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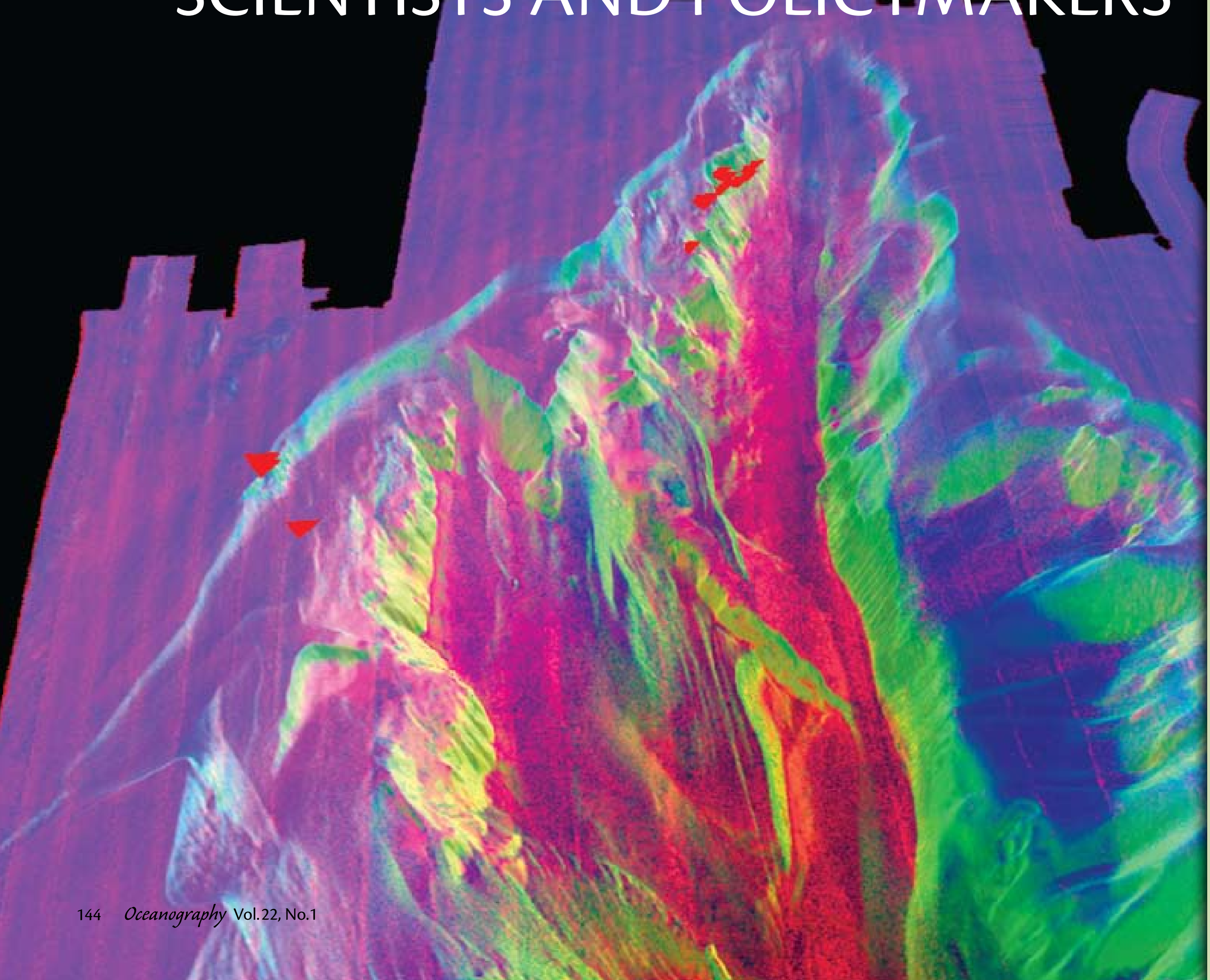
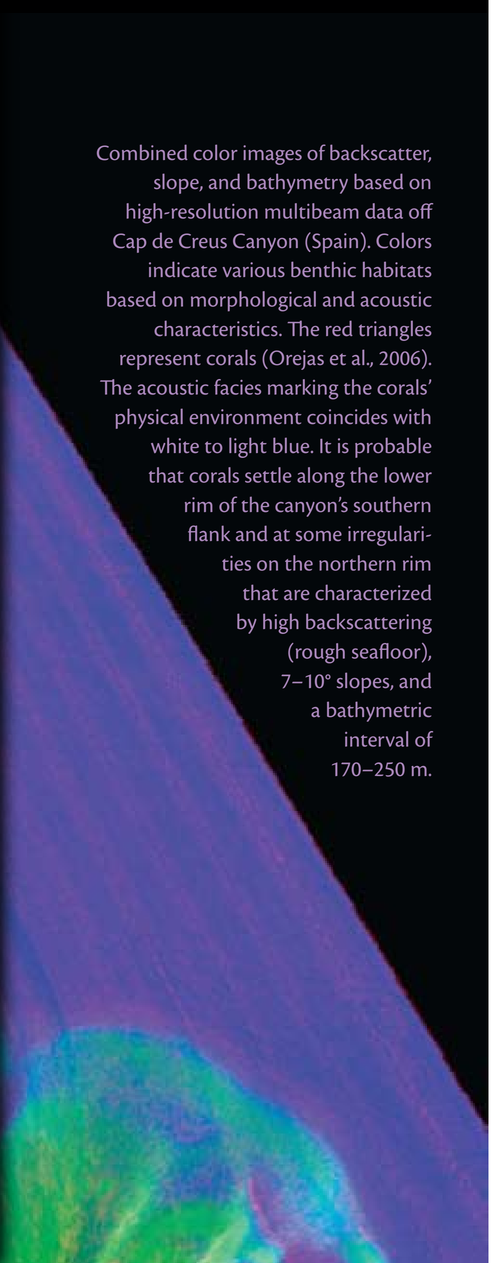
HERMES-GIS

