Wright, D.J., 2002. Introduction, in D.J. Wright (Ed.), *Undersea with GIS*, Redlands, California, ESRI Press, xiii-xx.

Introduction

We have made more progress mapping neighboring planets than we have our own seven seas. We know more about the dark side of the moon and the topography of Venus and Mars than we do of our ocean floors. When NASA announced that its high-profile Shuttle Ray Topography Mission had mapped eighty percent of the earth's surface, they neglected to mention that they had skipped the parts that are underwater—seventy-one percent of the globe's actual surface area—which remained impervious to the Shuttle's spectacular remote sensors. Recent development, however, of sophisticated technologies for ocean data collection and management has made it possible to imagine, and in some cases to begin to realize a tremendous potential for mapping and interpreting ocean environments in unprecedented scope and detail. It is specifically with these advancements in mapping, charting, and visualizing in three-dimensions (3-D) both the deep and the shallow ocean that *Undersea with GIS* is concerned.

As agencies and institutes such as the National Oceanic and Atmospheric Administration (NOAA) National Marine Sanctuary Program and National Ocean Service, the U.S. Geological Survey (USGS), and the Monterey Bay Aquarium Research Institute adopt GIS, it's becoming clear that not only are the needs of basic science and exploration being served, but those of ocean protection, preservation, and management as well. Exponential improvements in the speed and capacities of computer hard- and software, an accompanying drop in prices, and the increased availability of skilled practitioners in GIS are making implementation possible where costs have been, until very recently, prohibitive. Data, too, is easier to obtain via the Internet, the World Wide Web, and numerous public sources of spatial information, such as the National Geophysical Data Center, the NASA-funded Distributed Oceanographic Data System (DODS), the EarthExplorer of the USGS, and the Federal Geographic Data Committee's National Geospatial Data Clearinghouse. And finally, although the realization of true three-dimensionality remains a challenge (particularly in the marine/coastal realm where there are dissimilarities between the horizontal and vertical dimensions), the mapping of our oceans continues to be an area of research that pushes the boundaries of geographic information science, compelling significant attention from funding agencies such as the National Science Foundation and the NOAA Office of High Performance Computing and Communications.

Mapping, charting, and 3-D visualization have been chosen as primary subjects for this book for two reasons. First, the use of GIS for spatial analysis, modeling, and management of oceans has been adequately covered in several recent publications (for example, *Marine and Coastal Geographical Information Systems* from Taylor & Francis, the ESRI Press case study book *Managing Natural Resources with GIS*, and *Applications of Geographical Information Systems in Oceanography and Fisheries* forthcoming from Oxford University Press, as well as conference proceedings such as NOAA's *Coastal GeoTools*). Second, it's still necessary to take a good hard look at the data before proceeding with spatial analyses in GIS, input to numerical models, or preparation of charts for navigation. Mapping and visualization are critical first steps toward identifying patterns in data sets and the underlying processes that created those patterns. They are extremely important as well in assessing the accuracy and utility of one ocean sensor as compared to another, or for interpreting a data set, either singularly or in concert with another.

Undersea with GIS is divided into three sections: Part One deals with Mapping and Visualization, Part Two with Charting, and Part Three, Internet Access. The first section explores several ways in which oceans are currently being mapped in 2-D and "visually experienced" in 3-D. Using the travel-time of sound waves (which are transmitted both farther and faster through seawater than the electromagnetic energy used by satellites) to determine depth, reflectivity (or backscatter) of sound to sense the presence of objects (such as marine mammals or shipwrecks) or to determine hard versus soft spots on the ocean floor, we can dimly "see" in the oceans by "hearing." What we hear, however, is often not clear enough to make sense of the data being collected. We hear it, but we're not sure exactly what it is we're hearing, or what its importance is. Maps made from this kind of data are often aided by tools (today, mainly software) that facilitate visualization and comprehension in the usual two dimensions, but more importantly, spatial relationships and problems in 3-D.

In "ArcView Objects in the Fledermaus Interactive 3-D Visualization System: An Example from the STRATAFORM GIS," Fonseca et al. begin by reviewing the basics of the traditional 2-D map paradigm for GIS, where the two dimensions are horizontal and essentially equivalent. The authors show how this is insufficient for the analysis of complex, 3-D (largely vertical) relationships amongst data layers in the ocean, then describe the development of an integrated path between the 2-D ArcView GIS and the Fledermaus interactive, 3-D visualization package. Bathymetric, topographic, and seismic data, water temperature, and many other kinds data are explored with this integrated system, revealing a number of new geological insights.

"Notes on the Real-Time Interpretation of Seafloor Survey Data" briefly describes how data sets such as those in the previous and other chapters would be obtained during routine oceanographic surveys, reviewing the basic principles of multibeam echo sounding, sidescan sonar surveying, and seismic profiling. A near real-time system for processing, classifying, interpreting, and mapping these kinds of data is then presented. Continuing with the theme of characterizing the ocean floor with GIS, "Seafloor Mapping and GIS Coordination at America's Remotest National Marine Sanctuary (American Samoa)" presents the results of new bathymetric surveys of the Fagatele Bay National Marine Sanctuary in American Samoa, along with a description of efforts to integrate this data with digital video and still photography of the bay's coral reef, which is the main focus of conservation and management within the sanctuary.

