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Editorial

Advancements in Ocean Mapping and Nautical Cartography

Giuseppe Masetti [1,2,*], Ian Church [3], Anand Hiroji [4] and Ove Andersen [2,5]

[1] Center for Coastal and Ocean Mapping and NOAA-UNH Joint Hydrographic Center, University of New Hampshire, Durham, NH 03824, USA
[2] Danish Hydrographic Office, Danish Geodata Agency, 9400 Nørresundby, Denmark; ovand@gst.dk
[3] Department of Geodesy and Geomatics Engineering, University of New Brunswick, Fredericton, NB E3B5A3, Canada; ian.church@unb.ca
[4] School of Ocean Science and Engineering, University of Southern Mississippi, Stennis Space Center, MS 39529, USA; anand.hiroji@usm.edu
[5] Department of Computer Science, Aalborg University, Selma Lagerlöfs Vej 300, 9220 Aalborg East, Denmark
* Correspondence: gmasetti@ccom.unh.edu

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1. Introduction

Ocean mapping and nautical cartography are foundational to understanding and managing marine environments. These fields support a wide range of applications—from safe navigation and resource management to ecosystem conservation and assessment of the impacts of climate change [1]. The ocean remains largely uncharted at a high resolution, and new technologies are crucial to bridge this knowledge gap [2]. This Special Issue of *Geomatics* brings together nine studies, each tackling unique challenges facing ocean mapping. The articles highlight a wide-ranging spectrum of innovations, from automated data processing and high-resolution mapping systems to ecosystem-based planning and machine learning applications for habitat classification. Together, they showcase how diverse, interdisciplinary approaches are essential to advancing oceanography and marine spatial planning, facilitating sustainable development, and contributing to safer and more informed approaches to ocean use.

The collected works underscore the diversity of current research into ocean mapping and cartography, with methodologies ranging from traditional sonar-based mapping to advanced, machine learning-driven analyses of marine habitats. By exploring different technological and methodological advancements, this Special Issue emphasizes the importance of both preserving historical data and embracing new tools and approaches to meet the evolving demands of marine science and resource management [3]. This Editorial review provides an overview of these articles, highlighting their collective contribution to the field and their implications for the future of ocean mapping.

2. Data Collection and Review

2.1. A New Approach to Wide-Area Deep-Ocean Mapping

In response to the challenges of mapping deep-sea areas from the ocean surface, Ryu et al. [4] present a cutting-edge system that employs autonomous surface vessels to deploy a distributed array of sonar sensors. This design overcomes the limitations of sonar-based underwater mapping by achieving a high resolution at significant depths without the need to deploy costly and logistically complex underwater vessels. The sparse-array approach allows for the precise tracking of sonar positions relative to each other, compensating for oceanic conditions, and thereby advancing bathymetric mapping from the surface to unprecedented depths.

2.2. Open-Source Tools for Sonar Acceptance Testing

In the field of sonar data acquisition, testing and troubleshooting are critical for ensuring data accuracy. Younkin and Umfress [5] showcase the usefulness of Kluster, an open-source Python-based software, which streamlines sonar data processing and visualization, particularly for the Kongsberg EM712 system. By offering a user-friendly interface that supports common sonar tests, Kluster enables field professionals and scientists alike to easily evaluate and verify sonar system data, making it a valuable asset for marine data collection operations.

2.3. Automating Hydrographic Data Review for Nautical Cartography

Hydrographic data reviews involve a meticulous process that includes human error risks and substantial time investments. Masetti et al. [6] address these issues by introducing automated review tools that incorporate NOAA's hydrographic specifications, providing a standardized and efficient solution for hydrographic offices. These tools— named QC Tools and CA Tools—accelerate the data review process and improve reproducibility, serving as a model for conducting automated data reviews across the hydrographic community. This development marks a significant step forward in processing efficiency and data quality, improving navigation safety.

3. Bathymetric Modeling: Data Fusion and Interpolation

3.1. Automating Historical Data Compilation with Shom's Téthys Workflow

The French Hydrographic Service, Shom, has compiled over 300 years of data into an automated workflow known as Téthys. Le Deunf et al. [7] detail how this workflow integrates historical data from multiple sources, enhancing the accuracy of nautical charts by consolidating bathymetric data. The project emphasizes the importance of data fusion and ensures that modern digital models leverage centuries of seafloor data for current applications, demonstrating the importance of historical continuity in hydrographic sciences.

3.2. Multigrid/Multiresolution Interpolation to Reduce Data Artifacts

Traditional interpolation techniques often create artifacts such as over-smoothing in regions with a high data density. Rodriguez-Perez and Sanchez-Carnero [8] tackle this with a new multigrid interpolation approach that dynamically adapts to the data density, ensuring detail preservation in data-dense regions and achieving a smoother surface where data are sparse. This methodology allows for the creation of accurate digital elevation models (DEMs), improving seafloor mapping accuracy and providing realistic error estimations for applications like hazard mapping and habitat analysis.

