A Decision Support System for Marine Regulation

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Abstract: The implementation of marine spatial data management and decision support based on GIS provides a powerful tool for marine regulation. This study constructed a three-dimensional spatiotemporal data model of marine resources that is hierarchical, partitioned, and classified according to the management principle of using an underground resource layer, surface matrix layer, surface overburden layer, and management layer, taking the marine resource entity as the unit. Key research topics include marine multi-source information integration, visual expression, and spatiotemporal topology analysis for typical application scenarios such as sea area use, island development and utilization, and marine environmental monitoring and protection. The study developed a marine information decision support system with comprehensive integration and visual analysis of information on maritime islands, early warning and monitoring, the marine economy, and the marine environment. The system was applied to dynamic regulation of sea area use, spatiotemporal characteristic analysis of marine resources, the regulation of human activities in marine protected areas, and the monitoring of sea level rise. Practice has proved that a three-dimensional spatiotemporal data model of marine resources can meet the application requirements of “One Map”, the basic land and spatial information platform.

Key words: Marine regulation; Decision support system; Three-dimensional spatiotemporal database;

1. Introduction

As an important space for human survival and development, the ocean is rich in spatial resources, biotic resources, mineral resources, and marine energy. More and more marine development and utilization by humankind has greatly promoted local marine economies in coastal areas, but also caused problems such as the destruction of marine ecosystems, marine environmental pollution, and the decline of the retention rate of natural coastlines. Therefore,
it is urgent to strengthen the ability to comprehensively manage and control marine development and utilization. A research hotspot has emerged in coordinating the development of marine economies and resources and environmental carrying capacity from the perspective of comprehensive marine regulation.

Integrating marine information based on geographic location and building a decision support system can provide display, query, and spatial analysis capabilities of the ocean and its development and utilization in their current state. Furthermore, spatial land use planning can improve the scientificity, accuracy, and timeliness of marine development, utilization, and environmental assessment while improving the level of comprehensive management. Many scholars in China have carried out a series of studies and applications focusing on offshore oil spill emergencies, sea level rise, coastal erosion, and regional risk assessment.

This paper proposes a three-dimensional spatiotemporal model based on research on more general such models for natural resources but tailored to the characteristics of marine resources. Oriented to the typical application, this paper develops a marine information decision support system for marine regulation, integrating marine information, spatial topology analysis, and visual analysis applied to scenarios such as sea area use, island development and utilization, environmental monitoring, and protection of marine ecosystems.

2. Three-dimensional spatiotemporal model of marine resources

The Ministry of Natural Resources has issued the “Overall Plan for the Construction of Natural Resources Investigation and Monitoring System”, which proposes a hierarchical classification of various natural resource information. Three-dimensional spatial location is the basic link for organizing and connecting all natural resources, basic surveying and mapping results are the framework, digital elevation models are the base, and high-resolution remote sensing imagery is the background. The system scientifically organizes each natural resource entity in an orderly distribution on, above, and below Earth’s surface, forming a complete three-dimensional spatiotemporal model of natural resources supporting production, life, and ecology.

As an important part of natural resources, marine resources are hierarchically organized and managed according to category and content, such as an underground resource layer, surface matrix layer, surface overburden layer, and management layer. The system sorts out, cleans, refines, and transforms data with natural attributes and management attributes among data at each layer, then combines and merges them according to region, discipline, specialty, element, application field, and management theme.

- Underground resource layer: includes the location, distribution, and area data of marine mineral resources such as marine sand, oil, and gas.
- Surface matrix layer: includes seabed water depth, landform, and seabed sediment data.
- Surface overburden layer: includes marine ecosystem, marine water environment, marine biotic resources, and other data. The marine ecosystem includes the type, distribution, and area data of coastal wetlands and coastal tidal flats; the type, distribution, and area data of the sea, the number, location and area data of islands; the distribution, area, and composition data of coral reefs, mangroves, seagrass beds, and other ecosystems; and the marine water environment, including attribute data of the physical ocean, marine biology, marine chemistry, marine acoustics, marine optics, and elements of other disciplines at different water depths.
Management layer: includes data such as the type, length, spatial distribution, and change in the marine ecological red line and coastline; current protection and utilization of coastal wetlands and coastal tidal flats; the protection and utilization of coastal zones and sea reclamation in China; present situation and change in the development, utilization, and protection of islands and island resources; and the development and utilization of marine mineral resources.

