SCIENTIFIC AND TECHNOLOGICAL RESEARCH ARTICLE

Oceanographic cruises within a spatial data infrastructure. Colombia case study

Cruceros oceanográficos sobre una infraestructura de datos espaciales. Caso de estudio Colombia

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Ruby Viviana Ortiz Martínez[1], Diana Paulina Castañeda Rodríguez[2], Moisés Abraham Santizo Fuentes[3]

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ABSTRACT

Oceanographic cruises, and scientific expeditions at sea in general, constitute an important contribution to the historical memory of the beginnings and evolution of marine scientific research and, within the framework of the Decade of Ocean Science, access to the data collected for decades support sustainable ocean development. For this reason, the Colombian Center for Oceanographic Data carried out a process of archaeology and recovery of data and information from oceanographic cruises carried out in the Colombian Pacific and Caribbean from 1969 to 2020. Subsequently, the information was structured in a geographic database known as the national Maritime, Fluvial and Coastal Spatial Data Infrastructure. In addition, metadata was documented under a profile of the ISO 19115 standard, implementing good international practices, and a software application was developed to facilitate the search for geographic information and open access to measurements made on site. As a result, information from 130 oceanographic cruises (1969-2020) was made available, 96 technical cruise reports were recovered, 87 track charts were reconstructed, and 130 metadata were published, with the possibility of continuing to feed the system with new cruises and scientific expeditions.

KEYWORDS: Research vessel, expedition reports, oceanographic data, Geographic information systems.

RESUMEN

Los cruceros oceanográficos y, en general, las expediciones científicas en el mar, constituyen un importante aporte a la memoria histórica de los inicios y evolución de la investigación científica marina; y en el marco del Decenio de las Ciencias Oceánicas, el acceso a los datos recopilados durante décadas apoya el desarrollo sostenible del océano. Por esta razón, desde el Centro Colombiano de Datos Oceanográficos se llevó a cabo un proceso de arqueología y recuperación de datos e información de los cruceros oceanográficos realizados en el Pacífico y Caribe colombianos desde 1969 hasta el 2020. Posteriormente, se estructuró la información en la base de datos geográfica denominada Infraestructura de Datos Espaciales Marítima, Fluvial y Costera de Colombia. Además, se documentaron metadatos bajo un perfil del estándar ISO 19115 implementando buenas prácticas internacionales, y se desarrolló una aplicación software para facilitar la búsqueda de información geográfica y acceso abierto a las mediciones realizadas en sitio. Como resultado se dispuso la información de 130 cruceros oceanográficos

[1] Orcid: 0000-0003-0264-6254. Cecoldo Administrator at the General Maritime Directorate. Carrera 54 No. 26-50, edificio Dimar, CAN. Email: rortiz@dimar.mil.co

[2] Orcid: 0000-0002-8848-2600. General Maritime Directorate, Subdirectorate of Maritime Development. Carrera 54 No. 26-50, edificio Dimar, CAN. Email: dcastanedar@dimar.mil.co

[3] Orcid: 0009-0006-8986-7365. Researcher, Universidad Nacional de Colombia. Email: masantizof@unal.edu.co

(1969-2020), se recuperaron 96 informes técnicos de cruceros, se reconstruyeron 87 rutas de buques de investigación y se publicaron 130 metadatos, con la posibilidad de seguir alimentando el sistema con nuevos cruceros y expediciones científicas.

Palabras claves: *buque de investigación, reportes de expedición, datos oceanográficos, sistemas de información geográfica.*

Introduction

Between 1969 and 1970, the first oceanographic cruises in the Colombian Caribbean and Pacific were carried out aboard the vessel ARC San Andrés. This initiative arose from the need to conduct oceanographic research within the framework of the then Colombian Oceanography Commission. It aimed to address the scientific and economic significance of the country's coastlines and establish a basic infrastructure to contribute to the knowledge and sustainable technical exploitation of ocean resources. The effort involved close coordination between national institutions and international organizations (ARC, 1970, 1971). Other countries in the region also launched significant oceanographic operations around the same time. For example, Chile began in 1960 using the former Chilean Navy corvette Chipana (Sievers, 2017), and Peru initiated an intensive monitoring program of marine conditions up to 150 miles off the coast aboard the BAP Bondy between 1958 and 1963 (Zuta & Flores, 1980).

These activities took place in a global context under the coordination of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific, and Cultural Organization (UNESCO). The International Oceanographic Data and Information Exchange (IODE) of the IOC implemented a system of national oceanographic programs and the Reports of Observations/Samples Collected by Oceanographic Programs (ROSCOP) in the late 1960s to facilitate information sharing about planned and conducted research cruises (Rickards, 2007).