3.3. Denmark's Digital Bathymetric Model

In a comprehensive mapping of Danish waters, Masetti et al. [9] compile a 50 m resolution bathymetric model using datasets spanning decades. This model serves multiple purposes, from environmental management to infrastructure development, highlighting the value of accessible, high-resolution bathymetric models in marine policy and planning. This digital bathymetric model (DBM) also offers web access through the Danish Geodata Agency, illustrating how data transparency and accessibility are integral to effective spatial planning. Notably, the insights and methodologies presented in this work provided a foundational basis for the authors' subsequent article detailing the release of an enhanced version the model, further refining its applications in marine and spatial planning [10].

3.4. Mapping the Kerguelen Plateau's Tectonic and Bathymetric Structures

In an exploration of one of the world's most remote plateaus, Lemenkova [11] integrates satellite and marine geophysical datasets to map the complex structures within the Kerguelen Plateau. This study sheds light on the plateau's tectonic history and heterogeneous seafloor composition, enriching our scientific understanding of marine geology. By overlaying magnetic, gravitational, and topographic data, this study exemplifies how advanced cartographic techniques can elucidate the geological development of underwater landforms.

4. Spatial Planning and Machine Learning for Habitat Classification

4.1. Smart Marine Ecosystem-Based Planning (SMEP) for Greece

Recognizing the importance of data-driven marine governance, Contarinis et al. [12] introduce the SMEP framework, a spatial planning approach tailored to Greek marine ecosystems. The model emphasizes the importance of iterative planning cycles and continuous environmental monitoring to ensure sustainable development. SMEP brings together ecological data and human activity metrics, fostering a comprehensive planning process that reflects Greece's unique coastal environment. This approach aims to serve as a model for responsive, ecosystem-focused governance in high-activity marine zones worldwide.

4.2. Coastal Benthic Substrate Classification Using Machine Learning

Machine learning holds significant potential in marine habitat mapping, as shown by Labbé-Morissette et al. [13] in their comparative study of the application of supervised and unsupervised models to classify benthic substrates. By employing multibeam echosounder data from the St. Lawrence Estuary, this study not only advances ecological monitoring methods but also provides essential tools for resource management and conservation in coastal habitats. The findings reveal that supervised and unsupervised learning models both offer advantages, with Gaussian mixture models excelling in terms of their efficiency and classification accuracy.

5. Conclusions

This Special Issue of *Geomatics* presents an array of research on ocean mapping and nautical cartography with compelling results, reflecting the significant progress made in this field within recent years. The studies herein demonstrate that innovations in data processing, automation, high-resolution mapping, and ecological planning are not only advancing scientific understanding but are also improving the practical applications of such strategies across the maritime and environmental sectors. By addressing longstanding challenges such as data accuracy, coverage limitations, and the integration of historical datasets, these advancements are paving the way for a more comprehensive, accessible, and sustainable approach to marine spatial planning [14–16].

Future research into ocean mapping will likely continue to combine traditional data sources with emerging technologies like machine learning and satellite geophysics [17,18]. This convergence of technologies is essential in handling the immense and varied data required to map, monitor, and protect ocean ecosystems effectively. As the demand for accurate, high-resolution seafloor data grows, particularly in the context of climate change and resource management, the approaches presented in this Special Issue will serve as models for future research, policy-making, and applied marine sciences. Ultimately, the strides made in this Special Issue exemplify the need for a forward-thinking approach to oceanography, in which data-driven interdisciplinary efforts enhance our capacity to safeguard and sustainably manage the world's oceans.

