Research on the Measurement of Sea Area Use and Technology Development Trends Based on Blue Ocean

Yanxiang Liu [1], Jing Xie [1], Cunliang Xing [1,*], Hualuan Wang [1],
Xiaowei Yao [1], Ying Gao [1], Mingliang Li [1], Haichen Sui [1,2]

[1] Tianjin Research Institute for Water Transport Engineering M.O.T, Tianjin, 300456, China.

[2] Tianjin Key laboratory of Surveying & Mapping for Waterway Transport Engineering, Tianjin, 300456, China.

Abstract. The ocean is the cradle of life and a regulator of the environment. The development and utilization of marine areas constitute a vital aspect of national socio-economic development. Marine spatial use surveying serves as a critical technical link connecting "marine resources - ecological environment - human activities", with its significance permeating the entire chain of marine resource management, ecological protection, rights safeguarding, engineering construction, and scientific decision-making. Accurate marine spatial use surveying has become a fundamental cornerstone for promoting high-quality marine development and achieving the sustainable utilization of the "blue territory". From the perspective of protecting the ocean and developing and utilizing it scientifically, this paper elaborates on the significance of marine spatial use surveying by comparing and analyzing the implementation status, applied technologies, management mechanisms, challenges, and China's development status in this field internationally and domestically. Finally, the paper summarizes and discusses the development trends of marine spatial use surveying.

Keywords: Blue Ocean; Marine Spatial Use Surveying; Blue Granary; LiDAR; Ecological Protection.

1. Introduction

The ocean is a treasure trove of resources essential for human survival, hailed as the "Blue Granary", and plays a significant role in ensuring food and nutritional security. The ocean possesses not only spatiotemporal geographical characteristics but is also among the most dynamic of natural geographical units. Since the rise of the "Age of Discovery" in the 16th century, humanity gradually initiated the process of globalization through understanding the oceans [1]. As an important state-owned resource, marine space is also a fundamental element for developing the marine economy and improving livelihoods. Marine spatial use management is a crucial component of ocean governance, encompassing the processes of policy-making, guidance, organization, planning, coordination, and control implemented by social organizations to achieve the rational development, utilization, and sustainable development of waters under national jurisdiction [2].

Marine spatial use surveying is a key technical nexus linking "marine resources - ecological environment - human activities". As a core technical means for marine resource management and rights protection, countries have formed differentiated development paths based on their respective legal systems, technical capacities, and marine strategic needs. China's Sea Area Use Management Law defines sea areas as: the sea surface, water body, seabed, and subsoil of the internal waters and territorial sea of the People's Republic of China. The internal waters referred to in this definition mean the waters on the landward side of the baselines of the territorial sea up to the coastline. Against this background, and from the standpoint of protecting the ocean and utilizing it scientifically, this paper explores marine spatial use surveying and its technology development trends to provide necessary data for marine spatial use.

2. Implementation Status and Technology Application of Marine Spatial Use Surveying Internationally and Domestically

2.1 Implementation Status of Marine Spatial Use Surveying

2.1.1 Differences in Legal Frameworks and Policies

China adopts an approach combining central planning with local exploration.Unified Legislation: Centered on the Sea Area Use Management Law, it clarifies the approval procedures for sea area use rights, surveying standards, and regulatory requirements. For instance, coastal provinces like Jiangsu and Zhejiang have refined hierarchical approval standards through local legislation (e.g., setting thresholds for sea reclamation area). Local Practices: Areas like Shenzhen and Shandong have explored market-based allocation, such as Zhejiang implementing online trading rules for sea area use rights, achieving a "fully online process".Disputes and Coordination: Discrepancies in the scope of sea use demonstration and administrative penalties in regions like the Yangtze River Delta require efforts towards legislative unification.

Internationally, the United States employs a federally-led and market-oriented model [3].Legal System: Relies on the Coastal Zone Management Act to establish a marine spatial planning system. The National Oceanic and Atmospheric Administration (NOAA) coordinates hydrographic surveying, while allowing private sector participation (e.g., oil and gas development requires permits from relevant agencies).Technical Standards: NOAA uses risk-based models to prioritize hydrographic surveys, dynamically adjusting plans to balance navigation safety and resource development [3].Controversial Cases: Incidents like US fishing vessels illegally harvesting tuna in the South Pacific Exclusive Economic Zone expose gaps in international agreement enforcement and oversight.