ROSCOP initially served as a primary inventory for tracking measurements and samples collected at sea aboard research vessels, covering various data disciplines, including physical, chemical, and biological oceanography, marine geology and geophysics, fisheries, marine pollution and marine meteorology. In the late 1980s, the International Council for the Exploration of the Sea (ICES) led the digitization of cruise reports initially available in paper format. ICES pioneered the development of a database to manage this information (Rickards, 2007).

Following a significant revision, in 1990 the Cruise Summary Report (CSR) succeeded the ROSCOP form and, though it was developed for ICES member countries, it was extended to others interested in providing their information (Rickards, 2007). This activity received a boost in Europe during the development of the SeaDataNet infrastructure between 2006 and 2011. The French Institute for Research and Exploitation of the Sea (IFREMER), under the framework of SeaDataNet, took over this task. The CSR database, combined with ICES and SeaDataNet, contains information from oceanographic research cruises primarily conducted in Europe and other regions worldwide (POGO, 2023). In the same vein, the Partnership for Observation of the Global Ocean established a database covering open ocean research vessels operated by institutes worldwide (Rickards, 2007).

It is worth noting that CSR is part of the data management strategy throughout its life cycle. Its contributions range from data management plans to the point where the collected data is accessible, not only through metadata but also for data discovery, extraction, and analysis from various sources. This justifies the high cost of the expedition (Che-Bohnenstengel & Nast, 2013). Therefore, there has been significant interest in Latin American and Caribbean countries in recent years in creating databases related to ships and scientific expeditions.

In Colombia, several needs have arisen regarding the management of oceanographic cruises. In this regard, the Pan-European Infrastructure for Ocean and Marine Data Management (SeaDataNet) provides tools based

on international standards and best practices related to its CSR management experience. It utilizes a geospatial data model designed specifically for the marine geographical information system (GIS) community, developed by researchers from Oregon State University, Duke University, the National Oceanic and Atmospheric Administration (NOAA), the Danish Hydrological Institute, and the Environmental Systems Research Institute (ESRI), called "Arc Marine" (Serpa & Wright, 2005). This model is implemented using Colombia's maritime, riverine, and coastal Spatial Data Infrastructure (SDI) as a computer system containing a set of resources (catalogs, servers, programs, applications, etc.) that allow access to and management of the datasets and geographic services available on the network. It also complies with a series of standards, regulations, and specifications that regulate and ensure the interoperability of geographical information (Iniesto & Núñez, 2020) for the administration of open data from the Colombian Oceanographic Data Center (Cecoldo). Together, these components provide a solution to meet the needs for managing this type of information in the country.

Study Area

Figure 1 shows the study area covered by Colombia's oceanographic cruises and scientific expeditions at sea, coordinated or involving the General Maritime Directorate (Dimar). In the Caribbean, it encompasses the Colombian maritime territory between 11°00'00'' N and 16°00'00'' N and 71°00'00'' W and 82°00'00'' W, where oceanographic cruises have been conducted as part of initiatives such as 'Océano,' the programs of the Cooperative Investigation of the Caribbean and Adjacent Regions, 'Caribe,' 'Golfo de Urabá,' 'Guajira,' 'Islas del Rosario,' 'San Andrés Islas', the oceanographic and atmospheric forecasting system (SPOA, for its Spanish acronym), fishing research, and the most recent 'Expedición Científica Seaflower' (Scientific expeditions of the Seaflower biosphere reserve). On the other