3. Construction of a decision support system (DSS)

3.1 Technology framework
This study carried out the overall architecture design of the system, which is divided into a data layer, function layer, and application layer. The three layers proceed in an orderly way and are interrelated with one another. Through data and function encapsulation, the coupling between each layer and between modules is reduced, so that the system function is easy to expand and maintain.

![Architecture of DSS](image)

**Figure 1.** Architecture of DSS

- Data layer: processes and manages various kinds of basic data and thematic data such as basic geography, marine environment, marine economy, sea areas and islands, marine early warning and monitoring, ecological protection, and marine equity, both spatial and non-spatial data, structured and unstructured. Service encapsulation and publication is carried out in accordance with the Webservices protocol, and applications are registered in the unified application service resource pool.
- Function layer: function migration and transformation, including GIS functions and non-GIS functions, are carried out for different thematic applications based on the data layer and guided by application requirements. The GIS functions include two-dimensional display, three-dimensional display, overlay analysis, buffer analysis, inundation analysis, arbitrary spatial queries, and so on. The non-GIS functions mainly include user management, statistical charts (histograms, pie charts, curve graphs), tree lists, background service management (addition, deletion), and other chart visualization, statistical analysis, and service configuration functions.

- Application layer: data from all fields of study related to the ocean are integrated for the comprehensive management requirements of sea area and island regulation, monitoring and evaluation of marine economics, marine early warning and monitoring, maintenance of marine equity, and environmental analysis. Various interfaces are called based on the function layer, allowing the decision support system to provide collaborative services for comprehensive regulation and decision support functions based on One Map.

3.2 Database construction
This study adopted PostgreSQL database management software to construct and manage the database. The business database logically includes two parts: a spatial database and non-spatial database. The spatial database records the business information and spatial information of six aspects, including marine rights and interests, early warning and monitoring, marine environment, spatial planning, sea areas and islands, and marine economy, while the non-spatial database records the business information on disaster prediction and reduction and the marine economy. The background configuration database includes related database table contents such as layer, function, menu, service, and template configuration data tables. These comprise the functions of the background configuration management tool for the function menu, thematic tree, function content, web reference service and HTML template, and user configurations. In the background configuration database, the association between related table fields of the configuration at all levels is realized by means of foreign keys.

![Figure 2. Database for DSS](image-url)
3.3 System function R&D
An integrated marine management decision-making platform was established with unified interface standards, unified resource management, a unified basic platform, and a unified service portal, upgrading and organically integrating the existing application systems to provide a “one-stop” marine information query, retrieval, and visualization service.

3.3.1. Analysis of spatiotemporal characteristics of marine resources
(1) Analysis of interannual variation of coastline resources
Based on the continental coastlines extracted from remote sensing images in 1990, 2000, 2008, 2010, and 2014, the system provides overlay analysis of continental coastlines and remote sensing images over the years, which can visualize changes and provide support for further investigation and identification of the causes of changes.

Figure 3. Shoreline change analysis and statistical analysis of length in coastal provinces and cities in different years

(2) Spatial distribution analysis of marine biotic resources
Based on the statistical yearbook data of offshore marine biological species in China, the system has functions for the spatial distribution of phytoplankton, zooplankton, and benthos; species station data monitored in a spatial grid; a thermal map of species; and a morphological view of species.