2.1.2 European countries adopt an ecology-first and regional coordination model.

United Kingdom: Established the Marine Management Organisation (MMO) through the Marine and Coastal Access Act, integrating maritime functions such as fisheries and energy, emphasizing ecological protection (e.g., establishing "No Discharge Zones" to restrict ship sewage).Germany: Implements strict ecological red line systems in the North Sea and Baltic Sea. Survey data is used for wave/tidal energy development and Marine Protected Area (MPA) demarcation, prohibiting large-scale dredging in sensitive zones. Regional Cooperation: The EU promotes shared survey data and coordinated cross-border maritime management among member states through the Marine Spatial Planning Directive (e.g., multinational joint monitoring programs in the Baltic Sea).

2.2 Application of Marine Spatial Use Surveying Technologies

2.2.1 Marine spatial use surveying permeates the entire chain of marine resource management, ecological protection, rights safeguarding, engineering construction, and scientific decision-making. Against the backdrop of intensifying global maritime competition and increasing marine ecological pressures, accurate marine spatial use surveying has become a core foundation for promoting high-quality marine development and achieving sustainable use of the "blue territory".

China employs multi-source fusion and intelligent technologies.Technological Breakthroughs: Integration of multibeam bathymetry, UAV aerial survey, and 3D laser scanning supported the immersed tube installation for the Hong Kong-Zhuhai-Macao Bridge (error ±2cm); deep-sea LiDAR applied in polymetallic nodule surveys in the South China Sea.Standardization: The Specifications for Sea Area Use Area Measurement (current version) details underwater surveying rules, introducing GNSS-RTK and sonar fusion technologies to enhance accuracy.

2.2.2 Internationally, the United States utilizes high-precision and dynamic monitoring. Hydrographic Surveying: NOAA employs Differential GNSS and Inertial Navigation Systems (INS) to achieve centimeter-level positioning for harbor navigation; satellite remote sensing monitors coastal erosion, shortening update cycles to quarterly. Military Applications: The navy uses Synthetic Aperture Sonar (SAS) to map seabed topography, supporting anti-submarine warfare and channel obstacle detection/mine clearance.

European countries adopt an ecology-oriented and community-participatory approach. Ecological Restoration: Norway uses acoustic imaging to monitor cod spawning grounds, adjusting fishing quotas based on survey data; the Netherlands uses GIS to simulate sea-level rise impacts on dikes, optimizing coastal defense projects.Public Participation: France developed the "Marine Atlas" platform, allowing the public to query real-time sea use status and submit survey feedback, enhancing transparency.

2.3 Management Mechanisms and Challenges

2.3.1 China employs hierarchical approval and dynamic supervision models [4].

Hierarchical Management: Sea reclamation projects are approved based on area thresholds, requiring coordination and standardization.Enforcement Challenges: Weak supervision of temporary sea use, with instances of unregistered or overdue use in some areas, relying on UAV patrols to compensate for manpower shortages.

2.3.2 Internationally, the United States uses market-based and risk management approaches. Bidding Mechanisms: Sea area use rights are obtained through public auction (highest bidder), but require submission of Environmental Impact Reports (e.g., California's No Discharge Zone restricting sewage discharge from vessels).

Emergency Response: Established tsunami warning systems utilize real-time bathymetric data to adjust shipping routes, reducing disaster losses.

3. Overview of Marine Spatial Use Development in China

China possesses approximately 3 million square kilometers of vast maritime area, which is not only a resource treasure trove with immense potential but also a strategic space supporting future development. Reviewing the development history of marine spatial use in China reveals that since the founding of the People's Republic, it has generally undergone three stages [5, 6].

Stage 1 (1949–1993): The period of non-compensatory sea area use from the founding of the PRC to the early 1990s.

Stage 2 (1993–2001): The exploratory phase of compensatory sea area use from the early-mid 1990s to the early 2000s.

Stage 3 (2001–present): The development phase of compensatory sea area use from the early 21st century to the present.

Quantitative measurements based on the Super-MSBM model and GML index show three characteristics of China's marine spatial use efficiency [7, 8]: firstly, the current overall efficiency is at a medium level; secondly, there are significant regional disparities in efficiency, with polarization intensifying; thirdly, the efficiency has gone through three periods: a decline (2006–2008), a steady rise (2008–2013), and a rapid rise (2013–2018), basically showing a "checkmark"-shaped growth trend. Investigation, analysis, and practice demonstrate that the implementation of China's compensatory sea area use system is closely related to the improvement of sea use efficiency. Compensatory use is not only an effective resource allocation method currently but has also laid the foundation for establishing a sea area use rights trading mechanism.

4. Significance of Marine Spatial Use Surveying

Marine spatial use surveying is an activity that targets marine spatial resources, employing modern surveying and mapping, remote sensing, Geographic Information Systems (GIS), and other technical means to conduct precise investigation and measurement of the location, scope, area, ownership, current use status, and ecological environment of sea areas. It provides a scientific basis for marine resource management, ecological protection, rights maintenance, engineering construction, and sustainable development.