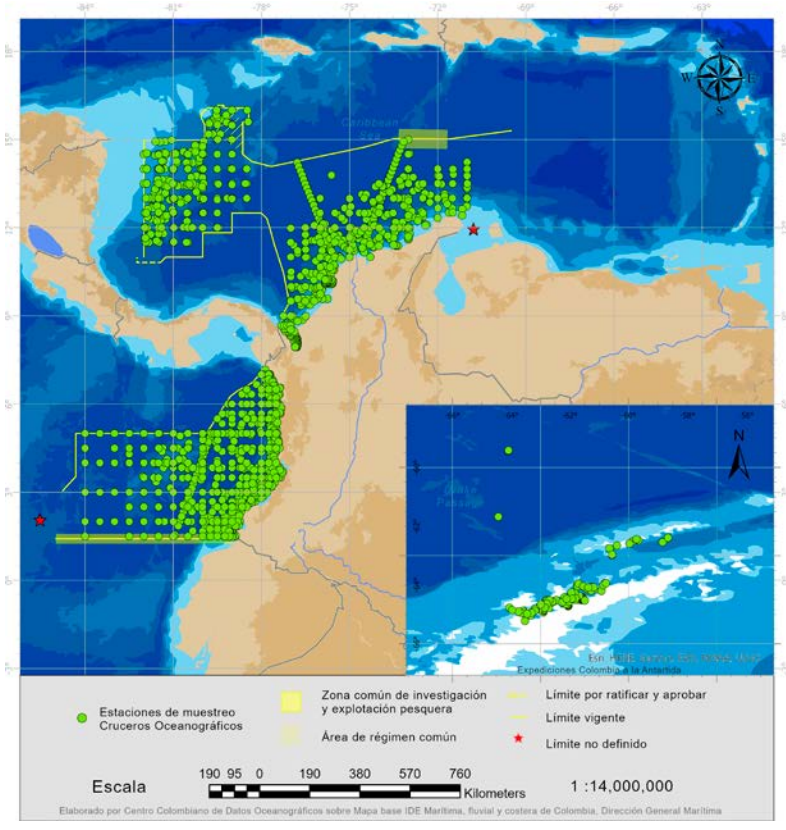

Figure 1. Location of sampling stations for oceanographic cruises (1970-2020) available from Cecoldo

hand, in the Colombian Pacific, oceanographic cruises cover the area between 01°20'00'' N and 07°10'00'' N and 77°00'00'' W and 84°00'00'' W, from 1970 until today, as part of initiatives such as the Regional Study of the El Niño Phenomenon (ERFEN, for in Spanish acronym), SPOA, fishing research, and the 'Expedición Científica Pacífico' (Scientific expedition of the Pacific).

In the context of the Colombian Antarctic Program, since the austral summer of 2014-2015, Colombia has also participated in expeditions to Antarctica through various research projects in the region. Specifically, in the Gerlache Strait, located between 63° 56 '43'' S to 64° 59' 29'' S and 61° 24 '33'' W to 63° 57' 09'' W.

Methodology

The methodology that was applied integrated international standards and best practices from various disciplines and was developed in three phases (Fig. 2). For the archaeology and retrieval of information regarding oceanographic cruises, the methodology proposed by Hernández, Ortiz, and Suárez (2007) was used. This methodology is based on the conceptual foundation of the Global Oceanographic Data Archaeology and Rescue (GODAR) project, aimed at increasing historical oceanographic digital archives for inclusion in databases accessible to the global community (IOC, 1993).

