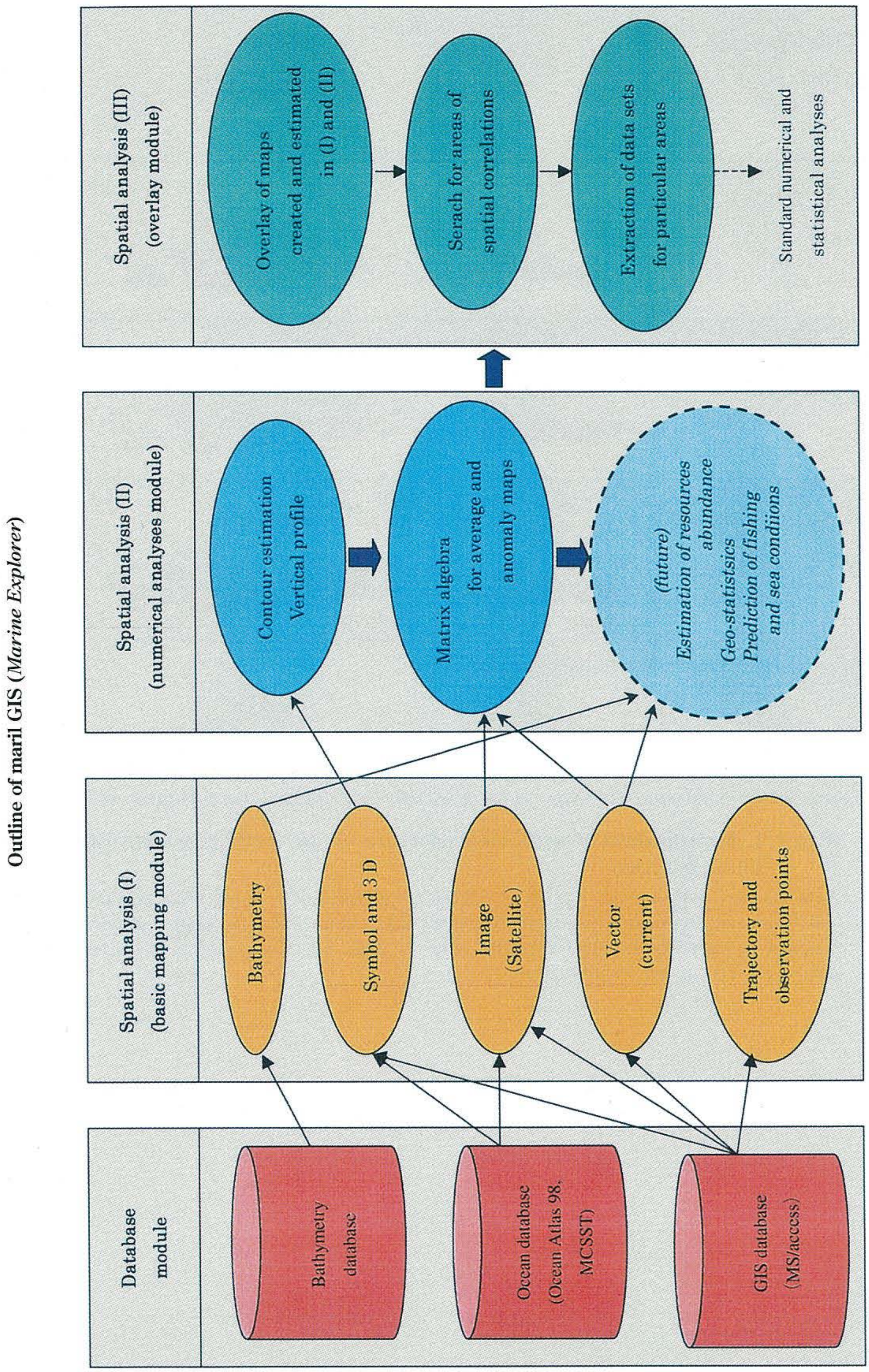
