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# Visualization for fisheries management from a spatiotemporal perspective

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Visualization is a very potent tool in the provision of decision support in fisheries information systems. Fisheries management involves distinct groups of participants with a common purpose but different perspectives on strategies to be pursued and the information required for effective management. This paper discusses the visualization capabilities of FishCAM2000 (FC), which is a computer-based integrated information system for fisheries management and marine environmental monitoring. The design of FC is modular, and comprises a real-time, on-board data capture component, resource management, and analysis modules for fishermen, regional and national fishery managers, plus modeling and analysis toolkits for scientists involved in longer-term stock prediction. In developing FC, particular attention has been paid to structuring the system's architecture so that a range of visual spatiotemporal graphics can be produced by all groups of users. It is also necessary to link the base data set derived from the mandatory logbook data to other marine data sets for biotic and abiotic variables to enable multivariate modeling and analysis of the marine environment. The visualization capabilities of FC are an integral part of all the analytical functions.



Keywords: fisheries decision support system, marine environmental analysis, resource management, spatiotemporal visualization.

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## Introduction

The analysis of oceanographic phenomena and activities involves several techniques including visualization of information at various spatial and temporal scales. The ever-increasing popularity and use of geographical information systems (GIS) and proprietary graphics and visualization systems is, in part, due to the sophisticated capabilities they provide for displaying georeferenced data in two and three dimensions (ESRI, 1996; Chen *et al*., 1999). Customized applications based on such systems have been used in many marine information and analysis systems to gain insights and understanding of the ecosystem being studied (Ault, 1996; Hatcher *et al*., 1997; Garibaldi and Caddy, 1998; Megrey and Hinckley, 2001).

The research described here concentrates on providing a flexible and integrated framework for management and decision support required by the different groups of users involved in fishery activities. In the rest of this section we explain the rationale for a visualization system that is closely integrated with the data management functions.

### Rationale for an integrated system

In the world's commercial fisheries, the situation has now been reached where there are few unexploited stocks and many of the traditional fisheries are being utilized at a rate that is unsustainable (Grainger and Garcia, 1996). It has been noted that: "... Projected increases in demand, future prices for fisheries products, and impacts of growing world populations on the ecosystem all require an urgent search for improved management frameworks ..." (Caddy, 1999). To demonstrate the potential of such an enhanced management and decision support framework, we have designed and implemented the FishCAM2000 (FC) prototype system.

FC has been designed as a computer-based integrated information system both for fisheries management and for a range of associated marine environmental modeling (Kemp and Meaden, 1998). A core principle underlying FC is that an effective management framework should seek to engage all the groups involved in fisheries and the management thereof. Within the European Union (EU), quota decisions are made for each species in each International Council for the Exploration of the Seas (ICES) fishing area (Holden, 1994). However, the scientific basis on which the stock assessments are made is liable to have a considerable margin of statistical error as the catch data used is generally recorded at a resolution that is too coarse to provide valid or reliable information. Obviously, catch statistics themselves do not reveal what stocks remain in the sea, but they give a reliable indicator of the accuracy of previous survey assessments and also have the potential to generate other meaningful data relative to actual fish dispositions. The base data set in FC, generated by and of interest to fishers, consists of fishing activity data captured in real-time. Georeferenced and temporally referenced data are recorded for each trip, as are trawls within trips and catch and discard data by species. The spatial and temporal resolution of this data is fine enough to provide the basis for future analyses by various groups. Associated data for management of fishing activities such as type of gear, ports of departure, arrival and registration, and quotas are also included in this data set. They provide useful onboard information as well as subsequent feedback for decision making by fishers. This core data set is augmented for fisheries resource managers and marine scientists by data about management zones and fishery policies, as well as data required for more exploratory research originating from instrumentation on survey vessels and, for instance, from satellite imagery. The effectiveness of the visualization functionality in FC arises from the close coupling with the data retrieval and analysis functions (Li and Saxena, 1993).

## Salient characteristics of the system

The flexible data subset specification capabilities of FC enable users to determine the content of the visualization on the fly. Fishermen, resource managers, and scientists have different space–time perspectives. The trends and statistics they wish to derive from the information base are specified as part of the visualization module interface. Sustainable fisheries depend on short and long-term investigations of the complex ecosystem. Analyses require data relating to the harvesting of the resources, referenced spatiotemporally, as well as the longer term physical and biological processes that influence the abundance, or otherwise, of fish stocks. For example, if a study focuses on the diurnal and nocturnal movements of planktonic forms, the temperature data would be aggregated into daily slices, whereas if the requirement were to consider seasonal trends, then the temperature values would be considered at a different dimension of the space–time composite (Kemp and Lee, 1998; Lee and Kemp, 2000).

The requirement to integrate data from multiple sources has been reported by several researchers (Panzeri and Morris, 2000; Su, 2000; Varma, 2000). The prediction of fish stocks and sustainable levels of each species, which in turn determine appropriate management policies, are based on complex interconnected calculations. Effort and catch per unit effort (cpue) can provide indices related to fishing mortality and density of exploited stock (Gulland, 1969; Hilborn and Walters, 1992) but there are various other factors that need to be considered in arriving at standardized fishing effort data: effective fishing time, fishing power, and the spatial distribution of the fishing effort.

From the spatial perspective, visualization functions have to cope with a range of underlying representations. Due to the different requirements of user groups, various spatial representations are used and spatial areas of interest can be denoted in different ways. A geographic area of interest may be denoted descriptively, e.g. "North Sea", "Irish Box" or by specifying the relevant bounding coordinates. On the other hand, scientists and researchers who focus on specific environments, such as pelagic and demersal habitats, are interested in the space occupied by these ecosystems. The characterization of "space" in this context is not a straightforward set of georeferenced values but determined by variables such as depth in the water column, distance from coast, type of sea bottom, temperature, salinity, and life cycle characteristics of the organisms within the ecosystem.