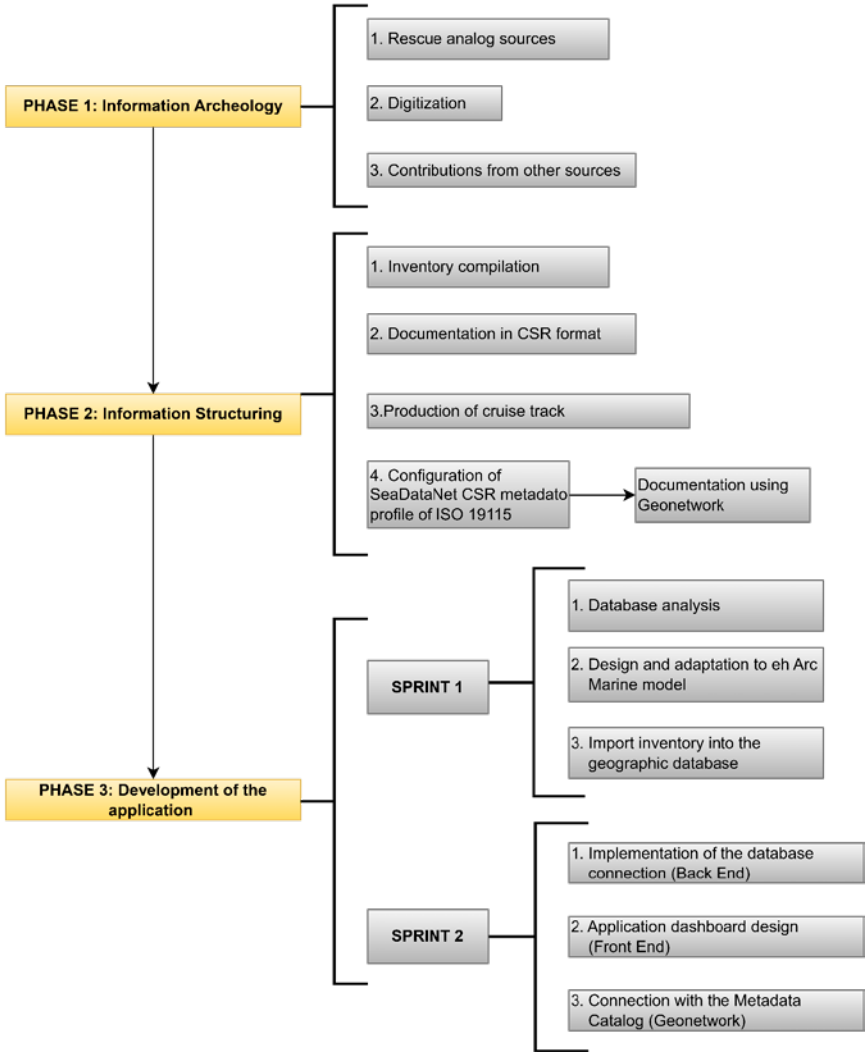

Figure 2. Summary of the methodology applied in the case study

Once the digital files were obtained, the CSR form was used to gather the required information, and each cruise track chart (derrota[4]) was prepared using a standardized template of the Colombian Maritime Authority (Dimar). This used information from the maps available in the technical reports of oceanographic cruises, and this information was correlated with the geographical and temporal data available in the collected data files.

In cases where it was not possible to retrieve the track chart because it was not included in the technical report of the oceanographic cruise, the ship's route was reconstructed based on the records of date, time, and geographical coordinates of the data collected on-site. This process began in spreadsheets, including the classification of information as public (unclassified or classified) in accordance with Colombian Law 1712 of 2014: "By which the Law for Transparency and the Right of Access to National Public Information are created, and other provisions are enacted." This information was imported into ArcGIS Pro to georeference the sampling stations. Subsequently, the ship's route was traced using the Points to Line tool, and the information was finally stored in a GeoDatabase (GDB).

For metadata capture, the ISO 19115 standard SeaDataNet CSR profile was configured in the Geonetwork Open Source catalog tool, as recommended in Volume 5 of the "Ocean Data Standards" (IOC, 2021). To implement the geospatial application, the Agile Scrum software development methodology was used, with a total of two sprints or work processes that included both the database and software components. The first sprint resulted in the GDB being implemented based on the ESRI Arc Marine model on the Maritime, Riverine, and Coastal SDI of Colombia. In the second sprint, the geospatial viewer was designed using the ArcGIS Online dashboard tool to configure geographical and thematic search filters, content visualization, and connection to the Geonetwork metadata catalog.

Results

Phase I. Information Archaeology

Data and information archaeology were conducted based on the results of the 'Strategic Positioning of the Colombian Oceanographic Data Center' project (2015-2017), funded by Dimar. Once the information sources were identified, on-site paper document management was carried out, following the recommendations of the National General Archive (AGN). The digitization efforts focused on recovering: (i) oceanographic cruise reports; (ii) forms with oceanographic and marine meteorological data; (iii) scientific articles, special publications, and related gray literature.

Additionally, a search for information in electronic media such as servers, computers, external hard drives, floppy disks, or any storage media was conducted to complement the digitized information. This effort resulted in the recovery of 96 technical report files (final or preliminary) from 130 oceanographic cruises and scientific expeditions conducted between 1969 and 2020 by the Colombian Navy (ARC) and Dimar, 35 track charts, eight CSRs, and the majority of data reported in the technical reports, except for data collected by institutions invited to the cruises.

Phase II. Information Structuring

Based on the content of the technical reports, and after validation with the geographical and temporal data collected in the field, 122 CSR forms were filled out and registered in Cecoldo's Single Format for Inventory of Oceanographic Cruises and Scientific Expeditions.

Since 67% of the technical cruise reports did not include a track chart, it was necessary to reconstruct the route of each of these cruises based on oceanographic and meteorological measurements. Key data for reconstructing the routes were the date, time, and geographical coordinates of the sampling stations, especially those recorded together with temperature and salinity measurements of the water column obtained with a conductivity, temperature and depth profiler (CTD), which is typically deployed at all stations, or with data from the onboard automatic weather station on the ship.

The key data were organized in a spreadsheet and imported into ArcGIS Pro, where the sampling stations were georeferenced, and the ship's route was traced. Upon completing

[4] The Colombian Maritime Authority defines "derrota" as the representation of the navigation that must be carried out, and indeed is carried out, to go from one point to another, while having to follow one or more courses. The "carta de derrota", or cruise track chart, precisely represents the trajectory followed by a vessel.

this geoprocessing, a set of polylines called tracks was obtained, and their attributes were subsequently adjusted to the Arc Marine model. As a result, 6 536 sampling stations were georeferenced, covering approximately 160 599 nautical miles traveled in 130 oceanographic cruises and/or scientific expeditions at sea, and 116 cruise tracks were drawn for 87 track charts, considering that an oceanographic cruise can have more than one study area and therefore more than one track.