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References

1. Winther, J.-G.; Dai, M.; Rist, T.; Hoel, A.H.; Li, Y.; Trice, A.; Morrissey, K.; Juinio-Meñez, M.A.; Fernandes, L.; Unger, S.; et al. Integrated ocean management for a sustainable ocean economy. *Nat. Ecol. Evol.* **2020**, *4*, 1451–1458. https://doi.org/10.1038/s41559-020-1259-6.
2. Mayer, L.; Jakobsson, M.; Allen, G.; Dorschel, B.; Falconer, R.; Ferrini, V.; Lamarche, G.; Snaith, H.; Weatherall, P. The Nippon Foundation—GEBCO Seabed 2030 Project: The Quest to See the World's Oceans Completely Mapped by 2030. *Geosciences* **2018**, *8*, 63. https://doi.org/10.3390/geosciences8020063.
3. Mayer, L. Uncrewed surface systems facilitating a new era of global ocean exploration. *Int. Hydrogr. Rev.* **2023**, *29*, 42–55. https://doi.org/10.58440/ihr-29-a05.
4. Ryu, P.; Brown, D.; Arsenault, K.; Cho, B.; March, A.; Ali, W.H.; Charous, A.; Lermusiaux, P.F.J. A Wide-Area Deep Ocean Floor Mapping System: Design and Sea Tests. *Geomatics* **2023**, *3*, 290–311.
5. Younkin, E.; Umfress, S.H. Performing a Sonar Acceptance Test of the Kongsberg EM712 Using Open-Source Software: A Case Study of Kluster. *Geomatics* **2022**, *2*, 540–553.
6. Masetti, G.; Faulkes, T.; Wilson, M.; Wallace, J. Effective Automated Procedures for Hydrographic Data Review. *Geomatics* **2022**, *2*, 338–354. https://doi.org/10.3390/geomatics2030019.
7. Le Deunf, J.; Schmitt, T.; Keramoal, Y.; Jarno, R.; Fally, M. Automating the Management of 300 Years of Ocean Mapping Effort in Order to Improve the Production of Nautical Cartography and Bathymetric Products: Shom's Téthys Workflow. *Geomatics* **2023**, *3*, 239–249.
8. Rodriguez-Perez, D.; Sanchez-Carnero, N. Multigrid/Multiresolution Interpolation: Reducing Oversmoothing and Other Sampling Effects. *Geomatics* **2022**, *2*, 236–253.
9. Masetti, G.; Andersen, O.; Andreasen, N.R.; Christiansen, P.S.; Cole, M.A.; Harris, J.P.; Langdahl, K.; Schwenger, L.M.; Sonne, I.B. Denmark's Depth Model: Compilation of Bathymetric Data within the Danish Waters. *Geomatics* **2022**, *2*, 486–498. https://doi.org/10.3390/geomatics2040026.
10. Masetti, G.; Granding, P.S.; Langdahl, K.; Schwenger, L.M.; Kristmar, K.V. Denmark's Depth Model version 2.0—Improved compilation of bathymetric data within the Danish waters. *Int. Hydrogr. Rev.* **2024**, *30*, 50-63. https://doi.org/10.58440/ihr-30-2-a17.
11. Lemenkova, P. Seafloor and Ocean Crust Structure of the Kerguelen Plateau from Marine Geophysical and Satellite Altimetry Datasets. *Geomatics* **2023**, *3*, 393–426.
12. Contarinis, S.; Nakos, B.; Pallikaris, A. Introducing Smart Marine Ecosystem-Based Planning (SMEP)—How SMEP Can Drive Marine Spatial Planning Strategy and Its Implementation in Greece. *Geomatics* **2022**, *2*, 197–220.
13. Labbé-Morissette, G.; Leclercq, T.; Charron-Morneau, P.; Gonthier, D.; Doiron, D.; Chouaer, M.-A.; Munang, D.N. Classification of Coastal Benthic Substrates Using Supervised and Unsupervised Machine Learning Models on North Shore of the St. Lawrence Maritime Estuary (Canada). *Geomatics* **2024**, *4*, 237–252.
14. Lecours, V.; Oxton, A.; Khor, D.; Tiplea, J. High-Resolution Ensemble Modelling of Coral Distributions in the Northern Gulf of Mexico Based on Geomorphometry: Coral Diversity and Benthic Habitat Fragmentation From Oil and Gas Infrastructure to Inform Spatial Planning. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2024**, *34*, e4234. https://doi.org/10.1002/aqc.4234.
15. Sowers, D.C.; Mayer, L.A.; Masetti, G.; Cordes, E.; Gasbarro, R.; Lobecker, E.; Cantwell, K.; Candio, S.; Hoy, S.; Malik, M.; et al. Mapping and Geomorphic Characterization of the Vast Cold-Water Coral Mounds of the Blake Plateau. *Geomatics* **2024**, *4*, 17–47.
16. Church, I.W. Multibeam Sonar Ray-Tracing Uncertainty Evaluation from a Hydrodynamic Model in a Highly Stratified Estuary. *Mar. Geod.* **2020**, *43*, 359–375. https://doi.org/10.1080/01490419.2020.1717695.
17. Elmore, P.; Calder, B.; Petry, F.; Masetti, G.; Yager, R. Aggregation Methods Using Bathymetry Sources of Differing Subjective Reliabilities for Navigation Mapping. *Mar. Geod.* **2023**, *46*, 99–128. https://doi.org/10.1080/01490419.2023.2166173.
18. Parrish, C.E.; Magruder, L.; Herzfeld, U.; Thomas, N.; Markel, J.; Jasinski, M.; Imahori, G.; Herrmann, J.; Trantow, T.; Borsa, A.; et al. ICESat-2 Bathymetry: Advances in Methods and Science. In Proceedings of the OCEANS 2022, Hampton Roads, Hampton Roads,VA, USA, 17–20 October 2022; pp. 1–6.