Analogous to the multiple spatial specifications, temporal specifications for visualizations and their underlying representations also vary. For example, fishermen may wish to investigate the most profitable trawls over specific time intervals, or resource managers may wish to monitor catch per species during different seasons. Simulations of the ecosystem can generate more complex temporal requirements (Lhotka, 1991; Brandt *et al.*, 1996; Laevastu, 1996). Various models for simulating fish species or the biomass as a whole are calculated in seasonal steps using trophodynamic equations, and input consisting of consumption by marine mammals and harvesting by humans. These calculations over time have to be further modified by the effects of physical phenomena, such as the El Niño southern oscillation and its effect on tuna abundance, as reported by Lehodey *et al.* (1997).

Analytical visualization depends not just on the data captured by underwater and remote sensors but also on derived data sets generated by applying aggregation and/or algorithmic functions to the base data (Musick and Critchlow, 1999; Lucas, 2000). Consider the spatial types: the fishing activity data is captured as ordered

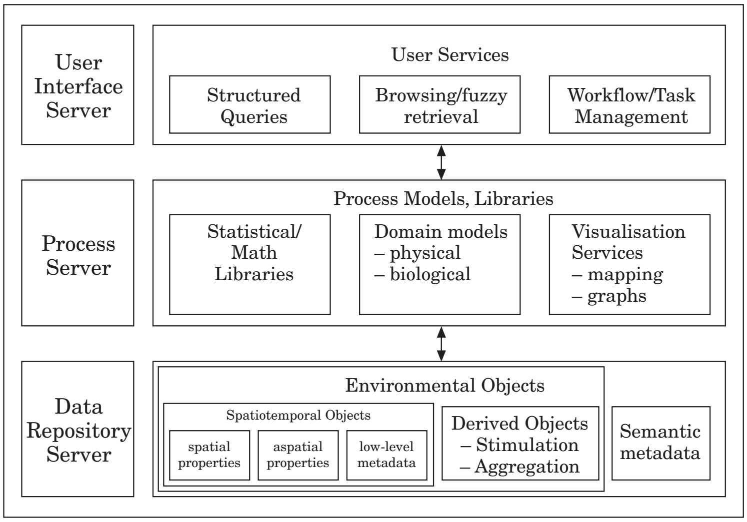


Figure 1. High level conceptual architecture of the component-based FishCAM2000 system.

sequences of point data along tow trajectories and is subsequently converted to gridded surfaces at resolutions that vary according to the analysis being carried out. Sea areas of special scientific interest such as spawning banks, or ecosystems such as coastal zones, are often specified using polygon topology, but need to be converted to a standardized surface format for comparison with other variables. Locations of sampling points for research stations or buoys, represented using point topology, are converted into surfaces using spatial interpolation functions such as kriging (Burrough and McDonell, 1998). Thus, managing a heterogeneous information base implies that transparent mapping between diverse data formats and viewing representations, must be provided for by the system.

# Methods

## System overview

The data management and visualization principles discussed above have been embodied in the design of FC. The system is modular, caters for the needs of different user cohorts and has visualization built in as an integral part of the data retrieval and analytical process. Figure 1 presents a high level conceptual view of the system. It shows the different process modules and data sets available and the functionality provided to access and visualize the data.

## The user interface

The design of the interface in FC:

(i) ensures that user groups have access to the data sets that are relevant to the visualizations they wish to carry out;
(ii) presents each category of user with a slightly different version of the interface depending on their category and the functionality required by that particular group;
(iii) allows functionality to be presented via simple graphical interfaces that prompt for required parameter values;
(iv) presents the functions available to the user via hierarchically structured menus to enable ease of use;
(v) provides a range of visualization mechanisms provided to enable users to produce maps to represent dynamic aspects of change and explore univariate data; and
(vi) makes assumptions about appropriate visualizations, i.e. how the data are presented, but the user has control over what data subset is visualized;

As an example of a typical user interface, consider the graphical representation of the interface for the primary producers, fishers group. The functionality provided is hierarchically structured as shown in Figure 2.

Note that only details of the query and visualization paths through the menu are shown as the other functions are outside the scope of this paper.

## Primary data input

To provide context for the examples in this section, Figure 3 presents a simplified conceptual scheme in the unified modeling language (UML) notation (Booch *et al.*, 1998), of the data set that is generated by the onboard task-based data capture module. The data consists of aspatial attributes such as species fished, vessel registration, gear, and so on, and details of fishing activity in the form of trip, tow and, catch weight by

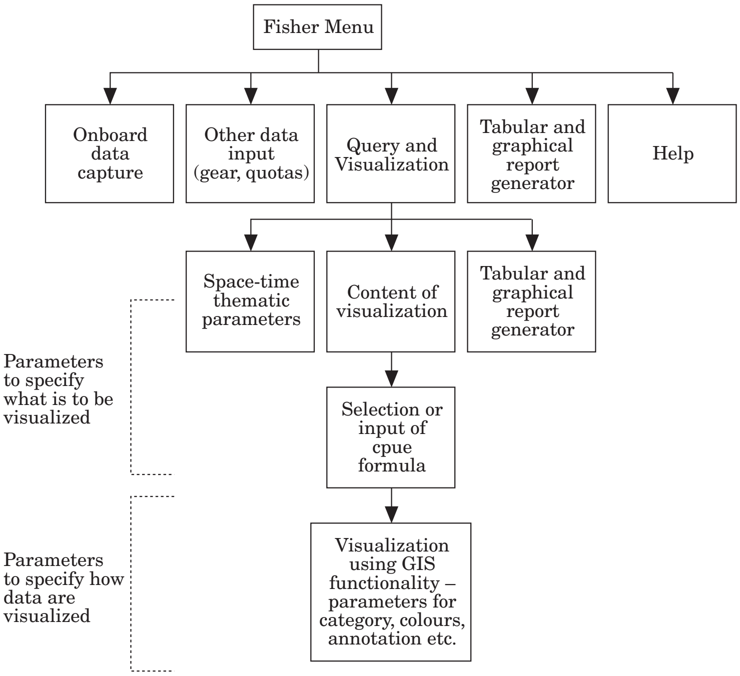


Figure 2. The conceptual hierarchy of the visualization interface.