A TOOL CONNECTING SCIENTISTS AND POLICYMAKERS



ABSTRACT. An important aim of large, pan-European scientific projects with numerous research groups is to integrate and visualize the acquired distributed data sets and results. The large volume of diverse data gathered and the need to disseminate results among the scientific community and beyond requires using a Geographic Information System (GIS). This article presents our experiences in creating a unified Web-based GIS for HERMES. The HERMES-GIS is based on Web Mapping Services that include direct links to the World Data Center for Marine Environmental Science and its large, long-term geoscience data archive and publication unit, PANGAEA (http://www.pangaea.de). It incorporates metadata and data from all project partners to provide users with basic analytical and visualization tools for archived (distributed) and personal (local) data, and it is also a policy-making tool. Additionally, we illustrate two important GIS applications inside the HERMES community—the use of data models to integrate several subdisciplines and the use of predictive habitat modeling.



Combined color images of backscatter, slope, and bathymetry based on high-resolution multibeam data off Cap de Creus Canyon (Spain). Colors indicate various benthic habitats based on morphological and acoustic characteristics. The red triangles represent corals (Orejas et al., 2006). The acoustic facies marking the corals' physical environment coincides with white to light blue. It is probable that corals settle along the lower rim of the canyon's southern flank and at some irregularities on the northern rim that are characterized by high backscattering (rough seafloor), 7–10° slopes, and a bathymetric interval of 170–250 m.

INTRODUCTION

Geographic Information Systems (GISs) are tools used to gather, transform, manipulate, analyze, and produce information related to Earth's surface. GIS can be as complicated as required, scaling with requirement and demand. Whole systems can be developed that use databases and workstations in network configurations, or that use simple desktop software. Governments, research institutes, and local authorities that cannot possibly handle the task of manually processing large amounts of geographical data use GIS. The HERMES-GIS (Figure 1) is an interactive tool for visualizing georeferenced information related to HERMES scientific cruises, major project results, and project-specific information. It was developed as a dynamic Web-based geographical information system (WebGIS) (Figure 2). The great strength of a Web-based GIS lies in its software independence and interactive querying and visualization tools that can be linked to distributed data archives and original data sets worldwide. The HERMES-GIS features a constantly updated inventory of margin hotspots identified by HERMES scientists (e.g., canyons, cold-water corals, cold-seep sites, landslides), together with socio-economic information superimposed on seafloor maps at various scales. In addition to metadata of cruise tracks and sampling stations, the HERMES-GIS can display very detailed information, such as side-scan sonar imagery, subbottom profiles, bathymetric data, and photographic images. These results can be presented as spatial rasters, tables, or vector data, allowing a range of information to be incorporated into the GIS. To ensure the availability and protect the intellectual property of data, unpublished sources can be password-protected and made accessible only to HERMES partners. Published and

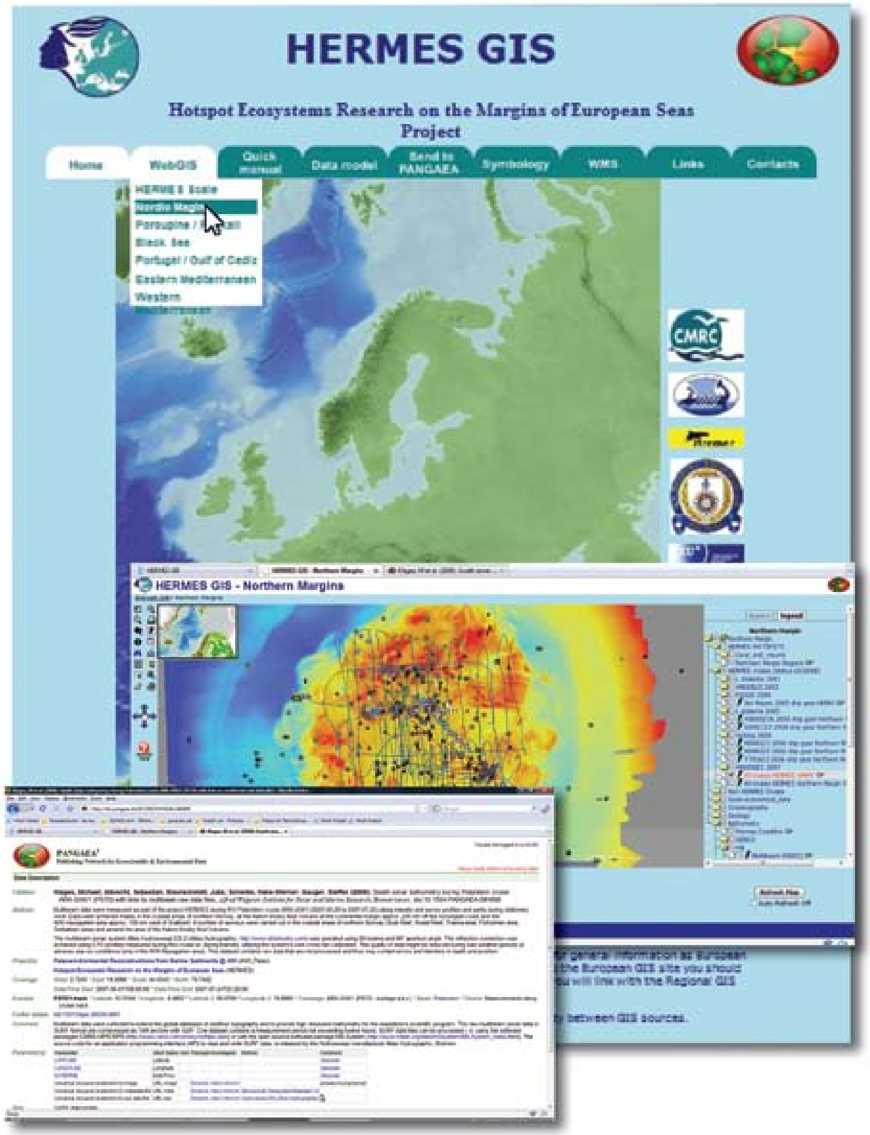


Figure 1. The HERMES-GIS Portal and WebGIS. This screen shot demonstrates the GIS structures and layout with the interactive hyperlinks that connect to the central data archiving system PANGAEA (http://www.ub.edu/hermes).

background data are available for general viewing through an open Web interface (http://www.ub.edu/hermes).