As an example, Figure 3 shows the track chart originally found in the technical report of the Pacific XXVIII / ERFEN XXVI Cruise of 1997 and the track chart reconstructed in this research. It is worth noting that it was not possible to reconstruct the track chart of 12 oceanographic cruises due to a lack of sufficient information related to the date, time, and geographical

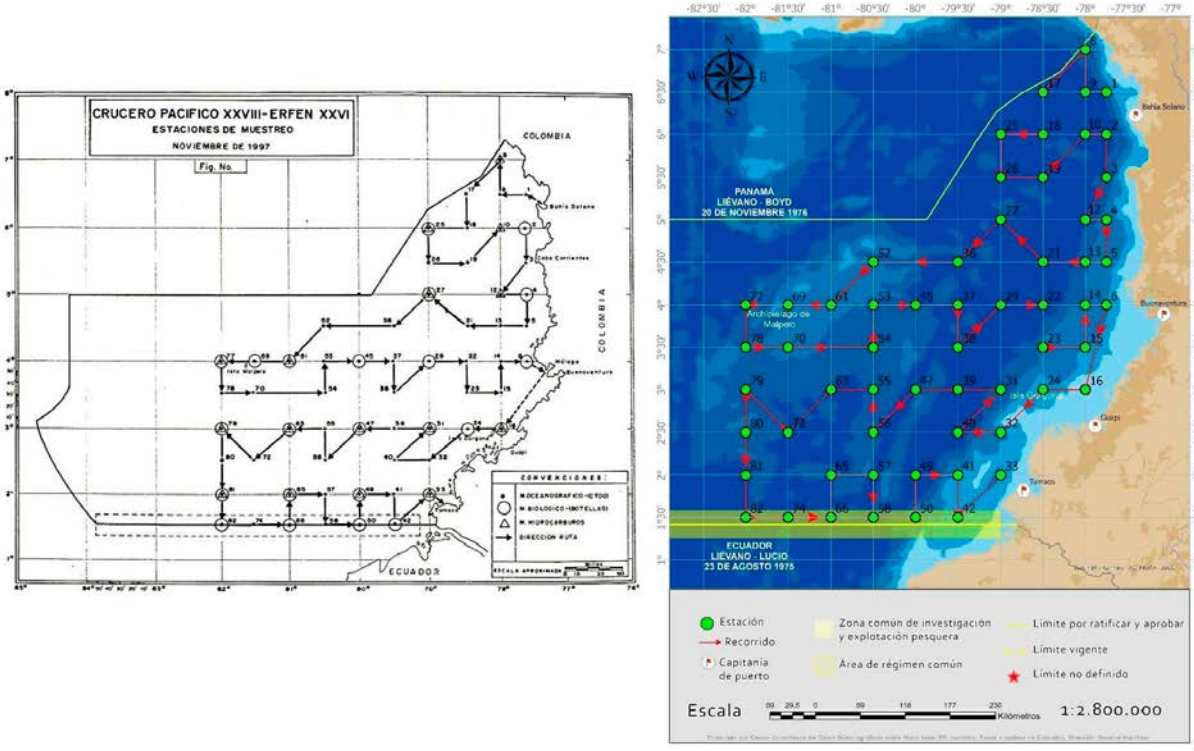

Figure 3. Original (**A)** and reconstructed (**B)** track chart of the Pacific XXVIII / ERFEN XXVI Cruise from 1997

coordinates of the sampling stations, which prevented the tracing of the ship's route.

Finally, the profile of the ISO 19115 standard SeaDataNet CSR and the encoding in the Extensible Markup Language (XML) version 5.2.0 available in SeaDataNet (2020) were configured in the Geonetwork Open Source catalog tool adapted by Cecoldo. Subsequently, 130 metadata records were captured based on the information documented in the CSR form and 118 graphic samples of track charts. For the tracks that could not be reconstructed, a graphic presentation with sampling stations was loaded.

Phase 3: Development of the application

This phase began with the design of the database based on the ESRI Arc Marine model implemented in the Maritime, Riverine, and Coastal SDI of Colombia. It was considered that this is a generic model that can be used as a central building block for the development of applications in coastal and marine environments (Wright *et al*.,

2007). For this case study, the classes associated with oceanographic cruise inventory information, ship tracks, and sampling stations were adapted.