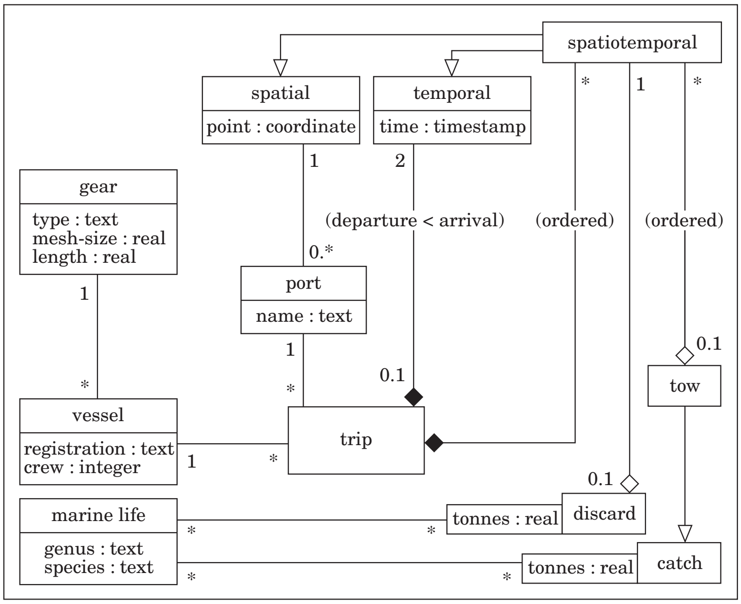


Figure 3. Conceptual model of fishing activity data set.

species. The movements of the vessel, and thereby indirectly all fishing activity, are spatiotemporally referenced using global positioning system (GPS) receivers. Although not included in the diagram, data regarding sales of catch are also included in the database.

The flexibility of the data subsetting capabilities can be demonstrated by considering the data retrieved as a multidimensional array or hypercube. Figure 4a shows an example where the retrieval request is for total catch of all fish species within the area specified by the bounding box defined by the coordinate pairs $bbox_{SW}$ and $bbox_{NE}$, and within the temporal interval $t_1$ and $t_2$. The resolution of the grid surface and content of each grid cell is determined during the user interface dialogue.

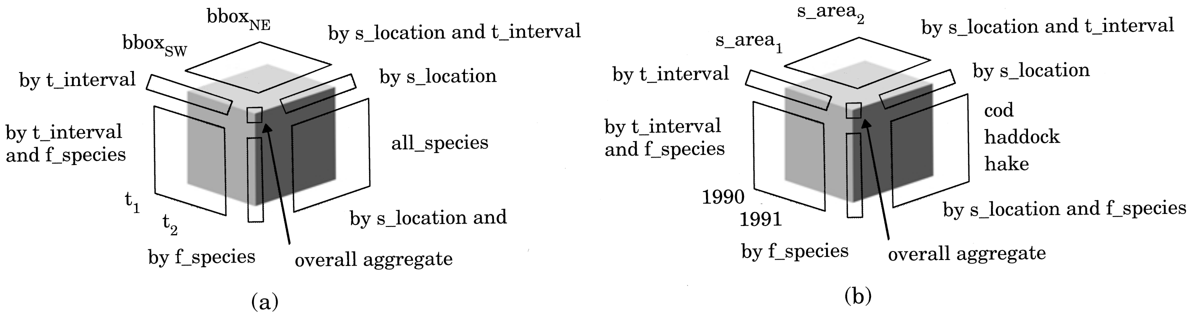


Figure 4. N-dimensional data retrieval.

If on the other hand, the multidimensional data subset requested was as conceptualized in Figure 4b, the visualization would consist of several maps, i.e. for each of the areas specified $s_1$ and $s_2$, for each time period, 1990 and 1991, and for each of the species, cod, haddock, and hake. In this case, FC would provide a suitable layout to highlight the comparison of the mapped measure in each dimension.

### Examples of user interface windows

Information systems developers have long contended that the user interface, rather than the computational functionality influences acceptance of a system by the user community. The design of the interfaces in FC strikes a balance between ease of use and provision of a rich set of functions that can be invoked. FC guides the user through the paths in the interface by prompting the user for required parameters. Figures 5a–c illustrate menu windows that prompt the user for the data parameters for the visualization of species, cpue measure and spatial extent of interest.

The user interfaces for the other groups of users are similar but consist of additional features. The regional and national fishery managers require aggregated data sets for their area in order to extract annual statistics and trends, flexibly by species, spatial extents, temporal intervals, and so on. In addition, they wish to determine appropriate management strategies for the future and evaluate those that have been previously implemented (Caddy and Carocci, 1999). Therefore, they have access to the fishing activity data sets as well as data defining spawning areas, prohibited fishing areas, and information about policies. The functionality provided enables them to produce visualizations to map trends in catch, against all the other dimensions of interest, and to support other aspects of their management tasks. For example, the functioning of EU policies controlling fishing effort can be evaluated by considering variables such as quotas and the effectiveness of closed areas/times by mapping fishing effort within the relevant space-time windows.

Fishery scientists have the most open-ended requirements for analysis and visualization. This group requires access to the data sets already mentioned as well as data from research cruises, data for primary production such as plankton abundances, environmental variables such as temperature and salinity, and oceanographic process models. In addition, as explained in the Introduction, access to standard geostatistical functions is also necessary for generating derived data sets, as well as for exploring observed data variables.