Before any data are entered into the GIS, they are first stored in the digital library of the World Data Center for Marine Environmental Science (WDC-MARE) Publishing Network for Geoscientific and Environmental Data (PANGAEA; http://www.pangaea.de) (Box 1), the main data archive for HERMES information. To ensure consistency, all partners submit their data to PANGAEA and make their results available for visualization via the HERMES-GIS. Although submitting data may seem like a chore, the benefits gained by contributing to a centralized data management system are huge. HERMES-GIS visualization capabilities benefit HERMES partners when planning cruises, and the online availability of data and results can also improve their scientific interpretations. This system facilitates communication among scientists and the overall integration of project results (Figures 1 and 2). Ultimately, the GIS is central to crosscutting work packages, such as the Sustainable Management and Policy Advice work package (see Grehan

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et al., this issue), that take a holistic view of all data collected throughout the HERMES project.

STRUCTURE

Given the large geographic area covered by HERMES, the GIS is managed at a regional scale. The second level of the GIS reflects the project's subdisciplines, displaying biological, geological, and oceanographic data. Additional background information, such as on hotspot ecosystems, bathymetry, general oceanography, and socio-economical boundaries, is included, if available. By following the project's structure, the GIS layers aim to facilitate information flow from the point of data collection to publication. By encouraging researchers to integrate their data into the WebGIS, it is anticipated that HERMES will yield results far beyond the project's duration.

REGIONAL GIS

The system's success depends on initial submission of data and results by HERMES scientists to PANGAEA. To motivate and support data submission and GIS use, local GIS coordinators were nominated for each HERMES geographical region. These regional coordinators liaise closely with the scientists in their regions and also maintain a regional GIS server. Each regional coordinating institute promotes and supports GIS use, from desktop GIS to online HERMES-GIS, and prepares GIS products on request from project partners, such as maps for cruise planning or presentations. All regional WebGIS are connected to the main WebGIS portal using a simple distributed GIS. Each regional coordinator provides a WebGIS interface using a standardized Web Map Service (WMS). WMS provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases (Box 2). In response to a request, one or more geo-registered map images are displayed in a browser application on the remote computer of the