The resulting Geodatabase (GDB) consists of four alphanumeric tables (green) from the original Arc Marine schema that store basic information related to each oceanographic cruise (departure date, arrival date, ship name, track chart, etc.) and two auxiliary tables (red) to address specific CSR requirements, such as ship description and the Unique Metadata Identifier (UUID) assigned by GeoNetwork for each documented metadata. Additionally, two geographical layers were implemented to store the geometry of the tracks (line type) and sampling stations (point type). The specifications of each type of attribute and other features were documented in the data dictionary of the geographical application. To conclude, the inventory information was imported into the Cruise table, and the established relationships in the Entity-Relationship (ER) model were validated (Fig. 4).

This phase concluded with the development of the geographical application that allowed the consolidation of the content of the CSRs, i.e., the information stored in the Arc Marine model, along with geographical and alphanumeric information, and the connection with the Geonetwork metadata catalog. With the support of the Maritime, Riverine, and Coastal Spatial Data Infrastructure

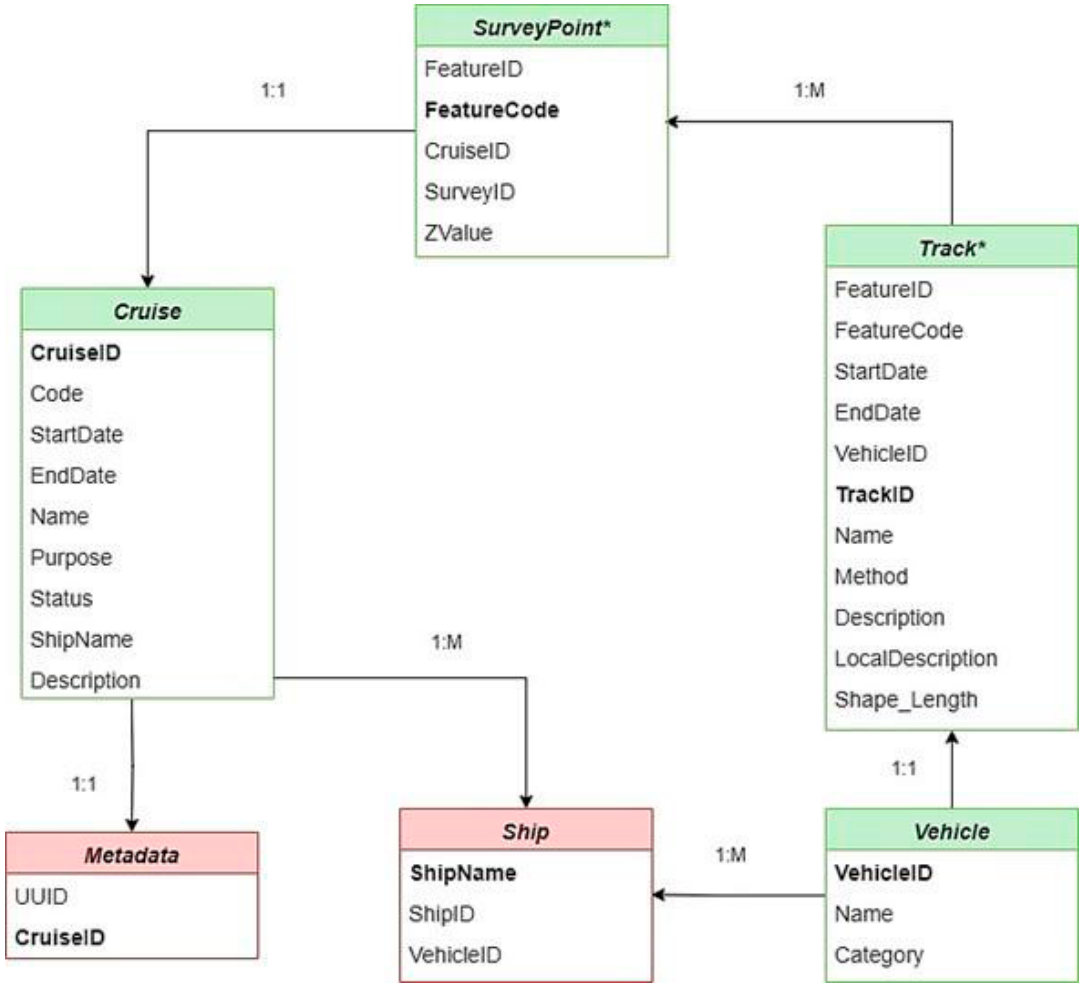

Figure 4. Adapted Arc Marine Entity-Relationship (ER) Model for the Geodatabase (GD**B)**

of Colombia, the process began by loading the GDB to their platform and establishing connection parameters for the publication of information.