## Results

### Cartographic and graphical visualization of fishing activity

As a consequence of the design of FC and the functionality provided, the visualizations produced by the system support the different groups of users in their various tasks. Here, we provide examples of the output produced to illustrate the power and capabilities of FC.

Figure 6 illustrates the gridded surface map produced in response to the query conceptually illustrated in Figure 4a. Maps of this sort, where the user controls the dimensions and the measures of the display, help with decision making at several levels. The fisher group may use the system to support economic decision making. Maps can be used to evaluate where, when and which species were most profitably fished based on recent activity data. In this context, cpue calculations and associated visualization, enables different scenarios to be evaluated and future activities planned. Advantages of FC to this group also arise from the on-line, on-board data capture mechanisms. Recent trawl trajectories can be visualized in conjunction with catch data to determine where fishing effort should be concentrated. Quota management at a detailed level makes future operations easier to plan.

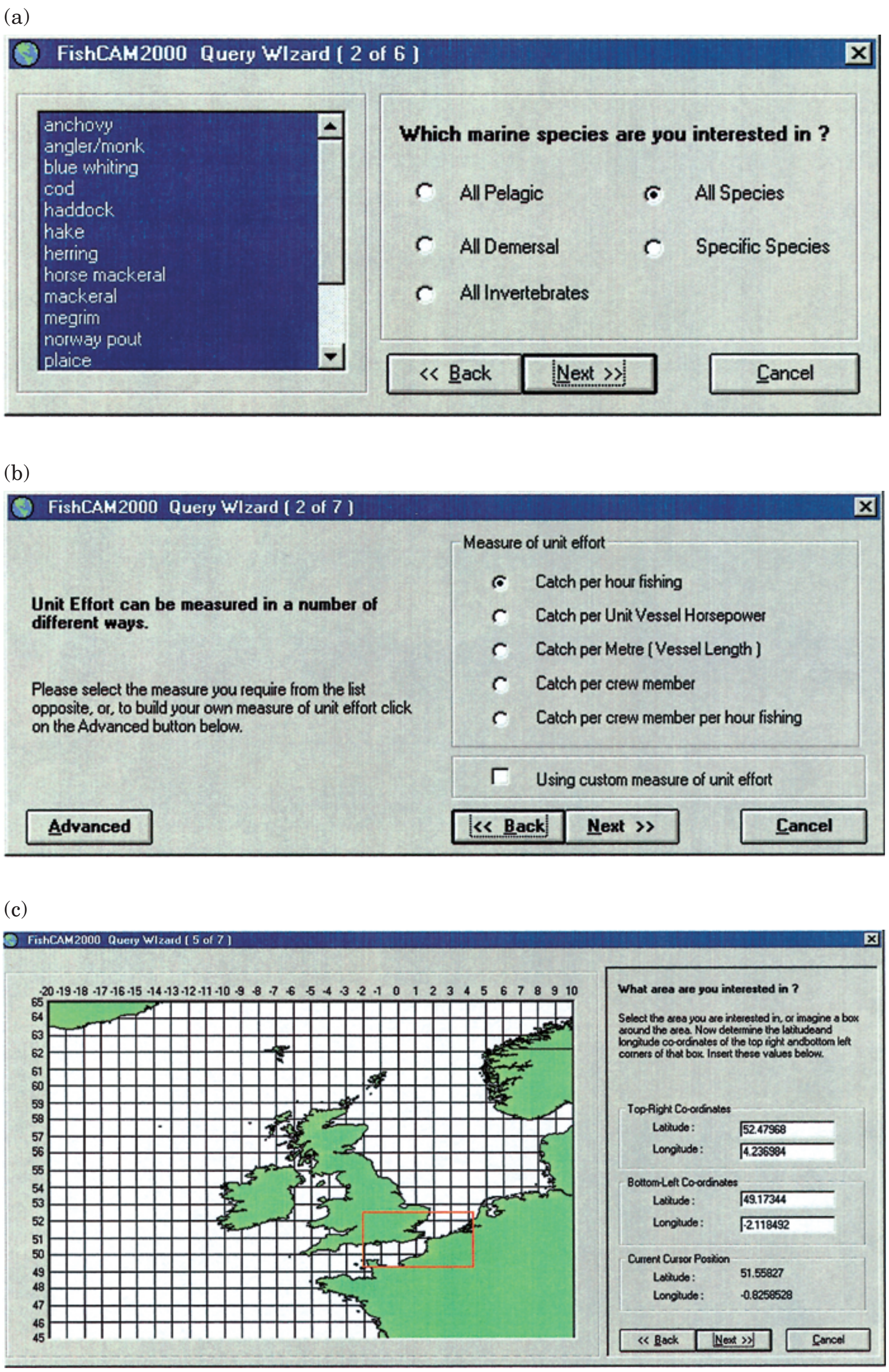


Figure 5. (a) Selection of catch measure (species category). (b) Selection of cpue algorithm. (c) Selection of spatial extent.

Figures 7 and 8 illustrate the use that regional managers and fishery scientists can make of the primary activity data sets. Figure 7 consists of graphical representations that enable the scientists to visualize the range and values of the depth and duration of trawls respectively for, in this instance, a data set of shrimp fishery activity.