Figure 4. Spatial distribution, species proportion, and morphology of Annelida

3.3.2. Statistical analysis of marine economy
The system integrates the overall operation of the marine economy, the development of major marine industries, and the development of regional marine economies in China since 2000. It analyzes the proportion of different industries, development situations, the marine economic
aggregate at the city level, and the sea area level, providing important support for the monitoring and evaluation of marine economic operation.

Figure 5. Statistical analysis of the proportion, growth rate and added value of emerging industries of the marine economy

3.3.3. Analysis of sea area use and island development

- Analysis of current sea area use and island utilization
The system integrates data on the current use of sea areas and data on the development and utilization of islands; produces the classification statistics, comprehensive query, and spatial topology analysis of different types of sea area use; and conducts the statistical analysis of island coastline types, vegetation coverage, and interannual comparative analysis of development and utilization.

- Analysis of the approval of new sea area use projects
The system provides overlap analysis of newly added sea use projects and current sea use data, compliance analysis of marine functional regionalization, and comparative analysis with applied length or area. Meanwhile, it is possible to query the status of the marine environment and marine protection planning around the sea use projects, providing support for analyzing the approval of sea use projects.

Figure 6. Spatial topology analysis of new sea use projects in any area
3.3.4. Early warning and monitoring analysis

- Vulnerability analysis of sea level rise
  
  Based on the vulnerability index calculation model of the impact of sea level rise, this paper integrates vulnerability regionalization data in coastal cities and counties nationwide, and analyzes the natural environment vulnerability, socio-economic vulnerability, coastal zone vulnerability index, and vulnerability level in coastal cities and counties.

![Vulnerability analysis of sea level rise in sea-related cities and counties](image1)

**Figure 7. Vulnerability analysis of sea level rise in sea-related cities and counties**

- Analysis of sea use in the marine ecological red line area
  
  A GIS spatial topology analysis was conducted for current national sea use, the marine ecological red line, and marine protected areas, and the analysis of suspected illegal sea use is provided according to the types and spatial scope of sea use.

- Analysis of vessel behavior in marine protected areas
  
  Information mining of vessels passing in and out of ports and channels can help judge whether vessels are possibly involved with illegal operation in protected areas. The information is based on target radar data with 5, 10, and 15 nautical mile buffers and the establishment of electronic fences, path pickup and target behavior analysis, and overlay analysis algorithms.

![Track diagram of a typical port and channel based on target radar data](image2)

**Figure 8. Track diagram of a typical port and channel based on target radar data**

3.3.5. Analysis of marine environment

A “One Map” visual analysis of marine environment information is provided to display and analyze the spatiotemporal change and regional characteristics, focusing on change in the marine environment. It includes a large-scale map, single point profile curve, spatiotemporal dynamic sequence map, profile map, and time remapping, providing information support.
services for further study of change mechanisms. Through the analysis of the topographic environment in coastal zones and nearshore and offshore areas, functions are provided for regional isoline analysis, maximum/minimum analysis, and tensile transformation analysis.

**Figure 9.** Visualization of sea surface temperature and flow field of the Northwest Pacific

4. Key technologies

4.1 Data synchronization and service technology

The decision support system for marine regulation, which maintains the freshness, continuity, and integrity of data, is an important link in information integration and decision support. It is the fundamental guarantee for the implementation of a business collaborative application. Data synchronization technology dynamically updates the database established in this study according to data type, data content, update frequency, and other factors, focusing on various data generated in the business application systems such as sea areas and islands, marine economies, disaster prevention and reduction, and marine equity. Based on the concept of SOA, the system conducts service encapsulation and processing of various database contents according to the WebService protocol, allowing for real-time registration in the service resource pool and unified management and publication of service resources.

**Figure 10.** Technology framework for data synchronization of the business system

This study published services for raster data, vector data, and map data according to OGC standards: WCS, WFS, WMS, and TMS\TFS tile map. Service encapsulation and publication, based on SOA, were done for multimedia data such as marine environment data and web
photos, providing users with data service registration, publication, and call interfaces.