Next, using an ArcGIS Online dashboard, the user interface (Front End) of the geographic application was configured, including the display of the data table (Data Frame) on the institutional base map of Dimar with the cruise tracks (Fig. 5). Additionally, a view with the data from the GDB of the CSR from Cecoldo was configured, which includes the UUID attribute for each piece

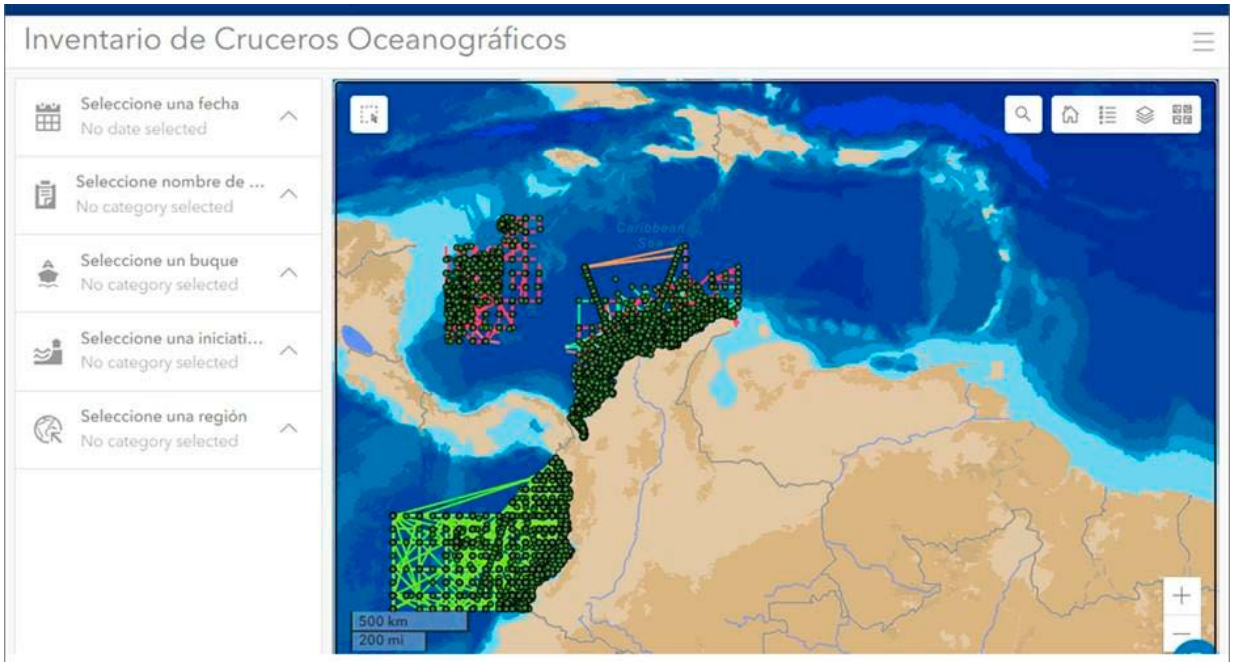

Figure 5. User interface appearance for CSR search

of metadata, so that the user can access detailed information about the oceanographic cruise (metadata) and download the related open data from the Geonetwork catalog.

Discussion

The process of data archaeology and information recovery of Colombian oceanographic cruises allowed for the gathering and structuring of relevant content for the CSR. However, it also revealed historical information gaps regarding the cruises, which might be associated with the abandonment of the ROSCOP best practice of documenting, as evidenced in the technical reports of cruises conducted in the Colombian Pacific by the Center for Oceanographic and Hydrographic Research of the former General Maritime and Port Directorate in the 1990s (CIOH, 1993). Around the late 1990s, there was a correlation of this best practice with the Southeast Pacific initiatives, which were supported by the Tropical Ocean Global Atmosphere (TOGA) program that contributed to the objectives of the Regional Study of the El Niño Phenomenon (ERFEN), within the framework of joint regional cruises of the Permanent Commission for the South Pacific (CPPS) (CPPS, 2000).

Therefore, the information recovery phase allowed the identification of the deficiency in the necessary records to report all the elements that make up the global inventory of cruises and expeditions at sea. Consequently, it is currently imperative to reintroduce this international best practice to contribute, not only by using online catalogs but also by incorporating the original CSR form into official technical cruise reports. The latter represents a significant contribution to the historical memory of oceanographic cruises and other activities, as are the devices that were installed, launched, and/or recovered during

these initiatives.

For its part, the IOC (2019a) recommends using controlled vocabularies from the NERC Vocabulary Server to describe marine and oceanographic data sets, in order to integrate permanent identifiers, concise text strings, and complete term descriptions in different applications. However, in the implementation of the XML encoding recommended by IOC (2021) for SeaDataNet CSR metadata, controlled vocabularies for 'projects,' 'vessels,' and 'organizations' could not be adapted, and they do not include initiatives from the Latin American community.