Figure 8 illustrates a visualization of the fishery activity over the same spatial area of interest, but here spatial clusters have been identified using geostatistical

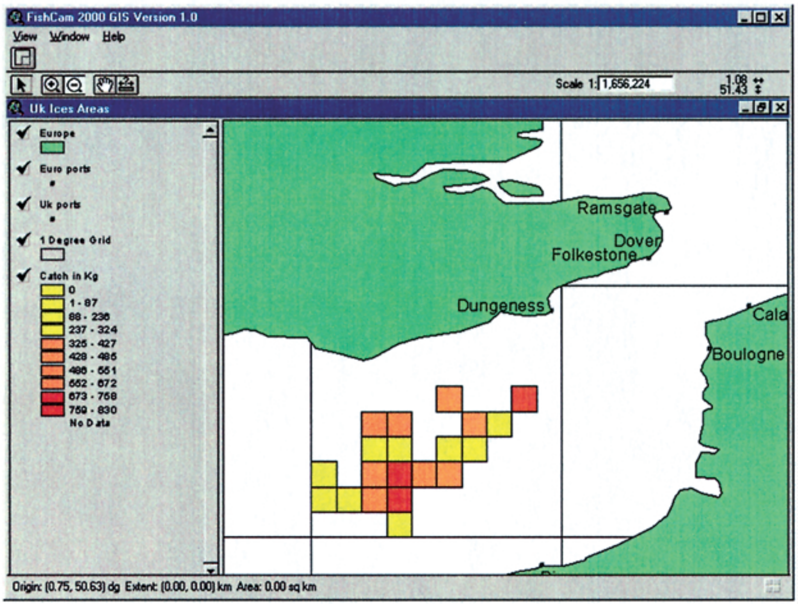


Figure 6. Gridded surface of total catch.

functions. Statistics for each cluster, such as average depth and duration of trawls, catch weight, and weight per time unit, have been extracted.

## Marine environmental modeling

In certain circumstances, fishery scientists investigate primary activity in the spatial area of the study with a view to modeling the relationships between, for example, plankton species, growth, and ocean environment variables (Dickey, 1992). In this case the data sets available to the researcher are augmented with data from various study cruises. Standard statistical capabilities are needed to enable the researcher to explore the relationships underlying the variables as well as to investigate the range and distribution of individual attributes (Petitgas, 1996). This is partly a consequence of the relative sparsity of data relevant to the marine environment and partly the uneven spatial coverage.

One of the deficiencies of most proprietary GIS is that they do not support the user in determining "fitness-for-use" measures for data sets. They read, store, and display the data without providing capabilities for the researcher to evaluate data quality. Usually the data comes from a wide variety of sources and formats. Sometimes information about the sampling techniques and lineage is not available (von Meyer *et al*., 2000). These uneven sampling strategies cause large data clusters in space, time, and quality; the data-clustering is exaggerated due to the fact that automatic sensors can transmit gigabytes of data within a short timeframe, thereby creating undesirable skewedness. The only spatially uniform distributed data are satellite images that are treated as snapshots after pre-processing, even though they were originally captured by a non-instantaneous pushbroom scanning process. Though satellite images are not perfect, they can be used as a benchmark to validate related data.

As an example of preliminary data exploration and evaluation, consider the relationship between temperature, salinity and density as illustrated in Tables 1–3 and Figure 9. Salinity is positively correlated with density, while both have a negative correlation with temperature as shown in Table 1. These dependencies are further confirmed by extracting factors to describe the composite data set. The results of the factor analysis are presented in Tables 2 and 3 and Figure 9. Figure 9 illustrates the plot of the eigenvalues on the left hand side and a 2D factor plot on the right hand side for temperature, salinity, density, fluorescence, irradiance, and transmission. Two factors with an eigenvalue of more than 1 can be extracted and they explain the data set by 78.54%. The first component is driven mainly by the physical parameters temperature, salinity, density, and transmission, while the second is determined by the biological factors fluorescence and irradiance. Hence there is clear discrimination of a physical factor (component 1) and a biological factor (component 2) in the data set (Table 3).

In multivariate analyses, in order to perform any meaningful spatial operations, it is necessary to transform diverse attribute representations into comparable structures. Environmental modeling deals with attributes that are by and large continuous over the

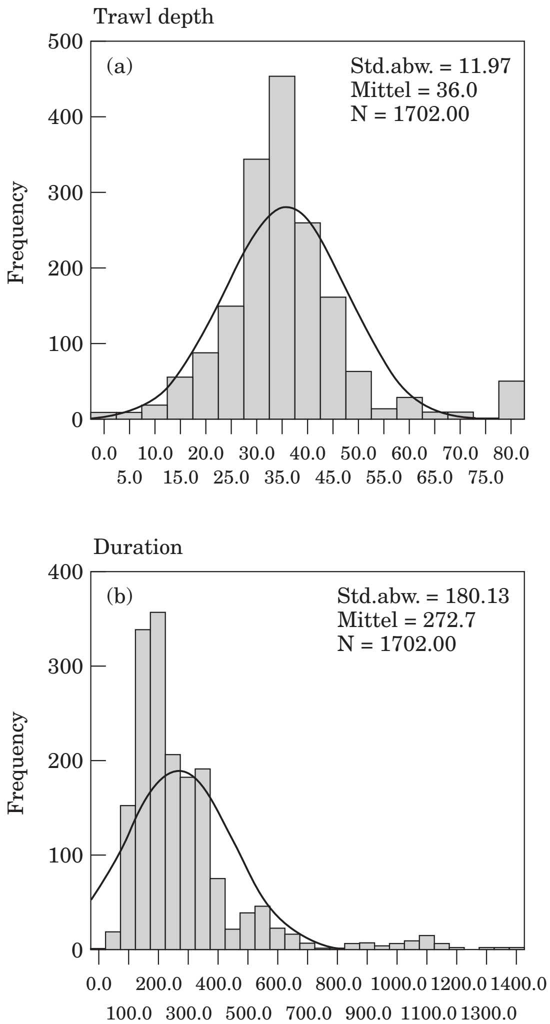


Figure 7. (a) Graph of trawl depth frequency. (b) Histogram of trawl duration.

problem space so the most obvious data structures to use are 2-, 3-, or 4D grids. Conversion of point sampled observations to grids requires geostatistical capabilities. The two minimum conditions that are sufficient for geostatistical analysis are stationarity and spatial correlation (Legendre and Trousellier, 1988). Therefore it is important to test these properties in the data set so that geostatistical assumptions can be made and correct weighting factors selected to represent the marine environment.