4.1 Supporting Scientific Marine Resource Management and Promoting Sustainable Use

Marine spatial use surveying supports rational planning and dynamic regulation by accurately quantifying spatial information (e.g., use type, area), enabling resource census , planning formulation, and dynamic adjustment.

Resource Inventory: Clarifies the potential utilizable sea areas (e.g., for ports/channels, MPAs), avoiding "blind development" or "resource idle". For example, surveying can identify waters suitable for offshore mariculture, optimizing fishery spatial layout.

Integrated Planning & Dynamic Supervision: Combines survey data to formulate marine spatial use plans (e.g., National Marine Functional Zoning), defining use priorities for different zones (e.g., ecological protection redline areas), and tracks changes through periodic surveys for timely policy adjustment and efficient resource allocation.

4.2 Strengthening Marine Ecological Protection and Preventing Environmental Risks

Surveying monitors the occupation and impact of human activities on marine space, providing technical support for ecological protection.

Demarcating Ecological Protection Boundaries: Precisely defines the extent and status of sensitive areas like MPAs, coral reefs, and mangroves, restricting or prohibiting destructive activities (e.g., large-scale sand mining) in their core zones.

Assessing Ecological Impact: Quantifies the impact of human activities on intertidal zones, bay tidal prism, and habitats by comparing survey data from different stages (e.g., coastline changes before/after reclamation), providing basis for restoration (e.g., artificial reefs).

Controlling Pollution Dispersion: Optimizes outfall locations by surveying water quality, topography, and flow characteristics near discharge points, preventing pollutant accumulation in semi-enclosed bays (e.g., Bohai Sea).

4.3 Clarifying Sea Area Ownership and Safeguarding Rights [9, 10]

Sea area use rights are important usufructuary rights (per the Sea Area Use Management Law). Their establishment, modification, and transfer require clear ownership boundaries, for which surveying is the core technical means.

Defining Use Boundaries: Determines the boundaries of use rights (e.g., coordinates for aquaculture ponds, width of port channels) via high-precision techniques (e.g., GNSS positioning, underwater topography), resolving disputes arising from "ambiguous ownership".

Protecting Legal Rights: Provides legally recognized "spatial credentials" (e.g., sea area parcel plans, boundary point coordinates), preventing rights infringement due to survey errors.

Supporting Market-Based Allocation: Precise survey data forms the basis for valuing sea areas (location, area) in auctions/tenders, ensuring fair market transactions.

4.4 Serving Marine Engineering Construction, Ensuring Safety and Efficiency

The planning, design, and construction of marine engineering projects (e.g., ports, cross-sea bridges) rely on accurate marine spatial information, directly impacting project safety and economy.

Site Investigation & Selection: Obtains bathymetric, topographic, and geological data to avoid unsuitable or ecologically sensitive areas.

Design & Construction Optimization: Survey data determines feasibility; e.g., bridge pier placement avoids strong currents, foundation design for offshore wind turbines depends on seabed topography.

Operational Monitoring: Long-term surveys (e.g., coastal erosion) warn of potential hazards (e.g., bridge scour), ensuring long-term stability.

4.5 Facilitating Marine Supervision and Law Enforcement, Regulating Use Order [11].

Surveying provides objective, traceable spatial evidence for enforcement across multiple agencies.

Identifying Violations: Detects unauthorized construction, exceeding approved scope, or ecologically damaging activities (e.g., illegal sand mining) using integrated satellite remote sensing, UAV patrols, and ground surveys.

Evidence Collection & Dispute Mediation: Survey data serves as key evidence for administrative penalties or litigation.

Dynamic Supervision: Builds an integrated "Marine Spatial Use One Map" system combining approval, ownership, and monitoring data for comprehensive oversight.

4.6 Promoting Marine Scientific Research and Supporting Decision-Making

Long-term, continuous spatial data from surveying is crucial for marine science and macro-level decision-making.

Marine Process Studies: Reveals interactions between human activities and natural processes by analyzing temporal changes (e.g., shoreline retreat from reclamation, sedimentation rates).

Climate Change Response Research: Analyzes climate change impacts on coastal ecosystems using data like sea-level rise rates, informing adaptation strategies.

Policy Simulation & Prediction: Uses data to model marine spatial use, simulating environmental, economic, and social effects of different development scenarios to support strategic planning.

5. Conclusion

5.1 Marine spatial use surveying is a key technical link connecting "marine resources - ecological environment - human activities".