Two of these vocabularies correspond to the themes being addressed in the architecture of the Ocean Data and Information System within the framework of the "United Nations Decade of Ocean Science for Sustainable Development," especially the Ocean Infohub (OIH) - Latin America and the Caribbean (LAC) mechanism of the pilot project "Clearing-House Mechanism LAC," implemented from Recommendation SC-IOCARIBE-XV.1 – IOC New Capacity Development Strategy: Implementation Plan (IOC, 2019b). OIH LAC allows for a hybrid model to provide access to information on resources identified in the region, including the themes of 'vessels' and 'projects.' This demonstrates the need to visualize global cruise initiatives in catalogs and, for the case study, the potential interoperability of the Maritime, River, and Coastal SDI of Colombia with the national cruise inventory developed.

Furthermore, while Arc Marine served as a base data model, meeting the primary needs of structuring and storing geographic data related to CSR and allowing for a logical representation of these data, it did not cover all the identified requirements. Therefore, it was necessary to add alphanumeric tables to the model, which turned out to be adaptive, as stated by Andrews and Ackerman (2008). They coincided in that "the Arc Marine data model provides both the basic elements to represent or model common marine data types and the tools to extend these basic representations to more complex marine objects through particular relationships and needs."

After a series of adaptations made to the Arc Marine model, Lord-Castillo *et al*. (2009) pointed out a key concept that can help guide future developments, consistent with the results of this study. It's the idea that "the model's foreseen multidimensionality can be effectively expanded with additional dimensions (such as time)." This way, the multidimensionality of the model was verified, successfully integrating the reconstructed ship route tracks for the 87 cruises by linking the *Survey Point* and *Cruise* tables.

Lastly, it is worth mentioning that Isenor and Spears (2013) emphasized the practicality of the Arc Marine model for incorporating aspects of the ISO 19115 standard for geographic metadata. This conclusion was confirmed in the present study, as the Metadata attribute was added, integrating the SeaDataNet CSR metadata model adopted by Cecoldo.

Conclusions

The Inventory of Colombian Oceanographic Cruises is the product of integrating records from various sources and formats, resulting from a process of data archaeology and information recovery, applying international best practices and information technologies. It is essential to recognize that the contribution of this process goes beyond the recovery of cruise information, delving into the beginnings of marine scientific research in the country and the evolution of oceanographic platforms and instrumentation used. It supports Colombia's work as an oceanic power for decades and highlights efforts to understand and explore Colombian maritime territory.

The objective of the inventory of oceanographic cruises should be seen as more than just implementing a database or providing access to collected data. It should be a tool for discovery to aid in the planning of cruises and expeditions, the efficient use of research vessels, and inter-institutional participation. In this sense, the initiative developed by Cecoldo on the Maritime, River, and Coastal SDI of Colombia represents an important starting point for improving the exchange of historical and current information about oceanographic cruises conducted in the country and in Antarctica, with growth potential to contribute to decision-making at different levels of management.

The ESRI Arc Marine model provided a scalable

framework for the Maritime, River, and Coastal SDI of Colombia, easy to adapt to encompass broader concepts in line with the current needs of marine geographic information management, especially related to CSR and its spatial representation. It can be combined with tools for configuring and developing geographic applications in a hybrid environment (cloud-based and on-site).

Adapting the SeaDataNet CSR metadata profile to the Geonetwork metadata catalog opens up possibilities for interoperability because the use of the XML schema enables communication and exchange with other data centers and platforms, using a common language and contributing to the FAIR principles (Findability, Accessibility, Interoperability, and Reuse). An important step toward a comprehensive and long-term archive of national oceanographic cruise information is to include metadata in the global SeaDataNet CSR database managed by IFREMER. This management can be performed through programs or projects associated with cruises via the Maritime, River, and Coastal SDI of Colombia and Cecoldo.

Finally, it is essential to continue making improvements to the CSR workflow to make it more efficient, timely (providing information as quickly as possible after a cruise ends) and decentralized (allowing input from different data providers and producers), and promoting interoperability with other processes related to the data lifecycle. This will help to avoid the need for future historical information recovery.

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Authors' contributions

Conceptualization: R. O.; Methodology: R. O., D. C.; Analysis: D. C., R. O.; Software: M. S., D. C., R. O.; Writing - Original Draft Preparation: R.O., D. C., M. S.; Proofreading and Editing: R. O.; Visualization: D. C. All authors have read and approved the final published version of the manuscript.

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