Most interpolation methods, including nearest neighbour and inverse distance weighting, assume a linear spatial correlation between the sample points. In contrast to reality, this is a simplification, because there are several factors that may affect a uniform distribution such as the shape of a coastline, water currents or biological interactions (Petitgas, 1993). In a marine environment, it is reasonable to assume that there is a higher spatial correlation along the coastline than perpendicular to it, as we usually expect a more even distribution along a coastline than in the perpendicular direction (Grioche *et al*., 1999; Grioche and Koubbi, 1997). These anisotropies represented as ellipsoids should be calculated for estimating a range for the reliability of the data. The search-ellipses indicate the statistical and average range of a specific value in two, or as an ellipsoid in three dimensions.

Figures 10 and 11 illustrate analyses involving the effects of the variables density, temperature, fluorescence, and salinity on the growth of fish larvae in a specific region during spring. The resultant 2D grid structures are visualized in Figure 10, which presents the physical variables at three depths through the water column, surface, mid-range, and bottom. Figure 11 shows abundance values of larvae through three stages of growth.

## Discussion

### Visualization issues

The overarching objectives of visualization systems can be summarized as follows:

(i) To enable extraction of spatial and temporal patterns from the underlying data.
(ii) To successfully reveal hitherto unknown or undiscovered spatial and temporal patterns.
(iii) "Dynamic" visualizations are much more effective than static ones. There is much discussion in the cartographic literature on the efficacy of dynamic visualization in displaying time-variant data (Andrienko *et al*., 2001). However, the dynamic aspect need not be confined to on-screen animation but can be extended further back in the analytical pipeline to include dynamic data exploration as well as display.
(iv) Visualization systems that enable spatiotemporal dispositions to be linked in order to show relationships between several attributes existing within a problem space are more effective for decision making and analysis than those that display one attribute only.
(v) Ideally, a visualization system should encourage the user to "mine" an observational data set so as to generate information to support management decisions.
(vi) Visualization components of information systems should enable users to view patterns in observational data sets and to view simulations of process models.

To provide effective support for decision making, visualization must be more than a mechanism to present or

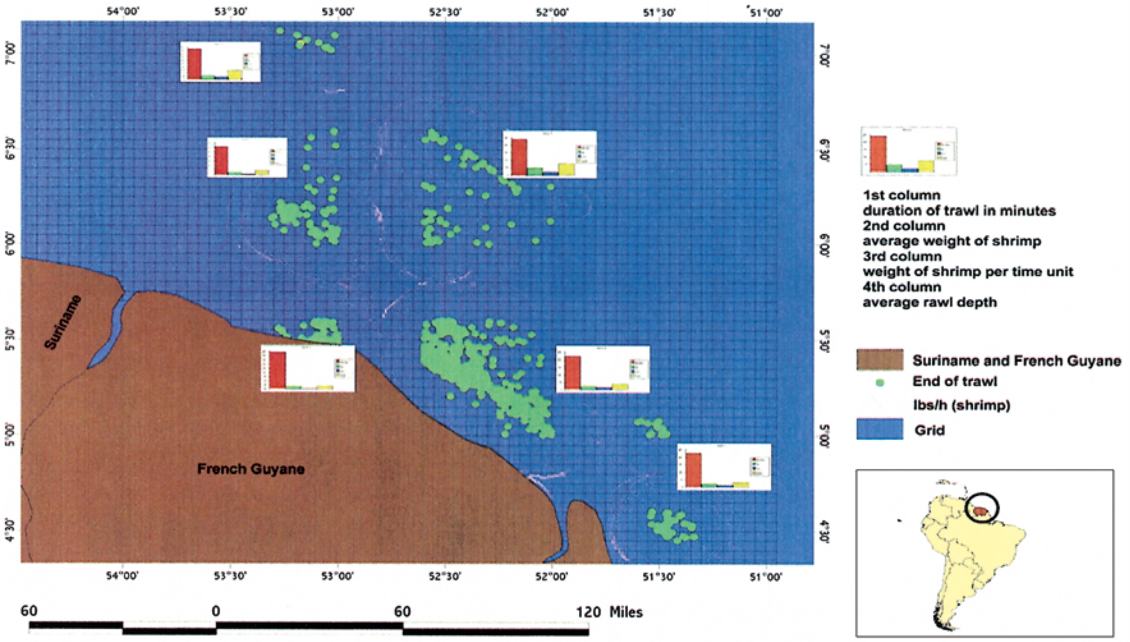


Figure 8. Evaluation of spatial disposition of shrimp fishery data.

Table 1. Correlation matrix of temperature, salinity, density, fluorescence, irradiance, and transmission on sea surface level.

| | TEMP | SAL | DENS | FLUO | IRRAD | TRANS |
|---|---|---|---|---|---|---|
| TEMP | 1.000 | − 0.527 | − 0.690 | 0.637 | − 0.071 | 0.463 |
| SAL | − 0.527 | 1.000 | 0.979 | − 0.303 | − 0.098 | − 0.672 |
| DENS | − 0.690 | 0.979 | 1.000 | − 0.411 | − 0.066 | − 0.684 |
| FLUO | 0.637 | − 0.303 | − 0.411 | 1.000 | − 0.323 | 0.161 |
| IRRAD | − 0.071 | − 0.098 | − 0.066 | − 0.323 | 1.000 | 0.239 |
| TRANS | 0.463 | − 0.672 | − 0.684 | 0.161 | 0.239 | 1.000 |

Table 2. Computed eigenvalues and percentages of the marine data set.