Moving on to marine biology, "Using GIS to Track Right Whales and Bluefin Tuna in the Atlantic Ocean" describes efforts at the New England Aquarium to understand linkages between right whale and bluefin tuna distribution and the movements of currents in the Gulf of Maine and the western North Atlantic. GIS analyses in concert with satellite tagging of these species have led to remarkable breakthroughs in the understanding of their behavior and migratory habits.

In “Finding the Green Under the Sea: The Rehoboth Bay *Ulva* Identification Project,” Cole et al. describe how Delaware Coastal Programs identified the spatial extent of a problematic species of macroalgae using field surveys, aerial photography, image processing software, and GIS. The resulting maps are aiding resource managers in developing a strategy for containing the macroalgae, and for assessing the broader impact of regional development, and agricultural and industrial activities on the aquatic ecology of the bay. In a similar vein, “Geopositioning a Remotely-Operated Vehicle for Marine Species and Habitat Analysis” discusses the management of habitats for marine algae, benthic macroinvertebrates, and finfish within the Punta Gorda Ecological Reserve in northern California. Veisze and Karpov present the development of non-invasive habitat observation techniques using a remotely-operated vehicle (ROV), geopositioned with a Trimble differential GPS, positions and video images from which are mapped and hotlinked with ArcView GIS.

Part Two looks at recent developments in electronic navigational charts (ENCs, also referred to as electronic nautical charts), which, due to increased benefits in efficiency and safety, may someday completely replace paper charts for the navigation of many vessels. Unlike the other kinds of maps discussed in this book, ENCs are produced only on the authoring of government-authorized organizations. They include not only all the spatial, graphical, and text features found on a nautical chart, but additional data from subsequent oceanographic surveys or publications. “The First Three-Dimensional Nautical Chart” briefly reviews the history of ENCs, and the subsequent development of electronic chart display and information systems (ECDIS), from the perspective of the author, Captain Stephen F. Ford, a pioneer in the field. Ford then describes the construction of a prototype for the world’s first 3-D nautical chart, made with data from Cape Cod Canal, which would theoretically allow a mariner to actually “see” underwater hazards and obstructions, and thus maneuver his or her vessel in a fashion similar to the operation of an automobile. Recommendations are also made in this regard for improvements in the quality and distribution of oceanographic data from federal agencies, as well as in GIS software.

A system for the management of ENCs, designed through the collaboration of the Swedish and the Finnish Maritime Administrations, Novo Meridian Ltd. (Finland), T-Kartor Sweden AB, and ESRI Redlands, is the subject of the next chapter. “HIS: A Hydrographic Information System for the Swedish and Finnish Maritime Administrations,” describes the architecture of a hydrographic information system for the management of ENC features, metadata, multiple scales of charts, and data lineage, all with the primary goal of a more efficient ENC production line.

In “Applications of GIS in the Search for the German *U-559* Submarine: A Brief Case Study,” Cooper et al. do not discuss nautical charts per se, but present issues that would likely be crucial for nautical chart accuracy and production. Nautical charts often include marker symbols for the location of wrecks, and the authors briefly describe the use of a GIS in planning a hypothetical search and salvage operation for a sunken World War II German U-boat in the eastern Mediterranean Sea. Sidescan sonar and bathymetric data were also used to supply information on mobile bottom sediments, possible slumps, and underwater canyons to amplify search parameters and highlight potential false targets.

The third and final section of the book is devoted to ways in which ocean GIS maps and data are being delivered via the Web. In many instances, the central problem with oceanographic data is not its paucity, but the fact that it exists in various formats, scales, and physical locations in a largely inert, non-interactive form (for example, as a graph in a journal publication), unlinked and incompatible with other data sets and models. Because of this there remains a wealth of observational data, results of experiments, and some data-driven numerical models that have not yet been fully utilized by research scientists, resource managers, or professional educators. The chapters in this section show what progress has been made with Internet map servers that support oceanographic data sharing and provide online spatial analysis tools.

"From Long Ago to Real Time: Collecting and Accessing Oceanographic Data at the Woods Hole Oceanographic Institution" describes three prototype, web-based applications that were developed to make researchers at the Woods Hole Oceanographic Institution more aware of the capabilities of current GIS technology: an application for geological oceanographers that serves data sets and maps of sediment cores, rocks and other marine geological artifacts recovered from the seafloor; and two applications for physical oceanographers that allow them to view, query, and download data for the tracking of ocean currents and water mass structure.