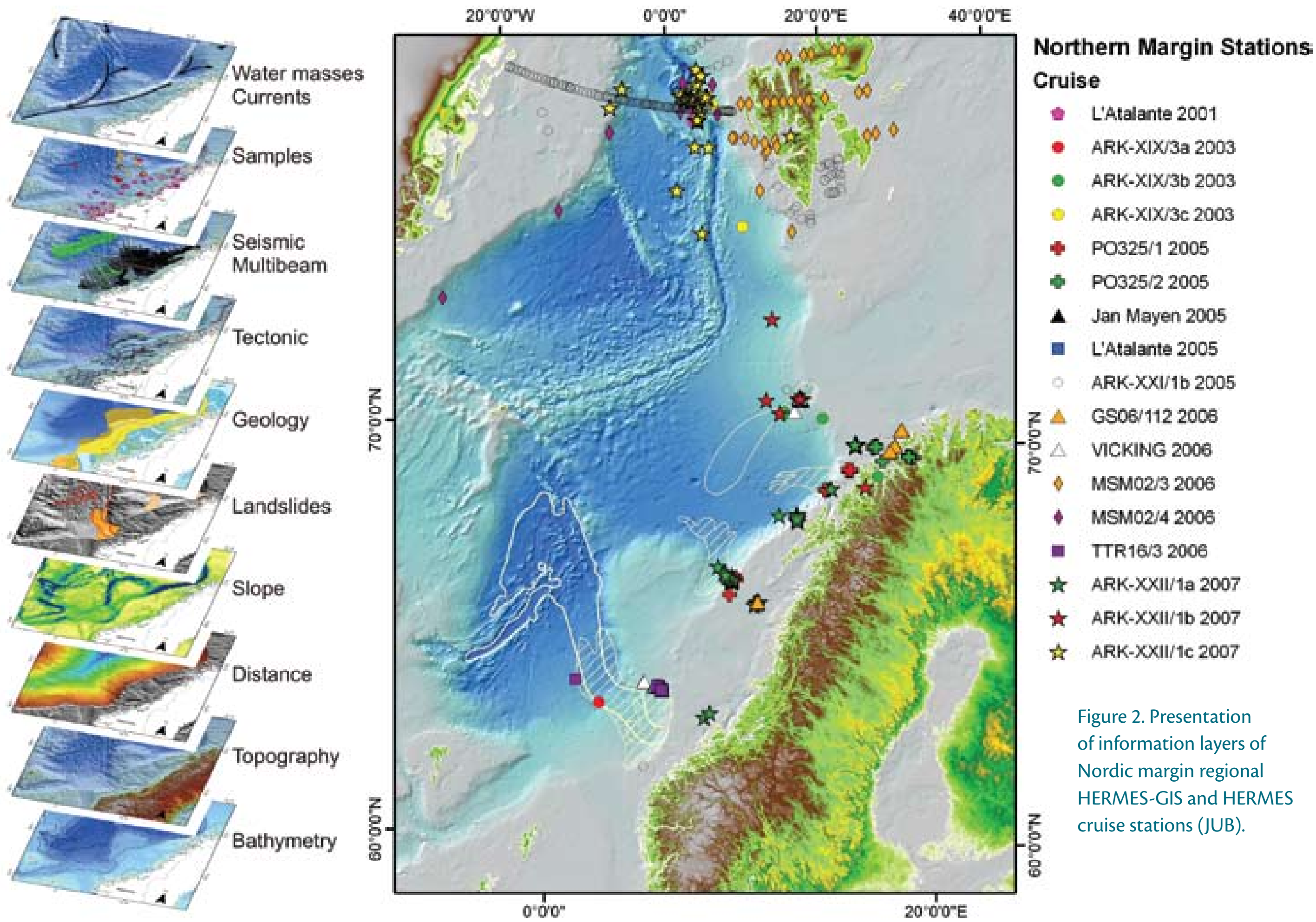

Figure 2. Presentation of information layers of Nordic margin regional HERMES-GIS and HERMES cruise stations (JUB).

BOX 1. PANGAEA®

During the last few decades, the capability and precision of tools used to sample and analyze the Earth have increased exponentially, resulting in a similar increase in data output. At the same time, information technology has made significant advances that now permit storage, distribution, and processing of an almost unlimited amount of data. However, the necessary concurrent development of a related culture for sustainable delivery of scientific data to future research has not yet fully evolved, despite the fact that it is no longer feasible to just publish data in journals. Unfortunately, the bibliographic archiving of primary data from projects and publications is still not an integral part of the scientific workflow; thus, most data are getting lost while hardware and software are changing quickly. Today, this deficiency is considered to be one of the most critical in science. Various institutions, foundations, and international organizations are currently formulating recommendations to improve data archiving. The HERMES project heeds this counsel and declares data management, in addition to data publication, as one of the major deliverables of this large integrated project. HERMES uses the PANGAEA information system as an archive, publisher, and library for its data.

scientist requesting data. Each regional WebGIS has a HERMES standard layout and layering scheme to ensure that all partners can work confidently on data from each region (Figure 2). In accordance with the philosophy of providing a long-term product, the University of Barcelona hosts a WebGIS client that is able to connect all regional GIS servers using cascading WMSs to provide a unified Web portal for centralized data visualization. This scheme allows researchers, managers, and the general public to find all the data they need in one easily searchable location.

HERMES-GIS TOOLS AND METADATA

The WebGIS provides several inbuilt tools, including measuring devices and extended querying and zoom tools. To ensure fast and accurate queries within the GIS database, a specific HERMES data model was developed to provide the user with a robust data structure. A data model organizes and describes the connections between different data entries in the real world. Without a model, one has only the sample data, and no inferences can be made about real-world behavior. Having a data model is an important step for producing and maintaining information to support the interdisciplinary activities of a project query response. The HERMES data model was based on the ArcMarine data model developed by ESRI (Wright et al., 2007). It has been extended and adapted to the needs of the HERMES data sets and the existing WMS. Additional features include more tables, which are now in a structure similar to the PANGAEA metadata model, facilitating fast and smooth data flow between the central database and the GIS. Metadata describing the actual data are integrated according to the international standard ISO 19115 for metadata that is used by PANGAEA. In addition to ensuring quality criteria, metadata allow researchers to select and search for information without having to download large and complex data sets or use specialized software.

INTEGRATION OF HERMES-GIS AND PANGAEA

Initially, all new metadata collected during the HERMES project are submitted to the PANGAEA database. Metadata usually consist of information about scientific surveys and sampling stations, which are given unique campaign and station labels in the PANGAEA database. Once the data have passed all quality-control checks, they are made available in the regional and overall WebGIS for visualization.

The next step is submission of actual measured data and scientific interpretations related to each metadata set, as soon as they are available. These submissions range from actual measured data sets to publications, reports, maps, and any kind of results that are of general interest to the project. In PANGAEA, each data set is provided with a digital object identifier (DOI) that allows rapid communication of information among scientists. In the digital age, due to the huge volumes of information generated, keeping track of individual items

BOX 2. OPEN-SOURCE GIS IN AN INTEGRATED PROJECT

Instead of using the commercial ESRI GIS software (http://www.esri.com), the Coastal and Marine Resources Centre, University College Cork (UCC), Ireland, designed and implemented an open-source WebGIS solution for the Porcupine-Rockall region, while maintaining the same overall functionality as other HERMES regional GIS solutions. This open-source technology is based on the University of Minnesota (UMN) MapServer (http://mapserver.gis.umn.edu). However, both HERMES WebGIS solutions can interoperate using WMS (Figure B-1). UMN MapServer supports the WMS feature, which enables the regional system hosted at UCC to exchange maps in real time with the central data visualization WebGIS client hosted at the University of Barcelona.

	ArcIMS	MapServer
Benefits	▪ Simple creation tool: ArcIMS Manager ▪ Key languages: HTML, Javascript ▪ Uses ArcView shapefiles and geotiff images ▪ Basic site creation ▪ High level of built-in GIS functionality ▪ Large user base with good online support and a helpful community ▪ Metadata server is included	▪ Free, open source and not locked into a software package ▪ Key languages: HTML, Javascript, XML, PHP, PERL for more advanced functionality ▪ Uses ArxView shapefiles, geotiff iamges and can read other GIS formats ▪ Simple structure with only 2-3 configuration files ▪ Program code is open for modification and simple installation ▪ Helpful community
Drawbacks	▪ Challenging installation ▪ Complex structure with many files to edit and manage ▪ Programing required to customise functionality ▪ Only ESRI can modify the program	▪ Not an 'out of the box' web GIS, has to be customised to functionality ▪ Programming required to customise functionality ▪ No metadata server included