| Component | Eigenvalue | Pct of Var | Cum Pct |
|---|---|---|---|
| 1 | 3.284 | 54.726 | 54.726 |
| 2 | 1.429 | 23.815 | 78.54 |
| 3 | 0.627 | 10.449 | 88.99 |
| 4 | 0.379 | 6.312 | 95.302 |
| 5 | 0.282 | 4.697 | 100 |
| 6 | $2.403 \times 10^{-5}$ | $4.005 \times 10^{-4}$ | 100 |

Table 3. Rotated component matrix.

| | Comp. 1 | Comp. 2 |
|---|---|---|
| TEMP_S | **0.701** | 0.497 |
| SAL_S | **− 0.921** | $-4.130 \times 10^{-2}$ |
| DENS_S | **− 0.954** | − 0.155 |
| FLUO_S | 0.367 | **0.796** |
| TRANS_S | **0.836** | − 0.171 |
| IRRAD_S | 0.261 | **− 0.791** |

display data. Scientific visualization can be considered from two major perspectives: what is to be viewed and how it is to be visualized.

The Introduction presented an overview of the factors to be considered in determining what data may be visualized. The overall objective of FC is to present the user with a system for exploratory visualization analysis (EVA), analogous to exploratory data analysis (EDA) that statisticians have been familiar with for a long time (Tukey, 1977). A few further points may be made with reference to what the user may visualize. First, in the fishery domain, the space and time dimensions are dominant. Many analyses depend on spatial operators, such as those provided by traditional geographical

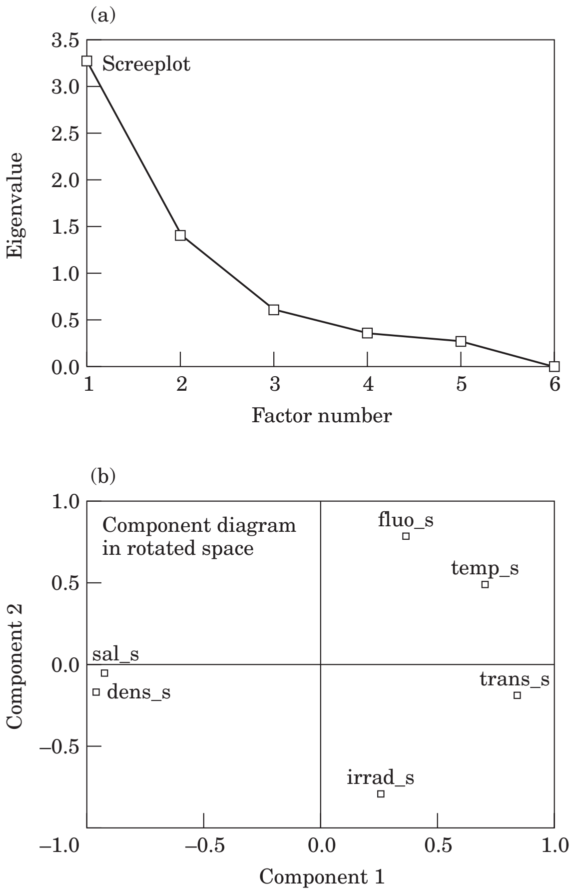


Figure 9. Graphical representation of the extracted factors.

information systems (GIS), to determine the spatio-temporal dispositions of various attributes. Thus, maps are the main mechanism for presentation of the retrieved information showing distribution of attribute values, for finding spatial clusters and for detecting anomalies and outliers. However, this may not necessarily be the only requirement. Often, exploratory analysis involves univariate analysis: visualizing the range, maxima/minima, averages, or trends of variables in which case box plots, histograms, etc. have to be used. Statistical, graphical exploration of relationships between variables are also required, for example, using techniques such as 2D scatter plots (Fotheringham *et al*., 2000). Thus graphical as well as cartographic visualization are integral parts of the system.

Another point to be emphasized is that when visualizing information using maps, the spatial and temporal dimensions are dominant. However, the attribute variable that is visualized, and the form in which it is visualized, is entirely under the user's control. For example, the user can determine whether a map showing the catch of a particular species in a specified area and within a specified time interval shows the total catch, in kg, or the percentage of that species within the total catch or cpue calculated by a built-in or user-specified formula. Moreover, the way the attribute variable is classified also enables the user to visualize the data more flexibly. Allowing the user the capability of determining the number and boundaries of classes of each variable enhances the power of exploratory visualization. Classification groups summarize a variable, and different groupings may expose different spatial patterns (Fotheringham and Wong, 1991; Kostylev *et al*., 2001).

How the data are visualized covers a variety of factors including use of symbols, colours, shape, texture, size, etc., to enhance the information being displayed. There have been many formalisms proposed for cartographic visualization including those by Monmonier (1992), Tufte (1992), Bertin (1983), Tufte (1993), and Buttenfield (1996). The details of these are beyond the scope of this paper but have informed the visualization capabilities of FC. However, we note a few important points. In many fishery analyses, change or evolution of variables is frequently a focus of study (DiBiase *et al*., 1992). Moreover, in our flexible system, time can be represented as a point, an interval or a series of intervals. In each case, appropriate visualization techniques are used to highlight presentation of the time-varying properties of the data. The data can be presented as series of maps, on a hard copy device or suitably animated on a raster display surface. A task-based perspective on visualization makes it possible to embed some "intelligence" in the system, which itself chooses an appropriate mechanism for presentation depending on the nature of the tasks and the variables involved. FC meets several of the visualization requirements highlighted in Wright and Goodchild (1997), Wright *et al.* (1997), and Fox and Bobbitt (2000).

## Implementation

The current implementation of FC meets most of these objectives. The framework is implemented in Microsoft Visual Basic and uses ESRI's ArcView and MapObjects (Hartman, 1997) for mapping and cartographic functionality. There are several reasons for choosing this software substrate. The intention was to achieve a modular component-based architecture to enable the system to be extensible. The user interface in a system such as FC is a major factor in its acceptance by the user community. It was important that the functionality be presented in the manner and the sequence in which the users approach the management and research tasks. Control of the structure and look-and-feel of the interface was easier to achieve using the component approach.