Caswell et al. moves the discussion from scientific data to underwater cables in "Using the Internet to Manage Geospatial Submarine Cable Data." They discuss a system under development that employs web-based GIS with C++, Visual Basic, and several other web-scripting languages to significantly improve the manner in which geospatial submarine cable data are managed and distributed.

In "Protected Areas GIS: Bringing GIS to the Desktops of the National Estuarine Research Reserves and National Marine Sanctuaries," Killpack et al. discuss the need for a data infrastructure to assist managers in especially sensitive areas of ocean. The Protected Areas GIS web site includes an Internet GIS mapping application and custom spatial support tools to address specific coastal management issues, such as the optimal siting within a sanctuary for marine reserves (with access that would be even more restricted) and the maintenance of accurate digital boundaries for these regions.

Although a variety of laws, regulations, and special jurisdictions have evolved over time to protect and manage ocean resources, this framework is still extremely vague with regard to the precise positioning of geographic boundaries in the marine environment, where there is really nothing of a fixed, static nature that can be mapped except on the ocean floor. In "Spatial Policy: Georeferencing the Legal and Statutory Framework for Integrated Regional Ocean Management," Treml et al. discuss the implications of current policies, along with the issues surrounding the development of marine boundary GIS data layers in support of regional ocean management and governance. Also described is the

Ocean Planning Information System, a web-based ocean governance and management GIS to facilitate the shift in the U.S. from fragmented management of individual ocean resources to a more integrated, region-wide approach.

Dragan and Fernetti, in "Geographical Awareness for Modern Travelers: A GIS Application for Maritime Transportation in the Mediterranean Sea," describe the development of the Ship Information and Management System (SIAMS), available either on the web or via multimedia information kiosks throughout the Mediterranean. SIAMS uses MapObjects and the MapObjects Internet Map Server to assist international travelers in obtaining real-time ship schedules, retrieving general tourist information on trip destinations, finding connections to other means of transportation and accessing on-line booking services (hotels, car rentals, etc.).

An additional feature *Undersea with GIS* is the CD-ROM in the back cover, with a variety of free GIS extensions, arc macro language (AML) scripts, data sets, 3-D fly-throughs, and even a sample educational module for K-12 teachers. Many of these tools are direct demonstrations of the concepts and applications described in the chapters of the book (for example, the actual 3-D flythrough of the Cape Cod Canal described in "The First Three-Dimensional Nautical Chart"). They are provided courtesy of ocean GIS specialists from the U.S. and Great Britain., and it is hoped that they will be suitable for selected research, management, and educational activities.

Fair Winds for the Future

Much research remains to be done to improve and extend the capabilities of GIS for the ocean realm. The impediments to further development are not only technological but also conceptual: the lack of complete understanding about the nature of spatial and *temporal* data continues to obstruct solutions to its manipulation in digital forms (and this is not restricted to oceanographic data). But the ideas and applications presented in this book show that excellent progress is being made. With recent advances in remote sensing technology, marine scientists are now able to apply high-resolution acoustic and optical imaging techniques that span an incredible range of mapping scales, from kilometers to centimeters. And after many years of focus on terrestrial applications, the commercial GIS sector is paying increasing heed to the needs of marine and coastal GIS users, with many leading vendors entering into research and development collaborations with marine scientists, particularly those in state and federal agencies. Recent advances include new cartographic production systems for ocean maps and nautical charts, specific extensions and interfaces for ocean analysis and resource management, fast and intuitive Internet map servers for delivery of products to users, and the design and development of complex oceanographic databases.

Two recent developments by ESRI, the Spatial Data Engine (SDE) and the object-oriented geodatabase concepts in ArcInfo 8, hold great promise for managing and modeling ocean features. SDE is essentially a database gateway that allows for the storage and management of spatial data with non-spatial data in a relational database management system; with GIS and tabular attribute data thus stored together, geocoding processing done on the fly, as well as versioning, direct editing of spatial data, and support for new data types such as raster files. As described more fully in the chapter "HIS: A Hydrographic Information System for the Swedish and Finnish Maritime Administrations," this technology is proving to be useful for managing the very large spatial databases that are often created from regional oceanographic surveys; i.e., databases approaching terabyte size that are challenging the capacities of today's computing systems. As for object-oriented geodatabases, these endow geographic features not only with coordinate position and attributes, but also with natural behaviors, so that any kind of relationship may be defined among features. The mobility of many ocean features (such as currents, schools of fish, and hydrothermal plumes) requires representations that are more object-based, with models that are dynamic in terms of position coordinates and time (Lagrangian), rather than fixed (Eulerian).

Finally, the new geodatabase concepts in ArcInfo 8 allow for the creation of standard data models for specific applications and industries, including data classifications, specific data structures, documentation on physical database design, and the provision of test databases. It is hoped that marine and coastal applications will join the group of existing ESRI data model development efforts in conservation, defense, energy facilities, forestry, hydrology, parcels, transportation, and water facilities. The publication of this book may provide an exciting segue into these areas. In the meantime, it is my sincerest hope that you will find it to be useful, informative, and fun.

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