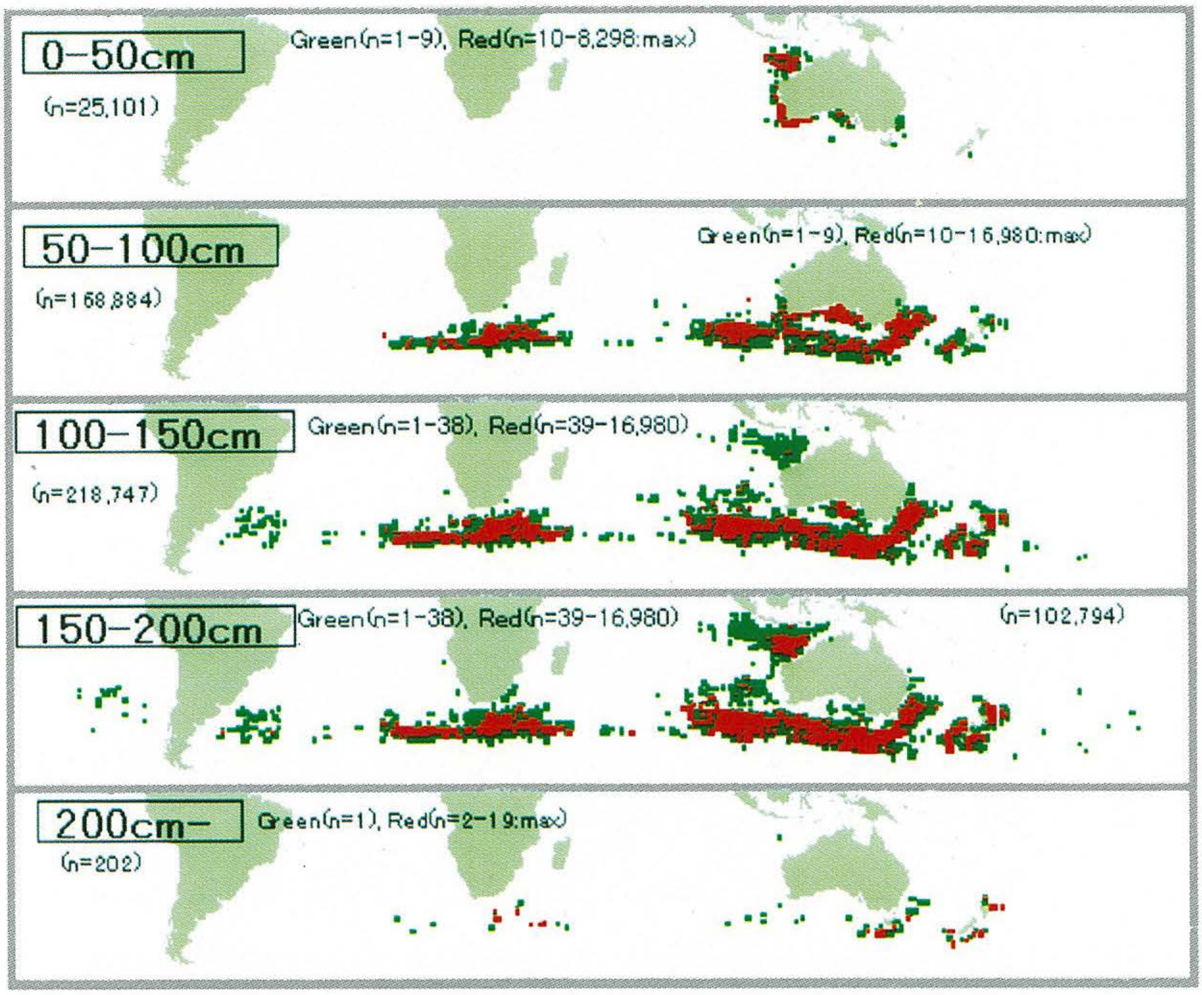