Another consideration was the fact that where possible reusable components should be used. In a

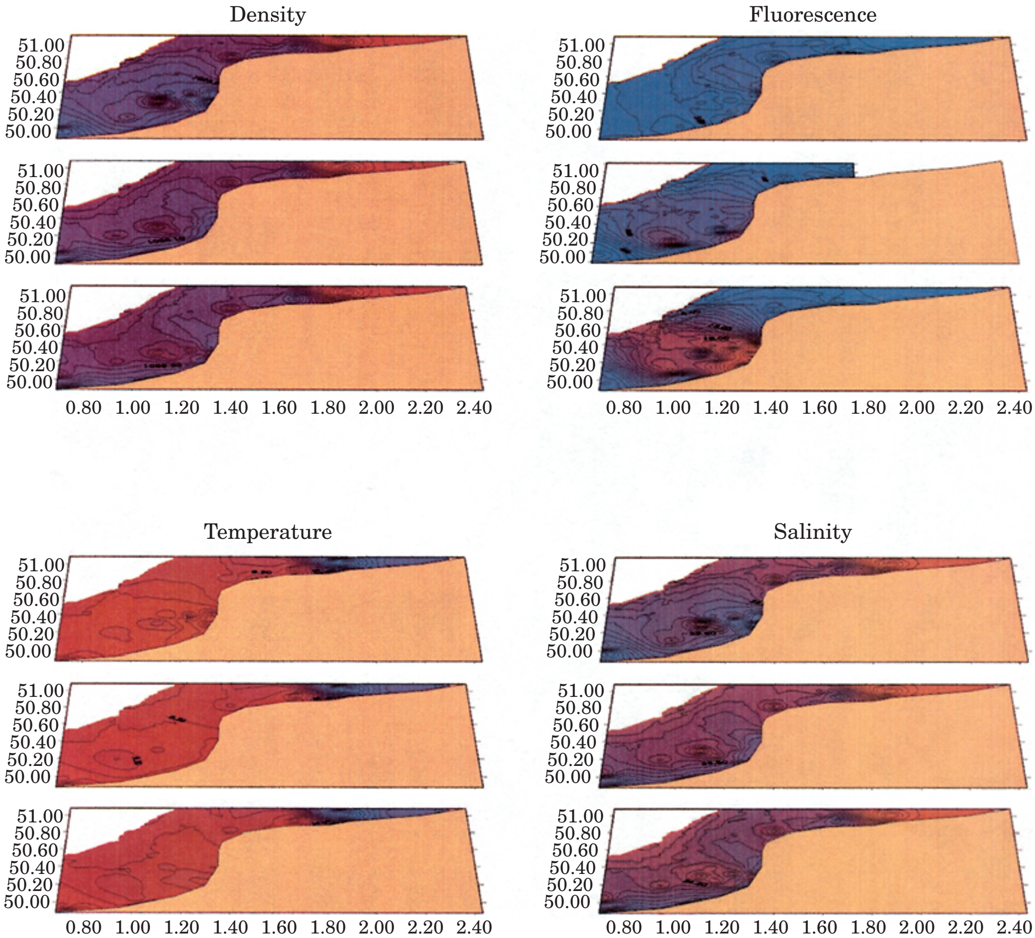


Figure 10. Temperature, fluorescence, salinity, and density at three different depths off the Opale coast (northern France).

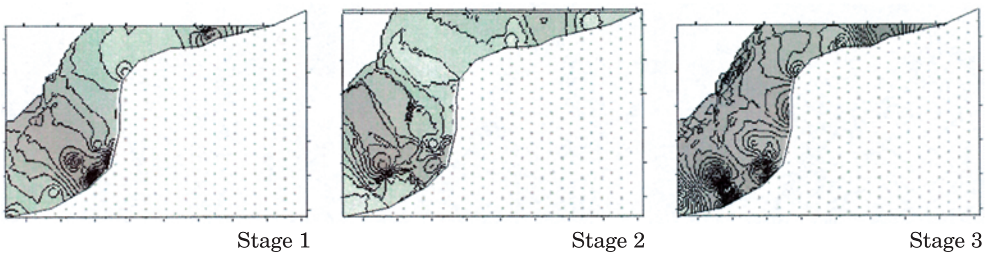


Figure 11. Interpolated growth stages for fish larvae off the Opale coast, northern France.

component-based environment the modules can be specially written or existing third-party components can be plugged in. We use a mixture of the two strategies; some cartographic functionality is based on proprietary libraries and others, such as the capabilities for manipulating raster or grid types, were custom-written.

The component model has also enabled us to manage the underlying databases independently of the computational and visualization engine. This makes the data subset selection tasks much easier to implement. Currently Microsoft Access is used to store the data but this is not an ideal solution as some object database capabilities are not available.

The results so far have been promising and prove that the basic requirements identified for supportive decision-making in fisheries systems are essential. However, ongoing research still needs to tackle several related issues. FC helps the user towards better interpretation and analysis of maps by tailoring the visualization to specific tasks. For example, visual clues can be used to highlight aspects of the mapped data such as percentage change in a particular attribute, or a marked change in its spatial pattern or an unexpected change in the shape/position of marine objects. Another useful aid to visual exploration is to enable the user to interactively manipulate the colours, sizes of icons, classes of attributes, etc., in a displayed map so as to gain further insights, i.e. to manipulate the graphic as well as its content. A further development that would support fisheries modeling and decision making is to provide built-in ecosystem behaviourial models which users could embed in their applications. With the ever-increasing use of the internet, a generic requirement for many information systems is to provide transparent distribution of data and functionality. These aspects remain to be addressed in FC.

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