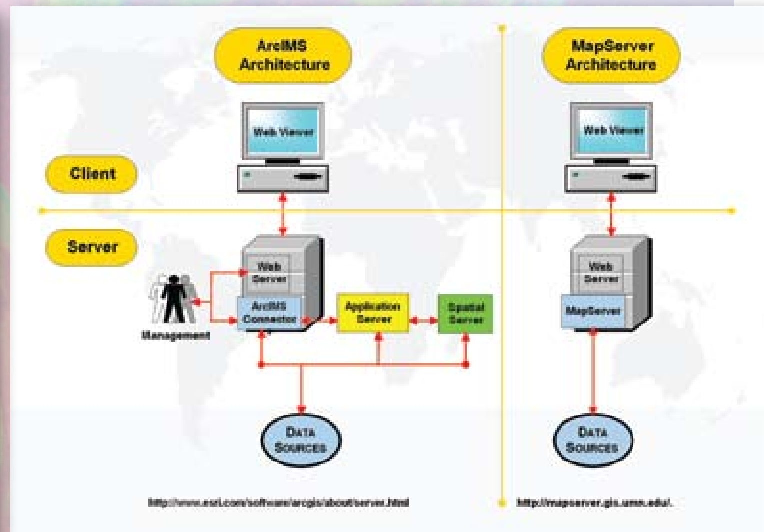

Figure B-1. Comparison between the two operating WebGIS systems in HERMES.

of information is difficult. This problem has led to development of the DOI as an international standard for naming digital data. DOIs provide persistent links to scholarly content, enabling users to get to the authoritative, published version of the content for which they are searching, even when the content changes location or ownership. They provide a system for consistent and actionable identification and interoperable exchange of managed information on digital networks. Hence, the whole process of data submission becomes comparable to publication of a scientific article that includes processes to assess quality and future referencing (Diepenbroek et al., 2002). Handling this type of information correctly is central to the objectives of the HERMES-GIS. From these data sets, useful GIS layers can be produced in collaboration with scientists. PANGAEA DOIs and fixed eventlabels are used by the WebGIS to interactively hyperlink each visualized data layer via point-and-click to its original data set source within PANGAEA. Depending on data restrictions, users will be able to download the original data or the derived products submitted by authors.

THE USE OF GIS IN HERMES

Over the last decade, the use of GIS to handle spatial information has increased significantly among scientists. Today, it is commonly used for querying large databases, visualizing large- and small-scale patterns, and assisting complicated predictive modeling. Within the HERMES project, GIS is central to many of our partners and end users.

GIS and Data Models for Submarine Landslide Research

The HERMES GIS aims to integrate all collected data and results from specific locations by means of a data model. The study of submarine landslides in the Strait of Sicily illustrates how large data sets can be easily queried and retrieved from the GIS data model, used in spatial analysis of geophysical and coring data, and employed to aid geological interpretation in combination with oceanographic and biological data. The HERMES data model proved to be the ideal framework for representing both spatial and nonspatial objects, storing time series data, and providing a three-dimensional representation of the morphological structures that influence environmental factors in the Strait of Sicily. Figure 3 shows three-dimensional swath bathymetry of two slides (the so-called "Twin Slides") exposed at the seafloor, just 6-km apart. In the left panel, several thematic layers are shown, including variables such as multibeam bathymetry, side-scan sonar, chirp-profile track lines, and sampling stations (core data are related to object classes storing physical, biostratigraphical, and hydrological parameters—for example, oxygen microprofiles). The right panel shows an example of the integration of several data sets in combination with background information, such as high-resolution multibeam bathymetry and side-scan sonar mosaics. The two submarine landslides are similar in age, runout, and fall height, and they exhibit a multistage evolution, but the organization of their displaced masses is dissimilar, likely reflecting the distinct source units affected by failure (Minisini et al., 2007).

Cold-Water Coral Predictive Habitat Modeling

In several projects, GIS has been used to predict the distribution of cold-water corals, classify habitat, and present acoustic data from side-scan sonar and multibeam echosounder surveys. Cold-water corals are significant ecological engineers that produce complex habitats in the deep sea. The geographical distribution of these species will be affected