Figure 11. Publication and reuse of multi-source heterogeneous data services

4.2 Data visualization technology

This paper visualizes marine information in three aspects: basic geographic marine data, marine management business data, and environmental data.

Based on the virtual sphere model, the basic geographic marine data constructs image and terrain pyramids, carries out LOD layering and tile map service calls according to the data spatial resolution, and publishes services as a data flow. Multi-scale images and terrain pyramids are composed of original multi-scale image terrain files, index files, data logic processing information, unified pyramid parameters, coordinate system parameters, environmental parameters, and other data files. This model stores all the original data, encodes them with a spatial index, and performs logical processing on the original data, such as clipping, removing outliers, local value editing, edge smoothing, image color equalization, and LOD setting, thus generating a unified pyramid model.

Data visualization is integrated into the sphere system according to its spatial geographic information. Data can include, for example, marine management data in the form of numerical values and text, such as the area and perimeter of sea use for fisheries, transportation, and so on; data on the management of sea areas; and the gross economic product in marine economies. Meanwhile, according to the actual business management
requirements, classification visualization is conducted towards various business needs in the form of statistical charts (such as histograms, pie charts, curve graphs, and scatter diagrams).

Marine environmental data are mainly scalar field and vector field. The visualization of scalar data such as ocean temperature and salinity provides methods such as large-area maps, single point process curves, and profile maps. For the drawing of flow field, the core content is the linear flow effect, which mainly calculates the movement amount and direction within \( T \) starting from point \( A \), calculates all positions within \( T \), draws this line segment, and gives the corresponding colors according to the length of the line segment. The specific implementation is as follows.

Through the calculation of
\[
\begin{align*}
(x_0 &= i/dx \ast dx, \quad \ y_0 = j/dy \ast dy),( \quad x_1 = i/dx \ast dx \quad y_1 = j/dy \ast dy),
\end{align*}
\]
the quadrangular coordinates are obtained for the data grid where \( B \) is located, the corresponding data according to the coordinates are obtained, giving the vector starting from point \( B \) through the bilinear difference algorithm
\[
f(i, j) = f(x_0, y_0) \left( 1 - \frac{i-x_0}{dx} \right) \left( 1 - \frac{j-y_0}{dy} \right) + f(x_1, y_0) \left( \frac{j-y_0}{dy} \right) + f(x_0, y_1) \left( \frac{i-x_0}{dx} \right) \left( 1 - \frac{j-y_0}{dy} \right) + f(x_1, y_1) \left( \frac{i-x_0}{dx} \right) \left( \frac{j-y_0}{dy} \right).
\]

The trajectory of point \( B \) is drawn within \( T \), and the motion trajectory of point \( A \) within \( T \) is obtained by continuous drawing.

To meet the requirement for allowing flexible configurations of system functions, menus, and data, a configurable system was developed with interaction between the logical design of the configurable database and the template customization and module packaging. The configurable database, which includes tables for the system menu, system function, layer-tree, and marine data, plays a logical supporting role in the system development and implementation process. Based on the customizable configuration, the system gives a choice of templates for front-end function-pages, function-modules, and layer-tree according to marine data type, attributes, and contents.

![Customization and encapsulation of template](image)

![Design of configurable database](image)

Figure 12. Logical flow of configuration and encapsulation for marine data visualization
5. Conclusion

The ocean is a complex, giant system, including the marine environment, marine development and utilization, marine targets, and human activity, bringing great challenges to marine regulation. Through the construction of a three-dimensional spatiotemporal model of marine resources, data for an underground resource layer, surface matrix layer, surface overburden layer, and management layer are uniformly organized and visually displayed. The system meets requirements for rapid access, statistical analysis, and auxiliary application of marine information. It is a platform for collaborative service, comprehensive regulation, and intelligent decision-making based on One Map. The platform offers comprehensive cross-system and cross-business information services, providing systematic support for refined, comprehensive management of marine resources.

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