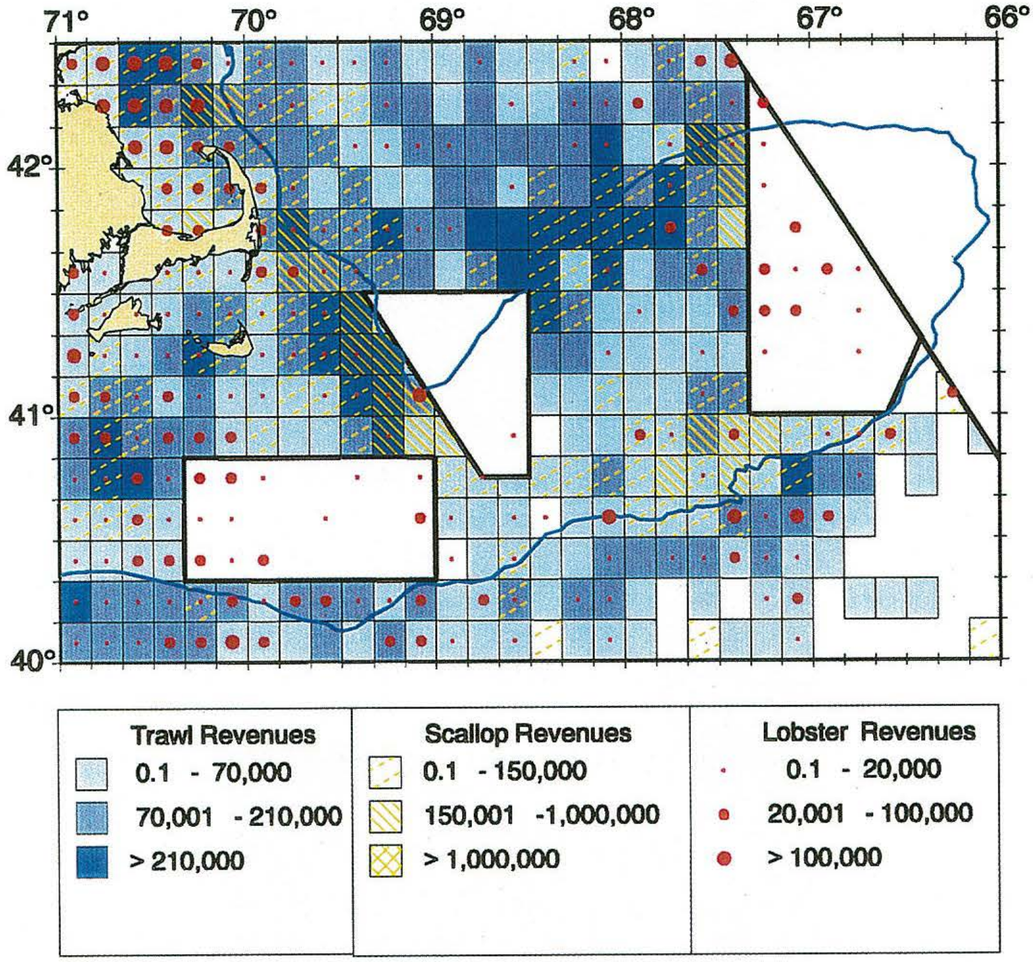