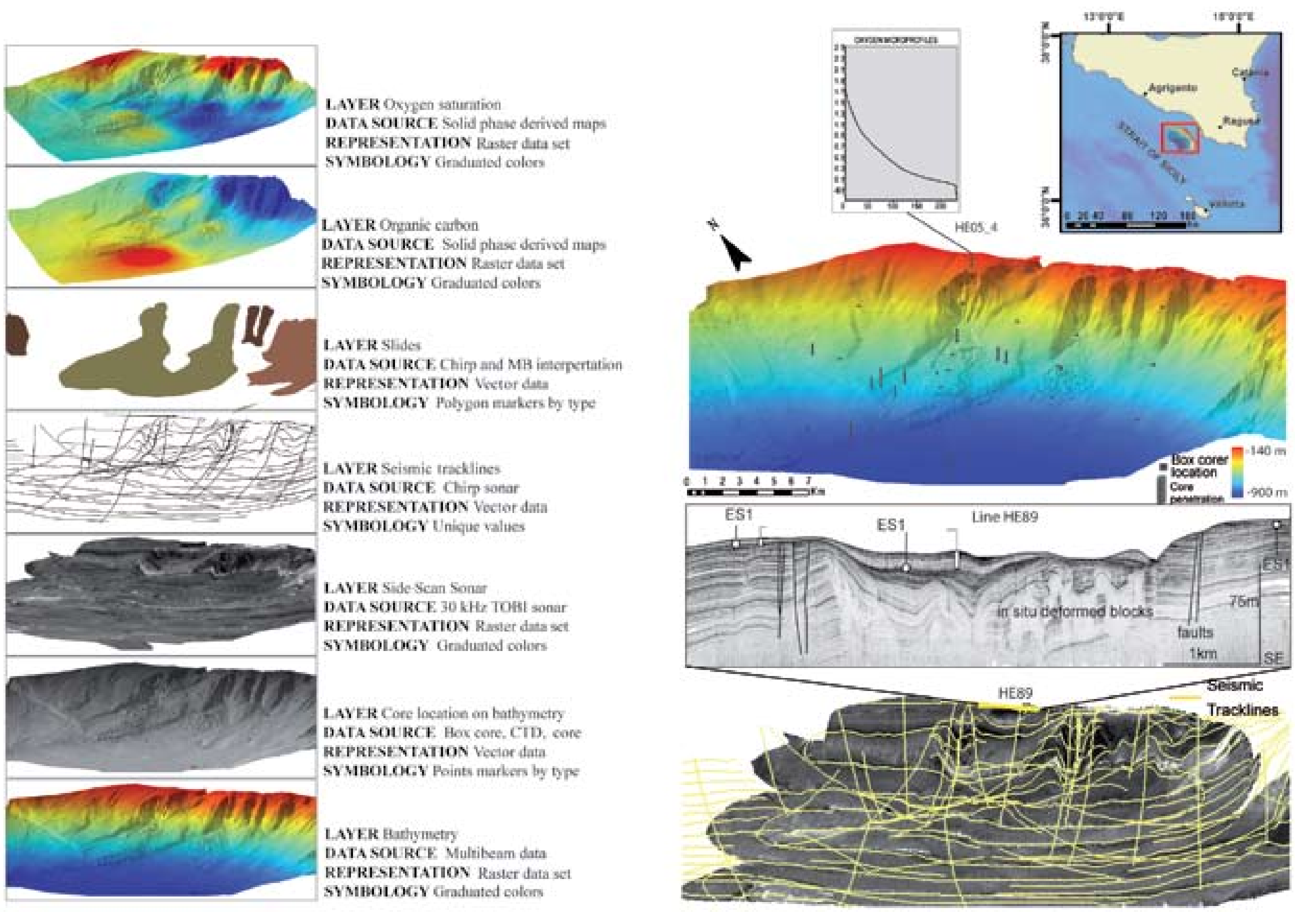

Figure 3. Left panel shows the thematic layers from the Strait of Sicily examples. Right panel shows an example of information retrieval combining geophysical and sedimentological data. Vertical exaggeration is 10x; artificial sun angle is from the north.

by a combination of different physical, oceanographic, and biological factors. Predictive modeling approaches can be used to generate habitat suitability maps, producing representations of geographical areas that match species' requirements based on multiple environmental parameters. Cold-water corals are ideally suited for predictive modeling approaches because of their sessile nature and longevity. Now recognized as vulnerable habitat by many governments, there is a significant focus on the prediction of where they may and may not occur. Here we describe two studies carried out as part of the HERMES project.

The first study used fine-scale data to predict the occurrence of the species *Lophelia pertusa* and *Madrepora oculata* from multibeam bathymetry and several derived variables such as slope, rugosity, and the bathymetric position index (BPI) in combination with backscattering data and remotely operated vehicle (ROV) observations (Figure 4). Statistical data analysis of the acoustic parameters of the seafloor at coral sites on the Swedish