Amidst intensifying global maritime competition and increasing marine ecological pressures, accurate marine spatial use surveying has become a core foundation for promoting high-quality marine development and achieving sustainable utilization of the "blue territory". Strengthening marine spatial use management safeguards state ownership and users' legal rights, effectively promoting rational development and sustainable use. Nationally, laws regulate the interests of stakeholders and mandate sustainable marine use and development.As rapid coastal economic development intensifies land use conflicts, leading to increased demands for maritime space, national marine administrative authorities continuously enhance supervision, strictly controlling reclamation, enclosure, and development activities potentially causing severe marine environmental damage. Sea areas intended for reclamation require rigorous use demonstration arguments and mid-term environmental monitoring. Post-completion acceptance surveys are mandatory before converting sea area use permits to land use certificates. This strengthens supervision and standardizes the acceptance process for reclamation projects. Marine spatial use surveying provides essential data support and technical service guarantees for this management [12]. Currently, the legal framework for marine spatial management is continuously being strengthened, and the regulatory system is gradually improving.

5.2 Development Trends in Marine Spatial Use Surveying

As a core technical means for marine resource management and rights protection, marine spatial use surveying plays a vital role in upholding maritime rights and interests and managing sea area use. By reviewing international and domestic implementation status and China's development, trends facing marine spatial use surveying can be summarized, involving technological convergence, ecological transition, and global governance challenges[13, 14, 15].

Technological Convergence: Multiple countries are accelerating the deployment of AI-driven dynamic surveying systems (e.g., China's "Haidou-1" Unmanned Underwater Vehicle, US Autonomous Underwater Vehicles) to enhance data real-time capability.

Management Coordination: Regional cooperation mechanisms (e.g., EU Marine Spatial Planning, ASEAN marine monitoring networks) promote data sharing, although sovereignty disputes still hinder the formulation of unified standards.

Ecological Orientation: Shifting from "resource development support" to "ecological protection priority", e.g., Australia uses LiDAR to monitor coral bleaching in the Great Barrier Reef, establishing no-go zones.

Future Needs: Nations need to deepen exploration in technical standardization, legal compatibility, and international cooperation to address the dual challenges of maritime rights disputes and climate change.

6. Fund Project

Fundamental Research Funds for Central Public Welfare Research Institutes (TKS20250409, TKS20250204); Tianjin Science and Technology Plan Project (23YDPYCG00010).

References

[1] ZHANG J. A Study of the Great Geographical Discoveries[M].Beijing: The Commercial Press, 2002.

[2] LÜ C X. On China’s sea area use management and its legal regime[D]. Qingdao: Ocean University of China, 2003.

[3] Sondra Eger. Jacek Zaucha and Kira Gee, eds., Maritime Spatial Planning: Past, Present, Future (Cham, Switzerland: Palgrave Macmillan, 2018), 477 pp.[J].Ocean Yearbook Online,2020,34(1): 618-618.

[4] WANG Q. The Study of Comparison and Relationship between the Division of Marine Functional Zones and the Division of Marine Main Functional Zones[D]. Qing Dao:Ocean University of China,2008.

[5] LU F.Establishment of Supporting Systems and Standardization of Sea Area Use Management[J].Ocean Development and Management, 2008(8):66-68.

[6] LI X L. Review of China's policy and management system for the paid use of sea area[J].Chinese Journal of Population Resources and Environment, 2019(17): 58-66.

[7] WU C Q,ZHENG K Y. Research on the Measurement of Total Energy Efficiency and Its Influencing Factors in the Yangtze River Economic Belt:Based on Super-MSBM Model[J].Journal of Jiangxi Normal University (Philosophy and Social Sciences Edition), 2020,53(2):56-66.

[8] YU X.Study on the Transaction Mechanism of Sea Use Rights[D].NingBo: NingBo University, 2021.

[9] LIU B Q,ZHAO J H. Research on the Design of a Remote Sensing Classification System for Sea Area Utilization[J].Ocean Development and Management,2014(6):20-24.

[10] ZHUANG D,ZENG J S,ZHU Q L. Discussion on Preliminary Analysis Methods for the Compilation of Cadastral Maps for Sea Area Use Projects[J]. Ocean Development and Management, 2020, 37(6): 100-103.

[11] GAO Z G, ZHANG H W, JIA Y.The international law of the sea: theory and practice[M].Beijing：China Ocean Press，2006.

[12] DING N, CUI D D, WANG H J, et al. Research on the Interim and Ex Post Supervision Mechanism for Sea Area Use[J]. Natural Resource Economics of China,2018,31(10):19-22.

[13] PAN X C. Perspectives on the Sea Area Resource Management[J]. Ocean Development and Management, 2016,33(S1):16-18.

[14] HU S L. A study on land reclamation and its management system[D].Qingdao：Ocean University of China, 2011.

[15] YANG L. Application of GPS Technology in Maritime Use Surveying and Mapping[J].Urbanism and Architecture, 2015(6):333.