**Fig. 5 Outline of the marine GIS (Marine Explorer) developed by Itoh (1999) and National Research Institute of Far Seas Fisheries (Japan), as one example of GIS software for fisheries and oceanography, which runs by the pull down menu without any programing**



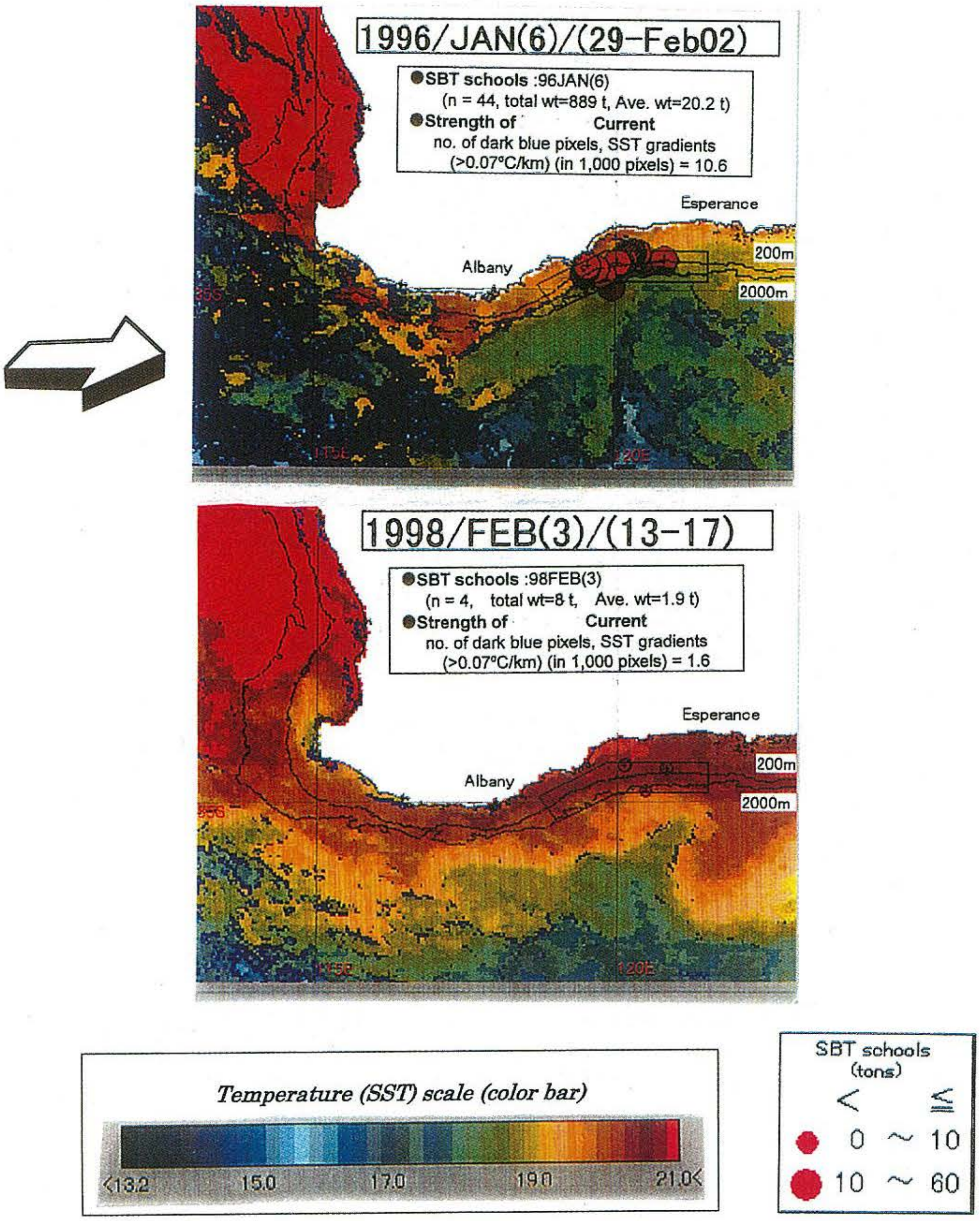

**Map 1 Essential habitat of southern bluefin tuna by size (Nishida and Miyashita, 2000, in press)**

Note: (1) pixel = 1° sq. area, (2) Green and red pixels represent 1° square areas with smaller and larger sample sizes (n) respectively. Nearly the same numbers of green and red pixels were assigned for each sub-map, (3) 0 cm (fish) refers to eggs, (4) Size range (*e.g.* 50-100 cm) is defined as 50 cm ≦ fork length<100 cm.