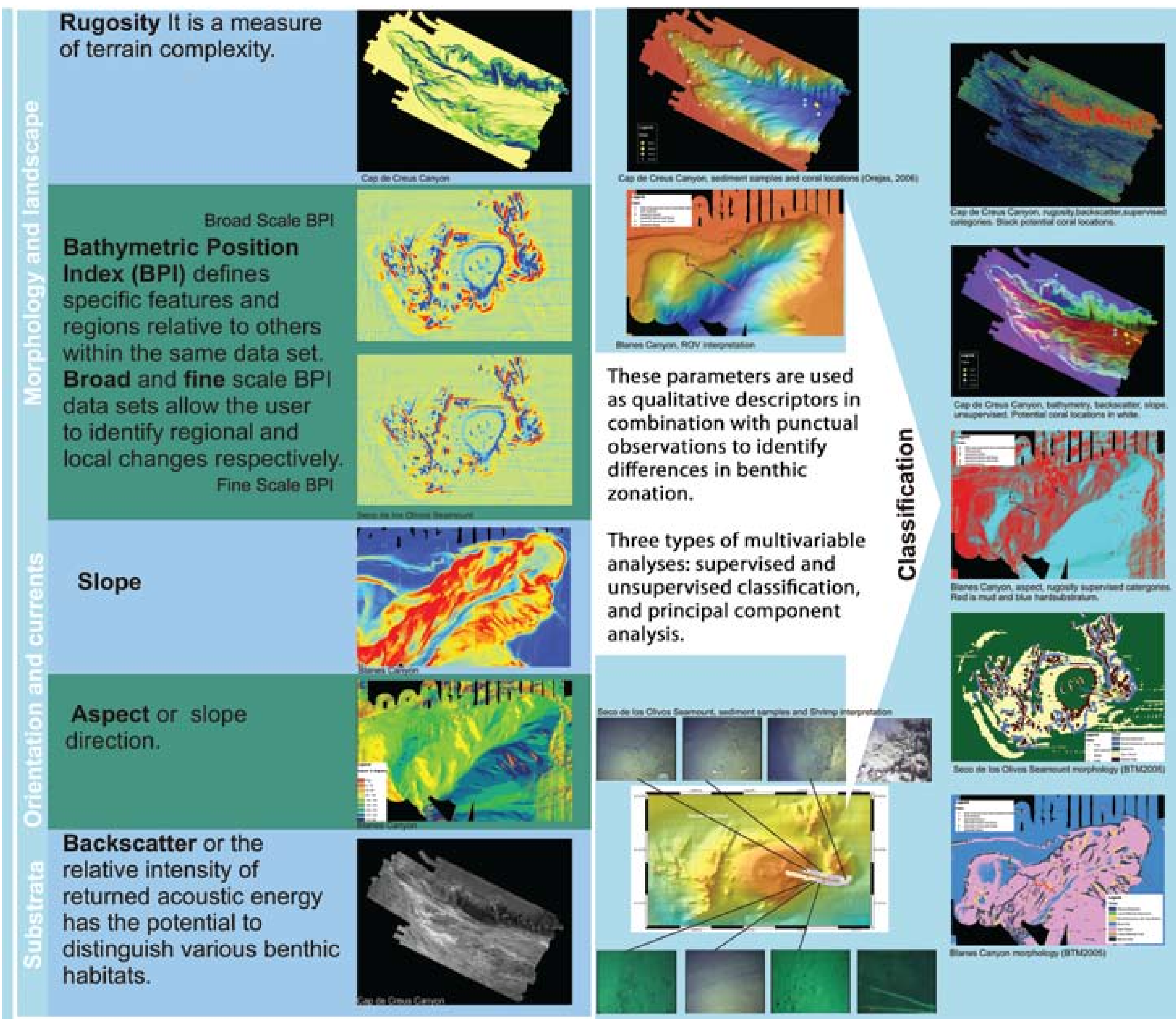

Figure 4. Canyons and sea hill predictive analysis combines morphological indexing and backscatter, which reflects long-term oceanographic conditions and sedimentary environments with punctual observation to classify the benthic habitats.

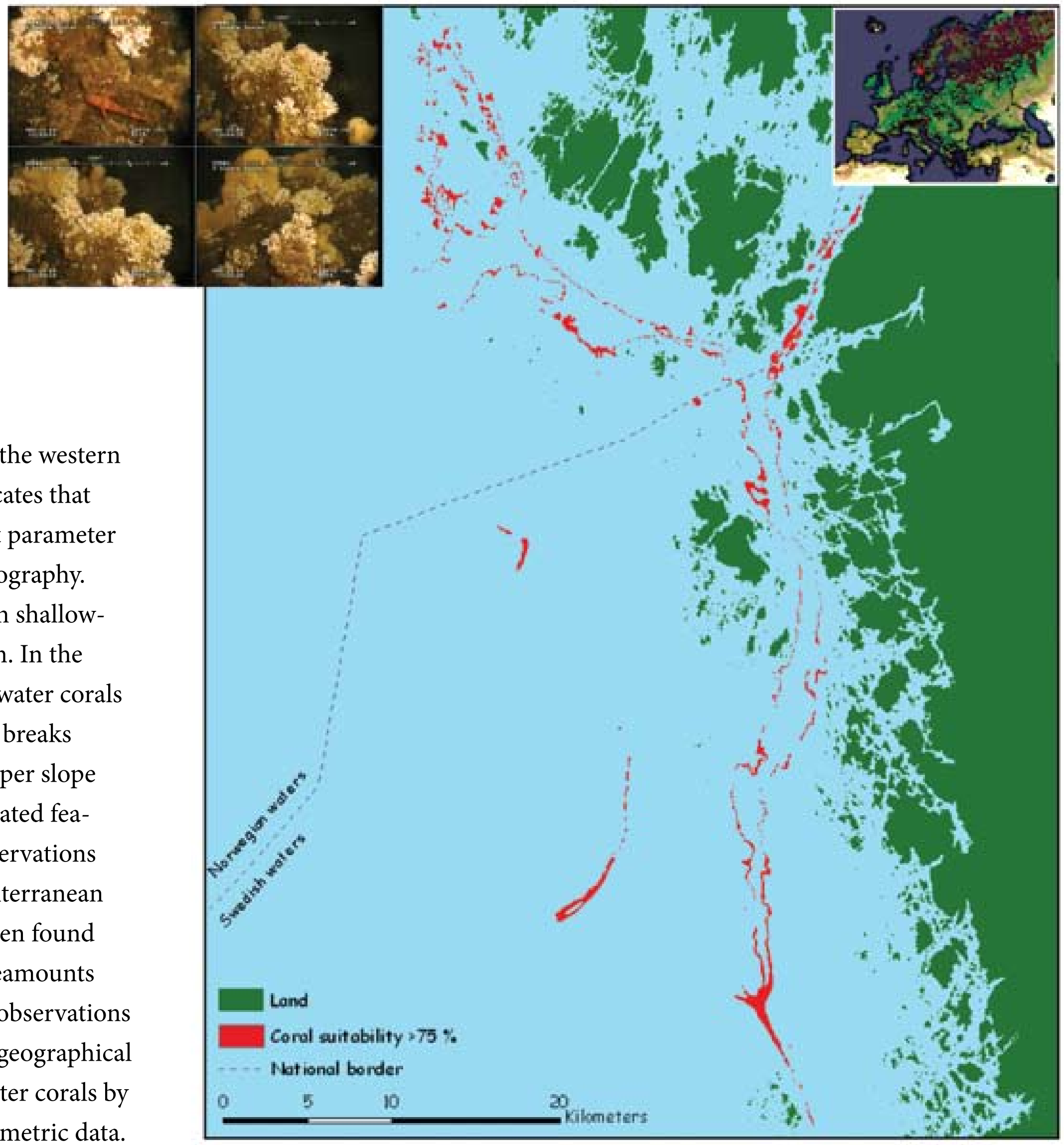

Figure 5. Results from the cold-water coral suitability classification tree. The area in red encompasses all cells that simultaneously met the criteria for a 75–100% probability of the presence of *Lophelia pertusa*, based on bathymetry, slope, and bathymetric position index.

and Norwegian shelves and the western Mediterranean margin indicates that depth is the most significant parameter that reflects the area's oceanography. In both cases, corals occur in shallow-water depths from 70–400 m. In the Kosterfjord (Sweden), cold-water corals have been observed at slope breaks such as ridges, lower and upper slope flanks, and tops of local elevated features (Figure 5). Similar observations have been made in the Mediterranean Sea, although corals have been found mainly on upper flanks of seamounts and at canyon heads. These observations allowed prediction of other geographical areas that may have cold-water corals by simply using available bathymetric data. This application of GIS enables effective targeting of areas for ROV surveys to enhance cruise planning (Figure 5).