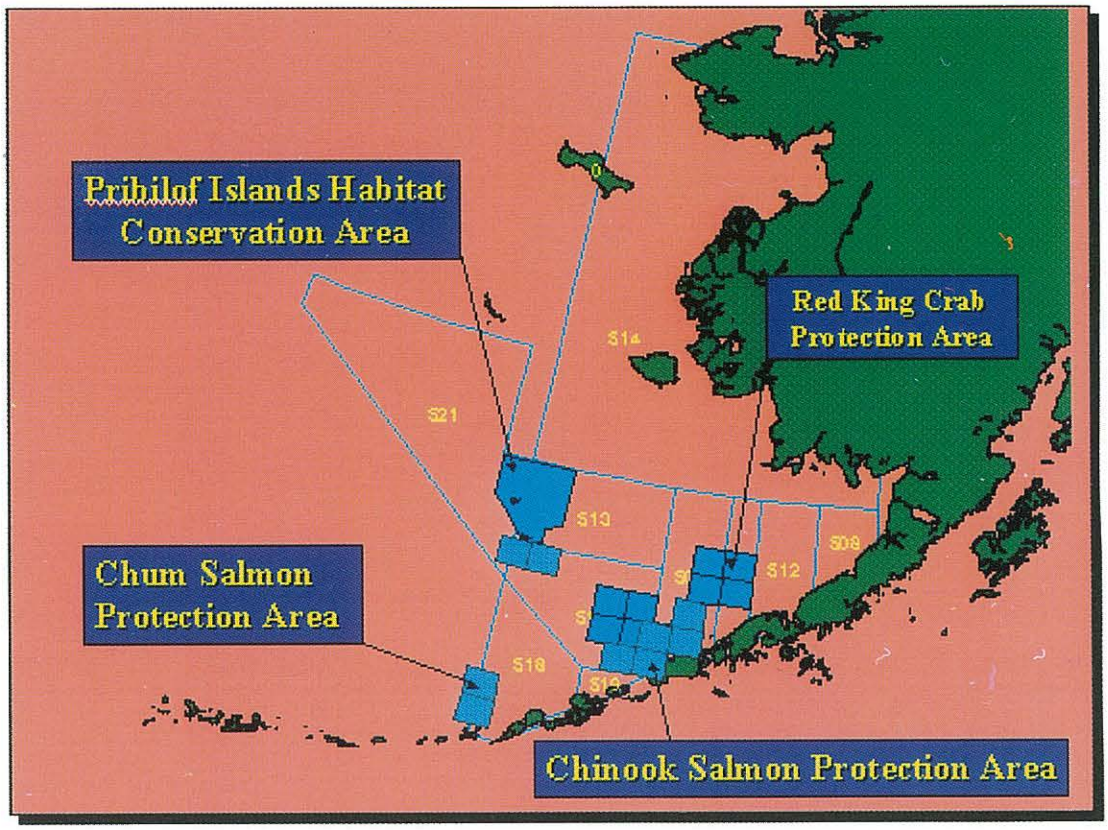



**Map 2 Average annual harvest revenues during 1995-1997 based on 10-minute squares: (a) harvest of Atlantic cod, haddock, and yellowtail flounder with bottom trawl gear; (b) harvest of Atlantic sea scallop with scallop dredge gear; and (c) harvest of American lobster with lobster pot gear**

Note: Three blank zones refer to closed area for trawl and scallop fisheries.




**Map 3** **Maps showing SST, its gradients and locations of southern bluefin tuna schools found during the sonar survey off Western Australia. SST gradients (blue dots) were taken to represent the expansion of the current into the survey area. SST, its gradients in 5-day averages and schools (red solid circles) found during the same time period in the survey area (in the black boundary), were overlaid. These two maps represent the two extreme cases in three years' survey (1996-98), *i.e.* above: the strongest expansion (29 Jan. - 2 Feb., 1996) and below: the weakest case (13-17 Feb, 1998). Average school sizes are considered to be proportional to the expansion (strength) of the current into the survey area.**




**Map 4 By-catch management : Established protection areas of Alaska's groundfish fisheries by-catch (four species) based on the GIS analyses using some 20 years of fisheries data**