In a second study, a team of researchers attempted to predict the distribution of *Lophelia pertusa* in the Northeast Atlantic and at global scales. They used a statistical approach known as Ecological Niche Factor Analysis (ENFA), which uses only species presence data for predictions, as species absence data are often unreliable in the deep sea. They began by extracting the environmental tolerances of *Lophelia pertusa* using readily available oceanographic data, including physical, chemical, and biological variables. This species was found at mean depths of 468 m and 480 m on the regional and global scales, and they occupied a niche that included higher-than-average current speed and productivity, supporting the theory that their limited food supply is locally enhanced by currents. Most records occurred in areas with a salinity of 35, mean temperatures of 6.0–6.7°C, and dissolved oxygen levels of 6.0–6.2 ml l^{-1}. The majority of records were found in areas that were saturated with aragonite but had low concentration of nutrients (e.g., silicate, phosphate, and nitrate). ENFA identified areas where species may occur based on the variables that appear to fit the species niche. Northeast Atlantic prediction was reliable due to numerous "presence" data points throughout the area (partly enhanced by the HERMES-GIS), whereas global prediction was less reliable due to the paucity of presence data outside

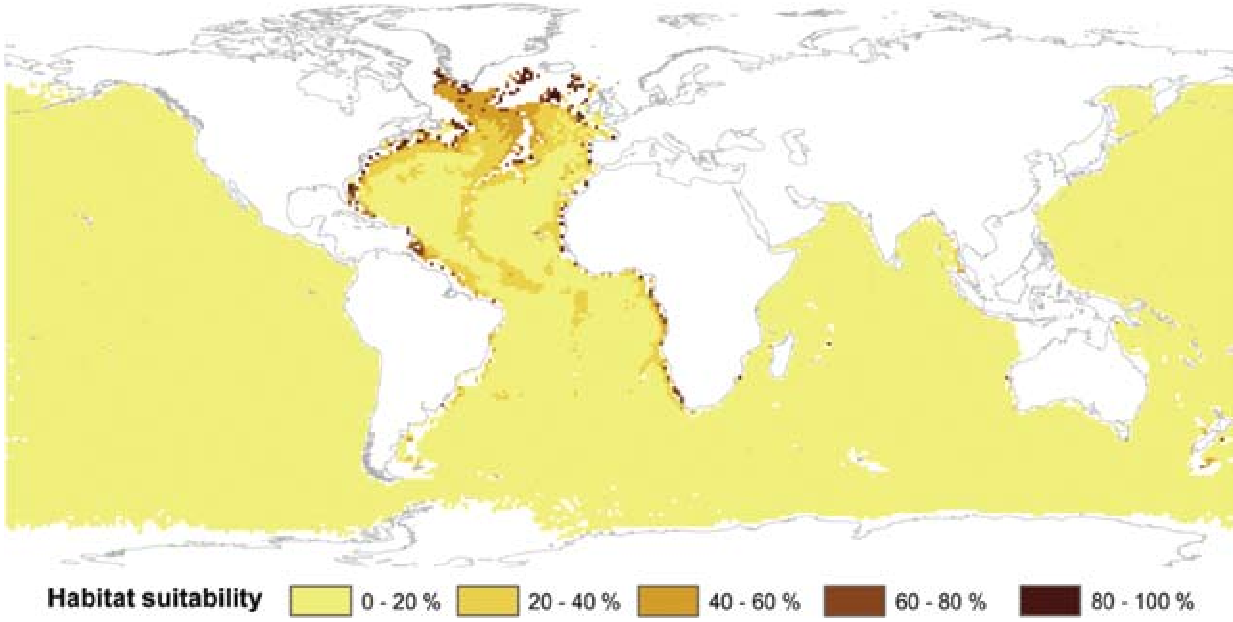

Figure 6. Global-scale habitat suitability map generated for *L. pertusa*. High percentages indicate more suitable habitat. *From Davies et al., 2008, with permission from Elsevier*

the Northeast Atlantic region. However, the known species niche was supported at each spatial scale. Predictive maps at the global scale (Figure 6) reinforced the general consensus that the Northeast Atlantic Ocean is a key region in the worldwide distribution of *L. pertusa* (Davies et al., 2008).

ACKNOWLEDGMENTS

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- HERMES-GIS (http://www.ub.edu/hermes): University of Barcelona, Spain
- Nordic margin: Jacobs University Bremen, Germany
- Porcupine-Rockall area: Coastal and Marine Resources Centre, Cork, Ireland
- Cádiz-Portugal margin: Instituto Hidrografico, Portugal
- Western Mediterranean Sea: University of Barcelona, Spain
- Eastern Mediterranean Sea: Hellenic Center for Marine Research, Greece
- Black Sea: Jacobs University Bremen, Germany

The PANGAEA database (http://www.pangaea.de) is hosted by the Alfred Wegener Institute for Polar and Marine Research (AWI), Bremerhaven, Germany, and the Center for Marine Environmental Sciences (MARUM), University of Bremen, Germany. The HERMES project (contract GOCE-CT-2005-511234) is funded by the European Commission's Framework Six Programme under the priority "Sustainable Management, Global Change and Ecosystems." GRC Geociències Marines (GRCGM) is funded by "Generalitat de Catalunya" excellence research grants program (ref. 2005 SGR-00152). Data in Figure 6 were released by Eni E&P Division and reprocessed at ISMAR (CNR) using PANGAEA Multi-Beam Manager.

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